smartwork

D2.1- ANALYSIS OF CURRENT PRACTICES

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AUTHORS - CONTRIBUTORS

Name	Organization
Otilia Kocsis	UPAT
Giorgos Papoulias	UPAT
Miriam Cabrita	RRD
Mattienne van der Kamp	RRD
Dimitrios Amaxilatis	SPARKS
Christos Tselios	SPARKS
Nikos Tsironis	SPARKS
André Pardal	IPN
João Quintas	IPN
Rita Kovordanyi	COIN
Nikos Fakotakis	UPAT
Charalampos Vassiliou	BYTE
Ignacio Peinado	RtF-I

PEER REVIEWERS

Name	Organization
Dimitrios Amaxilatis	SPARKS
Christos Tselios	SPARKS
Nikos Tsironis	SPARKS
André Pardal	IPN
João Quintas	IPN

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GLOSSARY

ABBREVIATION	DESCRIPTION
AFib	Atrial Fibrillation
AI	Artificial Intelligence
ANN	Artificial Neural Networks
API	Application Programming Interface
AR	Augmented Reality
ARLS	Autoregressive model-based Least-Square
ASM	Airway Smooth Muscle
BMI	Body Mass Index
C3PO	Continuous Care & Coaching Platform
CAC	Coronary Artery Calcium
CFD	Computational Fluid Dynamics
CFPWV	Carotid-Femoral Pulse Wave Velocity
CHD	Coronary Heart Disease
CNN	Convolutional Neural Network
CPAP	Continuous Positive Airway Pressure
CSE	Cognitive State Estimation
CSV	Comma-Separated Values
CT	Computed Tomography
CVD	Cardiovascular Disease
DSS	Decision Support System

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DNN	Deep Neural Networks
EC	Evolutionary Computing
ECG	Electrocardiography
EI	Embedded Intelligence
ESM	Experience Sampling Method
FCN	Fully Connected Neural Network
FDA	Food Drug and Administration
FL	Fuzzy Logic
FRS	Framingham Risk Score
FWA	Forward Wave Amplitude
GA	Genetic Algorithms
GPII	Global Public Inclusive Infrastructure
GPS	Global Positioning System
HP MRI	Hyperpolarized Magnetic Resonance Imaging
IFTTT	If This Then That (Internet-based services)
iOS	iPhone Operating System
IoT	Internet of Things
JD-R	Job Demands - Resources
KI	Key Innovation
KNN	K-Nearest Neighbor
LLL	Life Long Learning
LTE	Long Term Evolution

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LPWAN	Low-Power Wide-Area Network
LSTM	Long-Short-Term-Memory
MAR	Missing at Random
MCAR	Missing Completely at Random
MET	Metabolic Equivalent of Task
ML	Machine Learning
MRI	Magnetic Resonance Imaging
NoSQL	Not Only Structured Query Language
NMAR	Not Missing at Random
PB	Probabilistic Methods
PC	Personal Computer
PQRST	P, Q, R, S, T waves in an ECG
PSW	Particle Swarm Optimization
RBF	Radial Basis Function
REM	Rapid Eye Movement
REST	Representational State Transfer
RNN	Recurrent Neural Network
RST	Rapid Strep Test
SOA	State Of the Art
TPD	Teachers' Professional Development
TS	Tabu Search
USB	Universal Serial Bus

VFB	Volume Filling Branching
WAI	Work Ability Index
WiFi	Wireless Fidelity network
WP	Work Package

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1. Executive Summary

This deliverable is the main outcome of T2.1 State Of the Art (SOA) review and benchmarking of best practices, and its aim is to review the existing commercially available solutions and state-of-the art research methodology and approaches on the multi-dimensional aspects relevant for the implementation of the SmartWork system and services. This analysis provides a baseline definition and benchmarking of all latestest developments and advances in the main fields aligned to the technology implementation Work Pakages (WPs) of the project, as follows:

- Chapter 3 of D2.1 represents the starting point for WP3 Unobtrusive Sensing and Low-Level Processing
- Chapter 4 of D2.1 represents the starting point for WP4 Data-driven modelling and AI tools for decision support
- Chapter 5 of D2.1 represents the starting point for WP5 Ubiquitous Workplace and Accessible Personalized Interaction Interfaces
- Chapters 6 and 7 of D2.1 represent the starting point for WP6 Work Flexibility Tools and on-Demand Training

At the same time, the deliverable establishes the ground for the envisaged SmartWork advances, as defined by the major key innovations of the project:

- Key Innovation 1 (KI1): Smart Work Ability Sustainability
- Key Innovation 2 (KI2): AI for Functional and Cognitive Decline Risk Assessment
- Key Innovation 3 (KI3): Ubiquitous Work Environment
- Key Innovation 4 (KI4): Personalized on-Demand Training
- Key Innovation 5 (KI5): On-the-fly Work Flexibility

More specifically, Chapter 3 provides a detailed analysis of a large set of devices and services that represent SOA options to monitor various physiological parameters in the particular case of the office workers (e.g. smart mouse), the environmental conditions of indoor home and work spaces, as well as the activity of users and workers during their everyday lives. Most of the devices are available on the market as consumer ready devices, are on the low side as far as cost is concerned, and their data can be integrated into a larger system using the APIs provided by their manufacturers.

In Chapter 4 an analysis of existing AI methods and approaches for the various tasks relevant for the SmartWork data-driven, functional and cognitive, modelling of office worker is presented. The data-driven approach starts with the low-level processing of large volumes of heterogeneous data, with is challenging in order to ensure robustness and efficiency in the pervasive and ubiquitous data collection step. Thus, sensor embedded and edge processing techniques must be combined with server side (e.g. cloud) processing. Functional and cognitive modelling methods are reviewed with respect to their potential to capture short- and long-term characteristics of the user, both at individual and group level. Furthermore, the analysis includes individual models capturing dimension specific characteristics (e.g. specific chronic condition), as well as systems capable of reasoning at a higher level of data abstraction, such as decision support systems for self-management of chronic conditions.

Chapter 5 grounds the model-driven user interfaces development to the accessibility design principles, providing the initial research baseline for the design and development of the SmartWork interfaces, especially that of the ubiWork Service, which enables on-the-fly work flexibility through an ubiquitous computer work environment. These principles will be coupled with the GPII infrastructure for the implementation of the SmartWork interfaces.

The analysis performed in Chapter 6 expands the understanding on how task management tools can enable team collaboration and motivation in the work process and how work tasks can be modeled. Such work management tools have the capability to provide a ground for the implementation of the SmartWork digiTeam Service, for smart, flexible and optimized management of the workforce form the side of the employers (e.g. manager, supervisor), resulting in increased efficiency and productivity of teams working on specific tasks.

Chapter 7 reviews the main principle of life-long learning and special characteristics of professional educational approaches for older people. The analysis underlines the challenges and the importance of motivating older employees to participate in formal learning, and overall of encouraging their willingness to engage in learning which is relevant for their current work task. The findings of this analysis are critical for the design and development of the SmartWork workCoach Service, which will provide on-demand training support and new skills acquisition for the older office workers.

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2. Introduction

2.1. T2.1 objectives and activities

The main objective of **T2.1 SOA review and benchmarking of best practices** is to document and present existing, commercially available solutions as well as review and evaluate state-of-the art research approaches and methodologies of multi-dimensional aspects related to the implementation of SmartWork system and services. Prior engaging to design, implementation and testing activities, it is essential for the consortium to be aware of similar research and commercial solutions/methodologies that have already been carried out in the multidisciplinary fields that SmartWork will address. The aim of this analysis is to provide a baseline definition as well as thoroughly document all latest developments and advances in the areas of data-driven functional, cognitive and working ability modelling, pervasive health management and lifestyle and finally aspects, metrics and examples of health-oriented, ubiquitous and flexible working environments.

2.2. T2.1 positioning and interdependencies

The results of T2.1, namely "D2.1 Analysis of current practices", represents the ground information of every multi-dimensional aspect of SmartWork project. This analysis will be used as a starting point and further as a general guideline by all technology implementation Work Packages, to ensure the delivery of intended key innovation aspects. Although several interdependencies do exist, the main alignments of D2.1 are as follows:

- Chapter 3 represents the starting point for WP3 Unobtrusive Sensing and Low-Level Processing
- Chapter 4 represents the starting point for WP4 Data-driven modelling and AI tools for decision support
- Chapter 5 represents the starting point for WP5 Ubiquitous Workplace and Accessible Personalized Interaction Interfaces
- Chapters 6 and 7 represent the starting point for WP6 Work Flexibility Tools and on-Demand Training

2.3. SmartWork Architecture Overview

SmartWork will efficiently combine, in a trans-disciplinary approach, existing and new integrative computational developments, methods and sensing technologies, to build a Worker-Centric AI system for sustaining the working ability of participating individuals. The SmartWork infrastructure is worker-centric, aiming to establish a holistic model of the working abilities of office workers and employ Artificial Intelligence (AI)-based decision support tools for delivering improved Work Functions. Personalizing this model, to account and represent particular attitudes and abilities of

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the ageing worker, is driven by the effective modelling of functional and cognitive work capabilities, the motivation and values (including emotional satisfaction), other contextual parameters (e.g. tasks, office workspace comfort, etc.) as shown in Figure 1. Functional, cognitive work capabilities as well as the individual's motivation are, in their turn, directly linked to the overall health status and well-being of the worker in SmartWork.

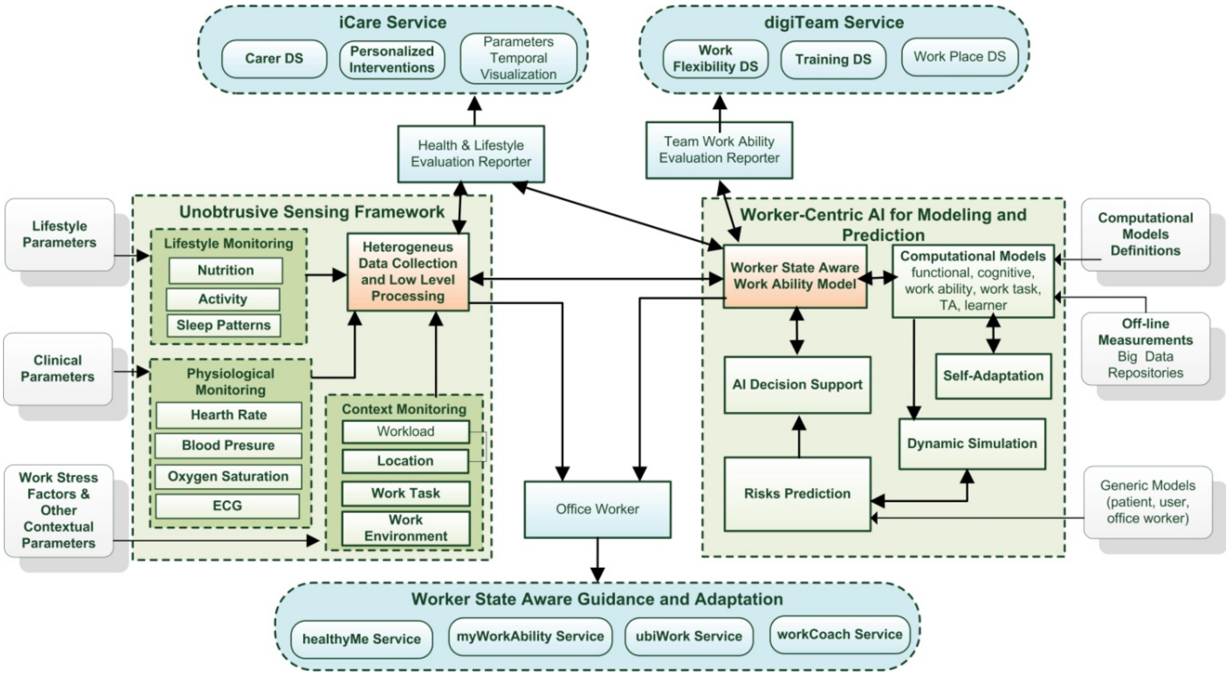

FIGURE 1 SMARTWORK MODELLING FRAMEWORK ARCHITECTURE

Continuous unobtrusive and pervasive monitoring of health and behavioural attitudes of a worker provides the means for efficient modelling of real-world working abilities which lead to the design and implementation of worker-state-aware working ability models. Moreover, these models also allow the early identification of potential health risks or functional/cognitive decline, which can be avoided or delayed through appropriate intervention strategies such as:

(i) care management and decision support for personalized health self-management and for encouraging positive behavioural changes;

(ii) physical exercise to maintain physical abilities;

(iii) mental exercise to maintain mental abilities;

(iv) healthy lifestyle (e.g. food, smoking) to better control chronic conditions (e.g. diabetes, asthma) and maintain health status.

2.4. Ambition and Key Innovations

The overall ambition of the SmartWork project is to implement a Smart Services Suite, employing novel devices and AI technologies to support work ability sustainability for older office workers, and

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improve state of the art in the fields of unobtrusive and pervasive monitoring, functional and cognitive decline risk assessment, self-adaptability and pervasiveness of computer work environments, worker need-driven flexible work practices, organizational knowledge management and personalized training. The major key innovations targeted throughout the project are presented in the following subsections, and relevant sections of this deliverable are establishing the ground for the envisaged advances through a detailed state-of-the art analysis of existing research and products.

2.4.1. KI1: Smart Work Ability Sustainability

Work Ability modelling in SmartWork project is grounded to the holistic multidimensional model which accounts for both the attributes and characteristics of the individual, as well as factors related to work/working and the environment outside of work. Thus said, Work Ability modeling will be based on (i) personalized patient models derived from the integration of the health condition specific patient models (e.g. multiple chronic conditions) and behavioural models, (ii) personalized emotion and stress models of the worker, (iii) personalized cognitive models, (iv) modeling of contextual work tasks, (v) work motivation and values. Continuous assessment of the various dimensions of Work Ability is facilitated through continuous unobtrusive monitoring of the health, behaviour and emotional status of the office worker. Next, AI tools for prediction and risk assessment will allow for dimension specific decision support and intervention, such as on-the-flay flexible work management (to cope with health management), coping with stress at work, on-demand training, memory training, behavioural interventions.

2.4.2. KI2: AI for Functional and Cognitive Decline Risk Assessment

SmartWork will develop an integrated framework for the heterogeneous data collection and processing, to enable the AI-driven preventive health care, behavioural and lifestyle interventions. Special effort will be given to the development of the innovative intelligent mouse SensIN, a work tool for the office worker, and at the same a sensing device collecting a series of physiological parameters (heart rate, temperature, grip force, galvanic skin response, inertial system). For data security and confidentiality SmartWork (i) will select cryptographic tools and blockchain-related encryption mechanism and (ii) will develop data collection procedures based on on-device secure partitions, explicit user approval for data access, and de-identification mechanisms for data-driven processing. Data heterogeneity will be addressed by developing models and data encoding and exchange standards for the low level modelling (e.g. disease-specific patient models) and for the integrated modelling approaches (e.g. functional model, cognitive model, Work Ability model) to ensure model reproducibility and sharing. Emphasis will be given in the development of modular approaches to ensure that self-contained models could be developed and validated independently before being incorporated into the higher level models (e.g. Work Ability model). The models will be enhanced with metadata and a semantic layer to ensure that data elements can be properly interpreted and compared and to facilitate semantic coherence of the integrated data to allow

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linking and reuse of knowledge. To deal with data complexity, a number of computational efficient machine learning algorithms will be employed, including fully connected neural networks (FCNs), convolutional neural networks (CNNs) and recurrent neural networks (RNNs). To support decision making, data interpretation will employ novel designed rule induction methods in combination with the identification of important risk factors for the higher level models to automatically extract interpretable rules for Work Ability sustainability.

2.4.3. KI3: Ubiquitous Work Environment

SmartWork will build on and expand the Global Public Inclusive Infrastructure (GPII) with new tools and services to support on-the-fly work flexibility for office workers through an ubiquitous computer work environment. The auto-personalization infrastructure will be employed to enable inclusive features in office products and assistive technologies to be turned on and configured to a workers needs and preferences. Accessible-born interfaces for the office workers, which adapt office environments to their current needs, are not of any use if they are too difficult to find, turn on, and configure to meet the user's needs. GPII's Morphic auto-personalization capability will enable transport of user's settings to any computer that has Morphic installed. And Morphic's Install on demand (IoD) feature can allow software that a user needs, but is not installed on the computer in front of them, to be fetched, installed and configured for them on any Morphic enabled computer, within the organization, at home, in other remote locations. In this way the user is presented with the same (or best matching, depending on device) accessible interfaces at any computer they sit down to perform work tasks. Furthermore, the SmartWork's AnyWhere delivery system allows for seamless transfer of work materials and computer working environment settings without any effort from the side of the office worker.

2.4.4. KI4: Personalized on-Demand Training

SmartWork aims at implementing a novel paradigm for training of older office workers, through a dedicated platform which allows co-workers to register trainer services, which can be accessed on-demand by the older adults, and allow the older worker to register own trainer services. The platform will also allow registration and access to on-line training modules. On one hand it facilitates individualized and hands-on training with peers, promoting the intergenerational transfer of knowledge within the organization, and on the other hand empowers the office workers to learn on their own through an easy to access service.

2.4.5. KI5: On-the-fly Work Flexibility

SmartWork implements a novel On-the-fly Work Flexibility Module which empowers both the employee and the employer with Artificial Intelligence decision support to coordinate team work and efficient task completion through flexible work practice. Rather than assigning employees tasks and goals, the SmartWork objective is a collaborative one, giving the employees a degree of

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freedom over their own career paths that will motivate and encourage them. SmartWork will shift focus onto results (efficient task completion) through optimization of team formation, collaboration, and coordination and assessment of training needs at team level in relation to specific tasks. Team optimization is guided by the Team Pairing Module, which simulates and predicts team work ability based on the individual work ability models of the workers in a team in relation to the tasks to be performed. It also helps the employers to optimize tasks such that they are achievable by a larger number of workers in a team. The Training Needs Prioritizing Module allows the employers to identify unmet needs of a task with respect to required knowledge or skills, and establish the training needs at team level.

3. Sensing systems for ubiquitous and pervasive monitoring of physiological and behavioural parameters

3.1. Physiological and Lifestyle sensing devices

3.1.1. Physical Activity tracking

An active lifestyle is crucial for the prevention and efficient management of chronic diseases. An adequate level of daily physical activity improves the overall physical function, delaying functional decline and supporting independent living of the older population. To be physically active includes, but it is not limited to, participate in structured physical exercise; it also means to be active throughout the day, for example, by avoiding long periods of inactivity. In this way, in order to support the older adult achieving the desired activity level, we monitor the physical activity throughout the day, and often night, as most activity trackers also monitor sleep. This means that we want the devices to be as unobtrusive as possible. The time is optimal as the 2010s marked the advent of a new market of consumer available physical activity sensing devices, often smaller, cheaper, more comfortable and therefore suitable for continuous use for long periods of time.It is out of the scope of this project deliverable to make a full overview of the available possibilities. Therefore, we have limited our research to devices that meet the following requirements:

- **Battery longer than 5 days**: to reduce the burden on the user of having to charge ÿet another device";
- **Bluetooth Low Evergy**: this feature enables continuous communication with the smartphone, and consequently, with the other SmartWork services. This allows real-time feedback everywhere and at any time. In line with the energy efficiency requirements of SmartWork, blueetoth low energy is the preferred communication protocol.
- **On-board storage**: directly related to the previous requirement. Sensors with on board storage enable the sensor to work by itself without need of an extra device with memory (as smartphone or computer);
- **Open API**.

3.1.1.1. Research Oriented Devices

Research-oriented devices for physical activity measurement date back in the beginning of the 1980s. However, the interest in measuring several consecutive days of physical activity outside the laboratory seems to have started in the early 2000s [1]. Daily activity investigation effort introduced devices capable to obtain real-time data, ultimately being connected to the terms 'wearable' and 'ubiquitous computing' [2].

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In this section we describe two sensors researchers useto monitor physical activity. The first one, from the Actigraph company, is one of the most popular sensors for physical activity [3]. Therefore, there are common practices followed by researchers and also a lot of (open) code available for data analysis. The second one, the Mox sensor, is less popular but provides a cheap and reliable option.

ACTIGRAPH WGT3X-BT[1]

Cost: approx. €320

Actigraph was founded in 2004, after several years of technical refinements and scientific validation of the "actigraph" device.Since then, ActiGraph has become the internationally recognized for ambulatory activity monitoring systems. The wGT3X-BT is ActiGraph'sflagship activity monitor, used by researchers around the world to capture and record continuous, high resolution physical activity and sleep/wake information. It uses 3-axis MEMS accelerometer and digital filtering technology for activity assessment. In addition, it includes integrated wear time and ambient light sensors. This device can be worn on the wrist, waist, thigh or ankle and is equipped with a Bluetooth connector.

FIGURE 2 ACTIGRAPH WGT3X-BT

Technical specifications:

- Output: Raw Acceleration (G's), Activity Counts, Energy Expenditure, Metabolic Equivalent of Task (MET) Rates, Steps Taken, Physical Activity Intensity, Activity Bouts, Sedentary Bouts, Body Position, Sleep Latency, Total Sleep Time, Wake After Sleep Onset, Sleep Efficiency, Ambient Light, (Heart Rate and R-R Intervals when combined with polar heart rate monitors).
- Communication protocol: USB / Bluetooth
- Battery: max. 25 days (depending on choice of epoch length)
- Location worn:wrist / waist / thigh / ankle
- Storage Capacity: 180 days.
- Display: No display
- CE: EN60601-1-Medical Device General Safety Requirements
- Additional features: Waterproof (IP27)

API

[1] https://www.actigraphcorp.com/actigraph-wgt3x-bt/

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Direct REST API access is available for all CentrePoint endpoints including raw (minute-by-minute) data (captured via mobile uploads or direct connect) and post-processed outcomes for each subject. Moreover, Actigraph offers cloud-based data capture to their Centrepoint platform via a central hub or mobile application.

Clinical studies / Validation:

Being one of the most widely used activity tracker for research purposes, the Actigraph sensor has been validated for assessment of activity in adults, both in laboratory and daily life settings [4], [5], [6]. Furthermore, it is often used to validated other activity trackers, such as the consumer-oriented devices from Fitbit [7].

Several clinical trials investigating the physical activity of the older worker were performed using Actigraph sensor. For example, Hall and [8] showed that the cut-off points to distinguish between physical activity levels (e.g. light activity vs. moderate activity) differ between young and older adults, emphasizing the need for specific activity cut-off points for this population.

MAASTRICHT INSTRUMENTS *MOX2*[2]

Cost:approx. 150€

The MOX is a smart activity monitoring platform. The compact and unobtrusive MOX device can be worn on several places of the subject's body (waist, lower back, pockets, thigh, bra, etc.) to measure accurately the level of physical activity and/or posture movement during daily living activities. The small, lightweight device can analyze the measured signals and transmit them wirelessly to a user interface.

FIGURE 3 MAASTRICHT INSTRUMENTS MOX2

Technical specifications:

- Output: Raw data / Counts per minute / Customer specific algorithms (activity intensity, posture)
- Communication protocol: Bluetooth Low Energy (4.0)
- Battery: Rechargeable Battery Lithium Ion125 mAh (battery life >48hours)
- Location worn: Thigh, hip, sacrum, arm
- CE: Certified
- Display: No display on board. The MOX2 has an indicator light to inform on battery status.
- Additional features: Dust & Waterproof IPX8

API

[2] https://www.accelerometry.eu/

Open API available.

Clinical studies / Validation:

The concurrent validity of the MOX was investigated by van der Weegen and colleagues [9], showing realistic and accurate activity measurements, also compared to the Actigraph GT3X in both treadmill and daily life measurements.

The MOX sensor has been used in several research studies investigating the relation between physical activity and risk of falling among the older population [10], [11].

3.1.1.2. Consumer oriented devices

While research-oriented devices prime for accuracy and reliability of collected datasets, often providing access to raw data, consumer-oriented devices are designed to be less bulky, less expensive, and focus primarily on the overal user experience. Furthermore, consumer-oriented devices provide feedback to the user via a display and in most cases are accompanied by an application with several features, mostly aiming at motivating the user to become more active. The choice between research-oriented devices and consumer market devices should be made looking at the aim of each specific study (e.g. is real-time feedback necessary?).

FITBIT[3]

Cost: from 60€ up to 200€

Fitbit is market-leader in consumer health technology for daily life monitoring. Fitbit has several types of devices from the simple clip version (Fitbit Zip), to wrist worn devices (Fitbit Alta and Charge) and smartwatches (Fitbit Versa and Ionic).

FIGURE 4 FITBIT DEVICES

Technical specifications:

- Output (all devices): Steps, calories burned, distance, minutes per physical activity category (inactive, light, moderate and vigorous)
- Output (some devices): floors climbed, heart rate, sleep stages
- Communication protocol: Bluetooth Low Energy
- Battery: 4-6 months (Fitbit Zip); 7 days (other devices)

[3] https://www.fitbit.com/home

- Location worn: pocket/bra/belt (Fitbit Zip) or wrist (other devices)
- Storage Capacity: 7 days of detailed minute-by-minute data, 23 days of daily summary
- Display: Steps, calories, floor, heart rate (when available)

API

Open API available[4]. Standard communication with API allows gathering of daily summaries. With a research request to Fitbit, it is possible to obtain minute-by-minute data.

Clinical studies / Validation

Literature has shown that the Fitbit devices provide a valid estimation of the number of steps in both the laboratory [12]–[15] and free-living [14], [16], [17] environments with accuracy values ranging between 0.90 and 1 in both conditions.

Coaching strategies

- Feedback: all output
- Reminders to move
- Gamified elements: rewards, badges, competition between users, challenges
- Tips on how to become more active

FIGURE 5 WITHINGS DEVICES

WITHINGS[5]

Cost: from 70€ (Move) up to 130€ (Pulse HR)

Withings offers a package of several sensors to monitor health, from activity trackers to thermometers and blood pressure devices. All get connected in the Health Mate app. Withings activity tracker is distinguishable from the competitors mostly due to its look, which mimic an analogic watch. Withings Move is a low-budget option that provides the basics of an activity tracker for a friendly price. Withings has recently announced a new activity tracker with ECG, currently undergoing FDA approval procedure.

Technical specifications:

- Output (all devices): Steps, calories and distance (walking & run); session duration and calories (swimming); deep and light sleep phases and sleep interruptions (sleep); distance, pace and elevation (connected GPS)
- Output (Withings Pulse HR): beats per minute (heart rate)

[4] https://dev.fitbit.com/build/reference/web-api/
[5] https://www.withings.com/nl/en/watches

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- Communication protocol: Bluetooth Low Energy
- Battery: up to 20 days (Withings Pulse HR); up to 18 months (Withings Move)
- Location worn: wrist
- Storage Capacity: 5 days of local storage of data between syncs
- Display: percentage of the goal achieved (Withings Move); heart rate, steps, distance, calories, activities, phone notifications and alarm settings (Withings Pulse HR)
- Additional: swim tracking

API

Withings API can be available on request[6].

Coaching strategies

- Feedback: all output
- Reminders to move
- Gamified elements: rewards, badges, competition between users, challenges
- Tips on how to become more active

XIAOMI MIBAND[7]

Cost: €20-€30

Xiaomi MiBand is an extremely successful low-cost activity tracker that can be used to monitor the wearer's daily step-count, calorie consumption, distance covered. The device is also capable of measuring the wearer's heart rate on demand but with a low accuracy and consistency on the generated measurements. The heart rate information is limited to beats per minute and the device can offer up to average of 1 measurement per 10 seconds due to its operation limitations. Communication with the device is based on the integrated Bluetooth interface and requires a smartphone application on Android and iOS devices. The device is available in 4 different versions, the MiBand 1, 1S, 2 and 3. From these versions, the MiBand 1 offers only activity tracking, while 1 and 1S can be directly controlled via 3rd party applications. The 2 and 3 versions can be controlled only via the official Xiaomi MiFit

FIGURE 6 XIAOMI MIBAND ACTIVITY TRACKER

[6] http://developer.withings.com/oauth2/#
[7] https://www.mi.com/global/mi-band-3/

application, but the collected data can then be synced with other services like Google Fit and Apple Health based on the user's smartphone manufacturer.

Technical specifications:

- Output (all devices): Steps, calories and distance (walking & run); session duration and calories (walking, running, biking); deep and light sleep phases and sleep interruptions (sleep); distance, pace and elevation, beats per minute (heart rate)
- Communication protocol: Bluetooth Low Energy
- Battery: up to 20 days
- Location worn: wrist
- Display: time, heart rate, steps, distance, calories, activities, phone notifications and alarms

API

The Xiaomi MiBand data cannot be accessed through an API but the device can be accessed locally from a smartphone application to actively measure heartrate or receive updates for the step count.

Clinical studies / Validation

Literature has shown that theaccuracy of the wearable fitness tracker products ranges between 79.8% and 99.1%, while the coefficient of variation (precision) ranged between 4% and 17.5%. The Xiaomi Mi band showed the best package compared to its price with an accuracy of 96.56% and a variation of 5.81% [18], [19].

APPLE WATCH[8]

Cost:starting from €300

Apple Watch Series 4 brings advanced activity and communication features, along with revolutionary health capabilities, including a new accelerometer and gyroscope, which are able to detect hard falls. Moreover, it integrates an electrical heart rate sensor that can take an electrocardiogram (ECG) using the new ECG app, which has been granted a De Novo classification by the FDA. Apple Watch Series 4 enables customers to take an ECG reading right from the wrist using the new ECG app, which takes advantage of the electrodes built into the Digital Crown and new electrical heart rate

FIGURE 7 APPLE WATCH

[8]https://www.apple.com/watch/

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sensor in the back crystal. With the app, users touch the Digital Crown and after 30 seconds, receive a heart rhythm classification. It can classify if the heart is beating in a normal pattern or whether there are signs of Atrial Fibrillation (AFib). All recordings, their associated classifications and any noted symptoms are stored in a PDF that can be shared with physicians. It can also alert the user if the heart rate exceeds or falls below a specified threshold.

Fall detection utilizes a next-generation accelerometer and gyroscope, which measures up to 32 g-forces, along with custom algorithms to identify when hard falls occur. By analyzing wrist trajectory and impact acceleration, Apple Watch sends the user an alert after a fall, which can be dismissed or used to initiate a call to emergency services. If Apple Watch senses immobility for 60 seconds after the notification, it will automatically call emergency services and send a message along with location to emergency contacts.

Monitored Parameters:

- Electrical and Optical heart Sensor
- Accelerometer
- Barometric Altimeter
- Gyroscope
- Ambient Light Sensor

Technical specifications:

- Output (all devices): Steps, calories and distance (walking & run); session duration and calories (walking, running, biking); deep and light sleep phases and sleep interruptions (sleep); distance, pace and elevation, beats per minute (heart rate)
- Communication protocol: Bluetooth Low Energy, or 4G LTE
- Battery: up to 1 day
- Location worn: wrist

APIs

WatchKit is an API that extends Apple's development environment for iOS applications to allow apps / notifications to extend to the Apple Watch product.

Clinical studies / Validation

The Apple Watch Series 4 is amongst the most reliable activity trackers available in the market today (an accuracy of 99.06%) based on [18].Its cost is quite high though reducing its wider user. It also offers the ability to monitor the wearer’s heart condition as customers now have access to two optional features enabling detection of irregular heart rhythms. A PPG-enabled algorithm classifies opportunistically collected tachograms in the background, notifying consumers who activate the feature to the presence of an irregular heart rhythm. The use of the ECG app and algorithm, generates an ECG similar to a single-lead (Lead I) ECG to look for the presence of Atrial Fibrillation

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and demonstrated > 98% sensitivity and > 99% specificity when compared with ECGs recorded with a reference device and interpreted by independent clinical experts[9].

3.1.2. Heart Monitoring

3.1.2.1. Smart Mouse

In this section, we present a state of the art on smart mouse devices, as the mouse is one of the most essential and widely used working devices for the daily activities/tasks of the office worker. This survey is focused on computer mouse devices with sensing capabilities related to monitoring of heart related physiological parameters and human behavior analysis. In addition, and extensive patent research was performed in European Patent Office (EPO)[10] patents database, and the results are presented in Annex 1 of this document.

IPN INTELLIGENT MOUSE

FIGURE 8 IPN INTELLIGENT MOUSE

Market: under development

Description: Intelligent Mouse that measures the physiological signals and analyses the psychophysiological patterns of people working in computerized environments. Technology validated in two end-user organizations in the Netherlands and in Switzerland; Pilot period of 19 weeks (1637 accumulated hours of use) with 50 employees that work more than 4 hours with the computer using Microsoft Outlook and Flow Fact;

Sensors: This mouse can be distinguished from other existing smart mice since it combines five types of sensors in a modular and expandable architecture (heart rate, temperature, grip force, galvanic skin response, inertial system).

STRESS LEVEL DETECTOR MOUSE[11]

[9] https://www.apple.com/healthcare/site/docs/Apple_Watch_Arrhythmia_Detection.pdf
[10] https://worldwide.espacenet.com/
[11] http://thecoolgadgets.com/stress-level-detector-a-computer-mouse-with-pulse-wave-sensor-and-infrared

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FIGURE 9 STRESS LEVEL DETECTOR MOUSE

Market: under development

Description: The Stress level detector is a computer mouse prototype with a pulse wave and an infrared sensor designed by Tokyo Metropolitan University's. This device has the capability to measure blood flow inside the fingertip, using the reflected infrared light by the flesh. It is also capable of detecting the stability of cardiac rhythm to gather more information about certain hormone levels on particular time.

Sensors: Bloodflow and Cardiac Rhythm.

BIOMETRIC SENSING COMPUTER MOUSE[12]

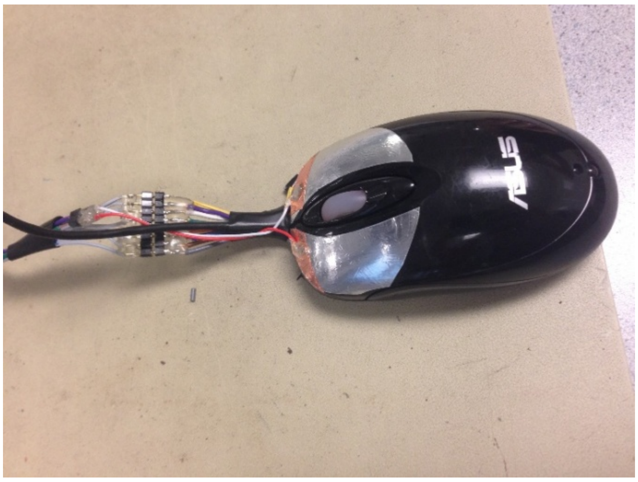

FIGURE 10 BIOMETRIC SENSING COMPUTER MOUSE

Market: under development

Description: Academic project developed by Cornell University which consists in creating a computer mouse capable of detecting user stress levels. The mouse consists in a galvanic skin response sensor and a heart rate sensor. All the gathered data is processed in order to measure changes in the autonomic nervous system

Sensors: Galvanic Skin Response and Heart-Rate.

SMART MOUSE BY SANWA SUPPLY[13]

FIGURE 11 SMART MOUSE BY SANWA SUPPLY

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[12] https://people.ece.cornell.edu/land/courses/e hnl27/ECE%205030%20Biometric%20Sensing%
[13] https://geekologie.com/2017/01/am-i-de
https://www.sanwa.co.jp/product/input/mouse

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Market: on the market (47€ - MA-HLS1; 65€ - MA-WHLS1)

Description: Sanwa Supply is a Japanese company that developed a computer mouse capable of measuring the user heart-rate. The three button wireless/cabled mouse comes with a sensor on the left side, responsible for Reading the heart rate. For that, the user needs to place the finger in the sensor and stay still until the process finishes. It also measures the clicks and distance the mouse has travelled.

Sensors: Heart-Rate.

MIONIX NAOS QG OPTICAL[14]

FIGURE 12 MIONIX NAOS QG OPTICAL MOUSE

Market: on the market (69.99€)

Description: The Naos QG (Quantified Gaming) is a next generation gaming mouse that measures the user's biometric information and movement data. It integrates a heart-rate sensor and a galvanic-skin-response sensor. The sensor pack is capable of measuring the heart-rate, activity and stress levels. The gathered data is compiled in Mionix HUB app, where users can analyse their behaviour and identify patterns.

Sensors: Heart-Rate andgalvanic-skin-response.

ASUS'S PULSE-SENSING VIT W1[15]

FIGURE 13 ASUS PULSE-SENSING VIT W1

Market: N/A

Description: The Vito W1 is a standard computer mouse which not also serves as a pointing device, but also packs a built-in heart monitor.

The mouse reads its user's pulse with a sensor which sits under the thumb (right-handed users only here) and feeds data back to a bundled software suite which displays not only

[14] https://mionix.io/products/naos-qg
[15] https://www.trustedreviews.com/news/asus-combir

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heart-rate but also various different smiley (or not) faces based on that information.

Sensors: Heart-Rate.

Alps Electric + Medtec Japan [16]

Market: under development

FIGURE 14 ALPS ELECTRIC MOUSE

Description: Japanese scientists have created a computer mouse which monitors users' mental stress levels.

The Alps Electric mouse monitors and feeds back information on mouse movement, as well as the user's pulse, haemoglobin levels and rate of oxygen saturation in the bloodstream.

The device is also able to keep tabs on the working environment, collecting data on UV, light, humidity and temperature.

Sensors: Body: Heart-rate, Hemoglobin levels, Oxygen Saturation. Working environment: Light, Humidity and Temperature.

MD MOUSE

Market: on the market

Url:http://www.mdmouse.com/products.html

Description: The MDMouse monitor is the first consumer blood pressure device incorporated into a standard computer mouse. No more digging in a drawer to pull out a stand-alone BP monitor and fumbling with cumbersome arm cuffs. You're already seated and in an ideal position to take a blood pressure measurement. Just a flip opens the cover and swivel out the cuff, tighten around your index finger, and take your measurement.

FIGURE 15 MD MOUSE

Sensors: Blood Pressure.

3.1.2.2. *Portable and wearable headphones*

[16] https://techerati.com/the-stack-archive/world/2016/04/28/japanese-computer-mouse-keeps-track-of-how-stressed-you-are/

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This section presents the most widely adopted portable headphones, which also incorporate sensing capabilities related to human physiological paratmers monitoring and behavior.

VINCI[17]

FIGURE 16 VINCI HEADPHONES

Market:indiegogo(199$)

Description: Vinci is the first smart headphones with AI and wireless connection. Vinci is a standalone device, so there's no need to connect to or search your mobile phone or computer. It includes an accelerometer, gyrometer, proximity sensor, optical heart rate sensor, GPS, and compass. It enables the device to be capable of learning body vitals, activities and other parameters.

Sensors: Body: Heart-rate.

MINDSET HEADPHONES[18]

FIGURE 17 MINDSET HEADPHONES

Market: Pre-order($299.00)

Description: Mindset are a work headphone set with integrated sensors that can perform an EEG. Embedded in Mindset are five electroencephalography (EEG) sensors, which measure the electrical activity in your brain.The read data is used to detect anxiety levels and concentration of the user.

Sensors:EEG.

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[17] https://www.indiegogo.com/projects/vinci-first-smart-headphones-with-ai#/
[18] https://www.thinkmindset.com/

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3.1.2.3. SPARKS wearable ECG

The SPARKS ECG Device is comprised of advanced compact integrated hardware and software tools developed into a commercially competitive small-factor ECG monitoring system. The ECG device weighs about 60g and splits the electronic board in four compartments to ease its application. The palm-sized ECG Device also comes in multiple prototypes in terms of signal quality (6-leads, 12-leads). The life-time of the device, when transmitting real-time ECG traces, from fully charged to fully uncharged battery state (using 1400mAh lithium-ion rechargeable batteries) is about 70 hours. When the device is storing the ECG traces to the internal memory module, from fully changed to fully uncharged battery state (using 1400mAh lithium-ion rechargeable batteries) is about 1 month.

FIGURE 18 SPARKS WEARABLE ECG VEST

The ECG Device is also accompanied with a smartphone application (for Android and iOS) that connects wirelessly to the ECG device and is capable of real time monitoring of the ECG recording and retrieval of the full-size ECG traces on demand. The application can store the traces in the smartphone, transmitting parts of it to the SPARKS cloud services for storage, sharing and analysis.

In brief the SPARKS ECG Device presents three basic advantageous features:

- A complete local amplification signal process.
- A unique easy-to-wear design.
- A local filtration and diagnostic process that allows distant monitoring.

Technical specifications:

- Output: beats per minute, heart beat characteristics, PQRST information, heart beat irregularities detection (heart rate)
- Communication protocol: Bluetooth Low Energy, WIFI or LPWAN
- Battery: up to 2 days

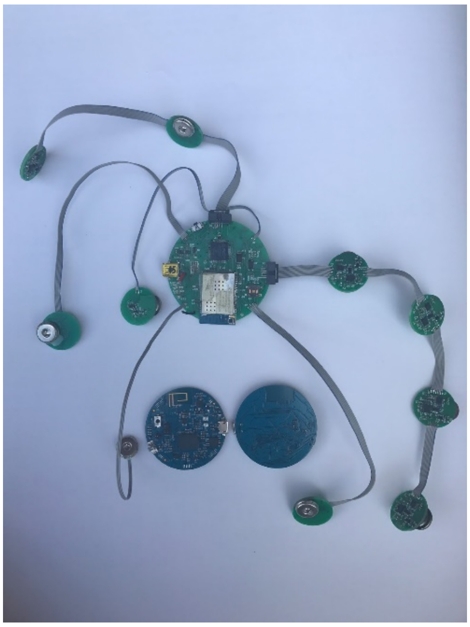

FIGURE 19 SPARKS ECG ELECTRONIC BOARD

API

All data collected by the SPARKS ECG Device can be also retrieved from the SPARKS platform through a well-defined web API that allows external applications to retrieve the generated observations and alerts as well as the raw recorded data based on the requirements of the application.

Clinical studies / Validation

The SPARKS wearable ECG device and ECG analysis algorithm was tested using the MIT-BIH arrythmia database [20] achieving an accuracy above 80% in all recordings available [21].

3.1.2.4. *Other wearable devices for heart monitoring*

SMART WATCHES

A good number of smart watches, commercially available, along with their capability to monitor physical activity, have also the capability to monitor certain heart-related physiological parameters. Further details are provided in Section 3.1.1.2 with respect to currently available commercial devices and their technical characteristics.

POLAR[19]

Cost:starting from €70

FIGURE 20 POLAR CHEST STRAP

Polaris a company that offers high accuracy wearable heart rate monitors for more demanding environments. Polar heart rate monitors and performance sports watches are known globally for their durability and accuracy. Their products include GPS-enabled bike computers, fitness and running watches, as well as heart rate monitors and performance trackers. Polar trackers are designed for any activity ranging from swimming, cross-training and yoga to tracking your daily activity and calorie consumption.

Technical specifications:

- Output: Steps, calories and distance (walking & run); session duration and calories; distance, pace and elevation, beats per minute (heart rate)
- Communication protocol: Bluetooth Low Energy
- Battery: long lasting

API

Most Polar heart rate trackers offer a simple Bluetooth interface for accessing the heart rate data collected in real time by a Polar or third-party application on a nearby smartphone device. Polar smartwatches offer access to the collected data through Polar OPEN ACCESSLINK[20], a proprietary

[19]https://www.polar.com/en/products/accessories/H10_heart_rate_sensor
[20] https://www.polar.com/accesslink-api/

API that provides a direct information sharing link between the Polar ecosystem and third-party data services. In some cases (Polar M600), Polar produces offer developers the ability to develop their applications for Android Wear, Google's smartwatch platform.

Clinical studies / Validation

Clinical trials for the accuracy of the Polar H7 sensor showed that the data from the device contain differences from real, clinical grade ECG recordings that can be considered trivial based on [22].

3.1.3. Breath Monitoring

3.1.3.1. Spire Health[21]

The Spire Health platform offers a set of wearable sensors that can be used to monitor a user's breathing patterns, heart rate, sleep patterns and activity. The only limitation is that the sensor always needs to be attached to the clothes of the user for the tracking to take place. Additionally, the Spire Platform also offers the ability to detect deviations from personalized baselines and generate alerts when such an event occurs. Spire offers two type of devices: the Spire Stone, a wearable device with a 10-day battery life that can detect breathing patterns and extract anxiety levels from that, and Spire Health Tag, a sensor that is attached to existing clothing, never needs charging, and goes through the washer/dryer tracking also the heart rate, sleep, and activity of the wearer.

FIGURE 21 SPIRE HEALTH DEVICE

Technical specifications:

- Output: respiratory rate (expansion of the thoracic cavity); beats per minute (heart rate); respiratory rate variability (stress levels), steps, sleep duration and state of mind
- Communication protocol: Bluetooth Low Energy
- Battery: 1 year (Tag) / 10 days (Stone)
- Location worn: Attached to clothing (preferably on the torso)
- Additional features: Respiration based "state of mind" assessment.
- Advantages: Resistant to washer/dryer. Comfortable wearing.

[21]https://spirehealth.com/

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- Disadvantages: No recharge options for the Tag (1 year use).

API

The Spire Health platform offers access to a user's data through a REST API[22] and using a personal access token. The API offers access to both the raw and unprocessed data collected from the Spire devices as well as the generated conclusions. Data can also be downloaded as Comma-Separated Values (CSV) formated datasets.

Clinical studies / Validation:

A heuristic usability evaluation in 2016, showed that the Spire stone scored the highest among four off-the-shelf wearable sensors (EmotivEpoc, Melon Headband, Spire Stone, and Muse™ Headband) [23]. Holt and colleagues showed the Spire accurately monitors respiratory effort compared to the ground truth (Continuous positive airway pressure -CPAP mask) with a relative median error of 6.8% and mean absolute error of 1.8 breaths per min (SD=0.14) [24].

3.1.4. Medication Adherence

3.1.4.1. Popit Medical Technologies[23]

Cost: €70

Popit is a health-technological company which improves medication adherence through a smart consumer device. Popit is developing Popit Sense, a smart reminder device to help everyone remember their daily medication. Popit Sense, uses three types of sensors to detect the pop sound when a pill is extracted, the motion of the blister pack and the touch of it.

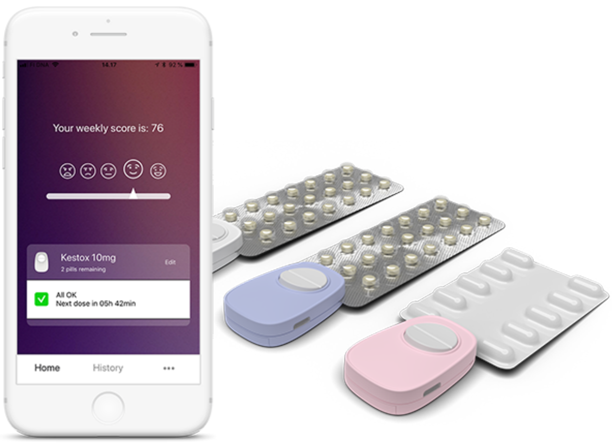

Figure 22 Popit Sense Device

Technical specifications:

- Output: medication adherence (using sound, motion, touch)
- Communication protocol: Bluetooth Low Energy
- Location: Attached to pill blister packs

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[22] https://www.spire.com/en/product-suite/spire-s-api
[23] https://popit.io/

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API

Popit does not offer any publicly available API for accessing information or data regarding medication adherence or any other user information that can be used by third parties.

3.1.4.2. Do-Pill[24]

TELUS Health offers the DO-Pill SecuR to Canadian pharmacies: an intelligent pill dispenser that reminds patients to take the right medication at the right time.Connecting to the DO-Pill SecuR server via a patients' in-home wireless network, the pill dispenser communicates actions, monitors habits, and reminds patients to take their medication. Any sign of medication non-compliance from them will have it:

- Triggers a non-compliance alert
- Send a reminder to the patient; and
- Advise a caregiver that it's time for the patient to take his/her medication.

Also recording time and other data related to medication intake, the dispenser allows for your patient's drug treatment history to be accessed at any time via a secure web portal, meaning you can:

- Customize service based on close follow-up or patient drug compliance
- Integrate portal access within websites to make your patients' drug history readily available

Clinical studies / Validation:

According to clinical studies with schizophrenic patient's medication adherence is extremely important in preventing relapse and lowering symptoms. However, estimates show that nearly half of these patients have poor adherence. The mean antipsychotic adherence ratio using DoPill was 67% after 6 weeks, significantly higher than the 49.5% recorded in literature [25].

3.1.5. Nutrition

Healthy nutrition throughout life is essential for good health. It can help reduce the risk of many chronic diseases such as, obesity, high blood pressure, osteoporosis, type 2 diabetes, coronary heart disease and many more [26]. Nutritional monitoring can be complex as it is not only the amount of food or calorie intake that influences health. It also depends on the exact composition of specific ingredients, such as the amount of sugar, the ratio of saturated versus unsaturated fat, the amount of salt etc. The clinical gold standard for monitoring nutrition is therefore the use of food

[24] https://www.telushealth.co/health-solutions/pharmacy-management/products/pill/

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diaries to retreive a complete overview of all the food aspects. However, compliance for long use of these food diaries is often not achievable. This means that we should focus on monitoring solutions that are as unobtrusive as possible. Moreover, there is no single or standard way to evaluate the nutritional status of a subject. It is important to use a multi approach to accurately assess a persons' nutritional status, namely considering: dietary habits and anthropometric measurements to monitor the effect. This is why we limited our research to the state of the art on monitoring dietart habits and on effect monitoring with anthropometric measurements.

3.1.5.1. Dietary habits monitoring

With respect to dietary habits, a division can be made in keeping (semi-automated) food diaries or using new physiological sensing devices to monitor chewing, swallowing and other digesting body signals. Wearable food intake monitoring devices monitoring are slowly emerging to complement self-reporting of users' caloric intake and eating behaviors. Passive sensing of food intake is to become a reliable gold standard in dietary assessment. Vu and colleagues identified and summarized different technologies and approaches for wearable food intake monitoring [27]. These approaches vary from monitoring the sound of chewing, a pressure sensor under the plate, continuous camera view of the food, inductance plethysmography to detect swallowing and many more. Unfortunately, almost all of these techniques are not commercially available and only tested in the lab environment.

Dietary assessment can be complex in some cases and depends on the type of questionnaire applied. There are several tools available for this purpose, namely weighed dietary intake record, semi-quantitative dietary intake record, 24 h dietary recall and food frequency questionnaire [27]. Although nutrition monitoring is very relevant for the monitoring of someone's lifestyle, keeping a food diary often constitutes a challenge for a patient. Mobile applications (and PC's) support most of current food diary solutions on the market [28]. New developments in smartphones and wearable sensor technologies have empowered automated food monitoring through food image processing and eating episode detection, allowing more adherent, less labour intensive and accurate food monitoring compared to traditional food journaling [29]. We focused ourselves on the most advanced automated food diary applications that meet the following requirements:

- **Unobtrusiveness**: Preferably has some sort of automated food logging features. (barcode scanning, food-database, image processing)
- Open API.

MYFITNESSPAL[25]

MyFitnessPal is a community-oriented site designed to help you lose weight and track fitness goals. The mobile apps let you keep these features at your fingertips wherever you are. You can input or

[25] https://www.myfitnesspal.com/

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edit your goals, enter your caloric intake (food) on the go, and add new food data to the library if it doesn't already exist. MyFitnessPal is a longstanding calorie counting app with accompanying website that is designed to help monitor nutrition status as well as raw calorie intake.

Specifications:

- Operating system: IOS / Android
- Advantages: Barcode scanning, Large (6million+) food-database. Broader view on nutrition in terms of protein, carbohydrates, fats, and fibers. Add recipes, stores previous servings. Large set of integration options with health-tracking services.
- Disadvantages: Manually select portion size and number of servings.

API

The MyFitnessPal API is currently a private API available to approved developers only. Companies interested in integrating with the MyFitnessPal API can submit a request at https://www.myfitnesspal.com/api

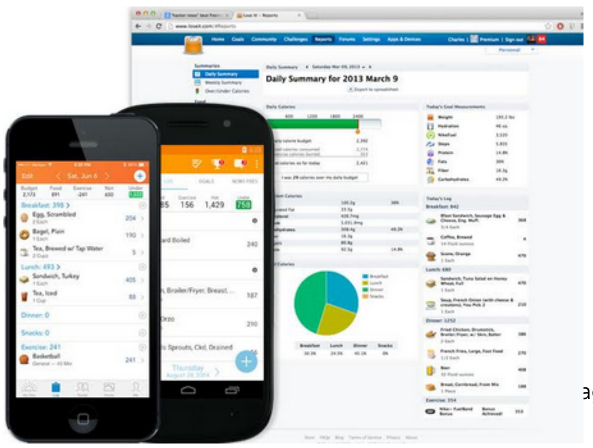
FIGURE 23 MYFITNESSPAL MOBILE APP

Clinical studies / Validation

Hartman and colleagues showed in a clinical intervention study with breast cancer patients that the use of MyFitnessPal as self-monitoring tool in combination with phone counselling resulted in more weight-loss compared to regular care [30].

LOSE IT[26]

Lose It was founded in 2008 and is mobilizing the world to achieve a healthy weight. In a 2016 study with the National Institute of Health, 72.7% of



[26] https://www.loseit.com/

users who actively used Lose It! achieved clinically significant weight loss. Downloaded by over 30 million people around the world, Lose It! is an effective, personal, app-based weight loss program.

Specifications:

- Operating system: IOS / Android
- Advantages: Snap it[tm] food image recognition and portion size recognition. Barcode reader. Multi connectivity to apps, trackers and scales (i.e. FitBit, Nokia scale/Withings scale).

FIGURE 24 LOSE IT APP

API

No open API available yet, but Lose It is looking for innovative initiatives that can assist users in reaching their weight loss goals[27].

Clinical studies / Validation

An American study of the school of nutrition and health promotion compared weight loss using three different diet tracking methods. The Lose it application showed similar results in weight loss compared to the more traditional methods, meaning that the Lose it Application could be a novel and more feasible dietary self-monitoring method [31]. Another study should similar results of weight loss in a group of overweighed cancer survivors. The lifestyle intervention provided using the Lose It application showed a significant reduction in body weight (mean 6.4kg) in 4 weeks.

3.1.5.2. Weight tracking devices

Anthropometric parameters reflect both health and nutritional status. Weight and BMI are the most widely used anthropometric measurements. BMI is a simple index of weight and height that is commonly used to classify underweight, overweight and obesity in adults. It is defined as the weight (kg) divided by the square of the height (m^2). Body length in adults is commonly stable over time, making weight monitoring the most relevant monitoring parameter for anthropometric nutritional status.

There are no exact defined monitoring protocols for weight in older adults. However, adults should frequently assess their weight to be able to correct for their normal fluid shifts. In case of an unexpected weight gain or loss of more than 3 kg/week, subjects should seek advice from a nutritionist or a general practitioner, since it can be associated with an increased risk of the health status of the subject. According to World Health Organization underweight is classified as a BMI lower than 18.5 kg/m2 and obesity is classified as a BMI above or equal to 30 kg/m2 [32].

[27] https://www.loseit.com/partners/

Because weight is such an important parameter to monitor for the evaluation of nutritional status. Bearing in mind the aim of the sensing tools to enable self-assessment in the daily life, we focused our state-of-the-art search on smart weight scales with the following requirements:

- Compatibility with android devices.
- WIFI or Bluetooth connection
- Long battery life (>1 month)
- Small size: smaller than 40cmx40cmx40cm
- Unobtrusiveness: No set-up for each measurement.
- API available

WITHINGS SMART BODY SCALE[28]

Cost:approx. €120

Withings smart body scale monitors offer more readings than most scales, besides weight also the heart rate and full body composition can be assessed. It can handle weights up to 396 pounds and can store up to eight profiles, which each person can sync to an online account that keeps the subject informed of their physical progress. It is also compatible with useful third-party health apps.

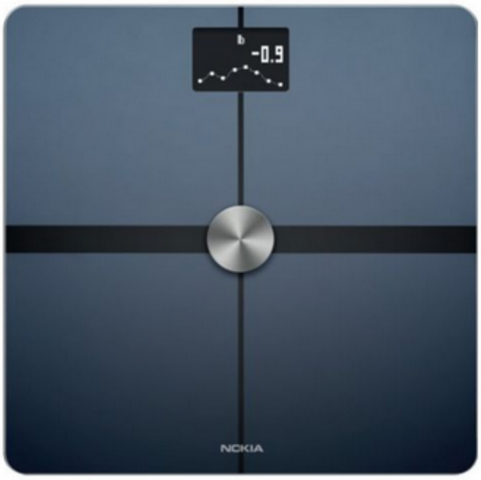


FIGURE 25 WITHINGS SMART SCALE

Technical specifications:

- Output: Weight (kg), body fat (%), total body water (%), muscle mass (kg), bone mass (kg), heart rate, (optional: PWV: Pulse wave velocity)
- Operating system: IOS and android
- Communication protocol: WIFI or Bluetooth
- Battery: Rechargeable li-ion battery (battery life up to 1 year)
- Datastorage: Offline storage capacity of 16 measurements. Data is transferred to the cloud and stored within personal Withings account. Data can be downloaded at any time, free of charge.

[28] https://www.withings.com/nl/en/body-cardio/shop

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- Advantages: Multi-user friendly (up to 8), clean look.

Feedback

Withings Health Mate app keeps track of the weight. Health Mate coaches with tips and encouragement to help reach the objectives that the subjects set. Every weigh-in appears in the Health Mate app automatically, via WiFi sync. With weight, body composition, and heart health history, the Health mate app helps the subject to reinforce positive behaviours and stay focused on the big picture.

API

Withings API can be requested: http://developer.withings.com/oauth2/#

Clinical studies / Validation

Campo et al. tested the validity and reproducibility of the Withings smart scale for accessing the pulse wave velocity, which is a screening parameter for vascular diseases. The results showed that estimation of this parameter is feasible with this bathroom scale, however repeatability could be improved, and accuracy must be tested in different populations [33].

FITBIT ARIA WI-FI SMART[29]

Cost:approx. €100

The Fitbit Aria smart scale measures body fat percentage by using body impedance. The Aria 2 recognizes up to eight individual users and can will automatically sync with the mobile application.

FIGURE 26 FITBIT ARIA WIFI SMART SCALE

Technical specifications:

- Output: Weight (kg), BMI, body fat mass.
- Operating system: IOS and android
- Communication protocol: WIFI and Bluetooth.
- Battery: 4 standard size AA batteries.
- Advantages: Multi-user, Fast installation,
- Disadvantages: No data on muscle mass and total body water despite bio-impedance measurements.

Feedback

[29] https://www.fitbit.com/uk/aria#i.1w1nwxdxbucsxr

The Fitbit app consists of multiple tools for lifestyle monitoring. Set goals, track exercise, log food and measure hydration. Weight-data can be reviewed over time in the dashboard of the Fitbit app. Fitbit provides individualized recommended goals that can be selected by the user, but also uses competitions (Fitbit challenges) to motivate. For more motivation feed. Friend and groups can be found in the Fitbit community tab.

API

Open API available.

Clinical studies / Validation

Shaffer and colleagues showed that the Aria had an excellent agreement with the seca 769 scale in 32 participant with 10 weight readings [34].

The Fitbit Aria is also used in clinical trials. For example the results of Ross and colleagues suggest that the use of the Fitbit aria plus brief phone-based interventions improve adherence and weight loss compared with traditional self-monitoring tools [35].

3.1.6. Sleep

Global studies show that 25% of elderly people have sleeping disorders [36]. The scientific output, measured by the number of publications in the field of sleep research, indicated an exponential growth of knowledge of sleep and the health related causes and consequences of sleep disturbances [37]. Sleep is essential for the functioning of body and mind and therefore a key factor in lifestyle monitoring.Shortened sleep cause people to feel tired and reduces work performances drastically [38]. The results of Pereira et all suggest that social stressors at work are antecedents of impaired sleep quality and increased psychosomatic health complaints leading to higher costs and loss of productivity for the working population. Sleep deprivation is furthermore associated with differences in appetite regulatory hormones which may contribute to obesity and weight changes [39].

There are several validated questionnaires that count as indicators of sleep quality, and this remains the most common used technique for sleep monitoring within research studies. However, where once objective sleep monitoring only took place in clinical practice, it is now possible to track sleep in your own home-environment. The opportunities for home monitoring of sleep arose quickly after the release of commercially available activity trackers. For the SmartWork solution we are looking for unobtrusive sensing solutions and therefore do not focus on questionnaires or obtrusive monitoring devices such as EEG and polysomnography.

3.1.6.1. Smartphone based applications

Several smartphone applications make use of the built-in sensors to provide sleep monitoring and coaching. These sleep apps use the accelerometer to determine the sleep quality. The microphone function is often used to detect snoring or coughing. By looking into smartphone application stores hundreds of sleep apps appear: Sleep time, relax and sleep, sleep analyzer, sleep cycle etc. They offer varying degrees of analysing sleep patterns. Some of them propose to wake the person at a moment which is the best to wake up because of the sleep stage were the person is in, according to the app's algorithms. There are some apps that also help persons to fall asleep, by playing nature sounds [40]. Research of Bhat et al. showed that the Sleep Time application app had an 90.5% agreement rate with PSG for sleep detection and had an 50.0% detection for awakenings [41]. Still a little is known about these smartphone-based sleep applications and real clinical studies are not established yet. Therefore, state of the art review will be based on (wearable) sleep monitoring devices, such as activity trackers and matress sensors.

3.1.6.2. Consumer oriented devices

Several activity trackers also provide monitoring of sleep. This is the case of the Actigraph (mentioned in section 3.4.1.1) and most Fitbit devices (mentioned in section 3.4.1.2). In the remaining part of this section we look at devices that are placed in the bed of the user (e.g. matress sensors), and not on the body.

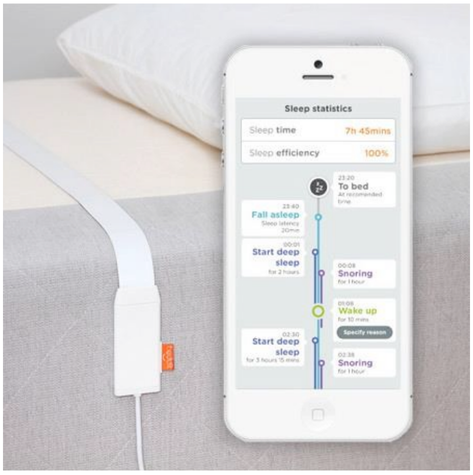

FIGURE 27 BEDDIT SLEEP TRACKER

BEDDIT[30]
Cost: €130

Beddit measures sleep using unobtrusive force sensors. It measures the forces caused by the body on the bed with a flexible film sensor that is placed below the bed sheet. The measurement methodology provides a ballistocardiograph (BSG) with physiological information: heart rate, respiration and movement. The Beddit makes an estimation of sleep based on several physiological parameters. The sleep quality estimation converts data into 3 "states" of sleeping: wake, sleep and deep sleep. Using these states many regular used sleeping parameters will be calculated. Besides the estimation for the sleep state the Beddit also measured snoring sound, temperature and environmental light in the room. Snoring is based on the sound and the registered breathing pattern.

Technical specifications:

- Output: Heart rate, respiration, movement, total sleep time, sleep efficiency, amount of restlessness, time awake, sleep latency, deep sleep time, snoring sound, temperature and humidity (USB plug), environment light.

[30] https://www.beddit.com/

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- Operating system: IOS
- Data storage: Beddit does not longer support of the Beddit Cloud, which allowed back up of sleep data on a personal online Beddit account and view it across multiple iOS devices. Therefore only local storage of data on an iOS device is now available.
- Communication protocol: Bluetooth 4.2
- Advantages: Multi-sensor approach, complete mapping of sleep parameters.
- Disadvantages: No Android compatibility.

API

API documentation is available[31], but for commercial purpose API request is needed.

Clinical studies / Validation

The Beddit sleep monitoring enterprise is the results of the PhD research on force sensor-based sleep monitoring [42].

WITHINGS SLEEP TRACKING MAT[32]

Cost:€100

The Withings Sleep is a sleep tracker that is placed underneath the mattress and features advanced sleep tracking. The sensors using ballistocardiography to monitor breathing, movement and heart-rate, and translates this into sleep cycle data. It also allows home automation scenarios with IFTTT such as turn on/off the lights and turn up the thermostat.

FIGURE 28 WITHINGS SLEEP TRACKING MAT

Technical specifications:

- Output: Heart rate, sleep cycles (deep, light, REM) snoring, sleep quality score, time to sleep, time to get up, total sleep time, amount of sleep interruptions.
- Operating system: IOS and android
- Communication protocol: Bluetooth 4.0 / WIFI
- Data storage: Data is transferred to the cloud and stored within personal Withings account. Data can be downloaded at any time, free of charge.

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[31] https://github.com/jakusgy/beddit-api
[32] https://www.withings.com/us/en/sleep

Advantages: Home automation options: Control lights, temperature, and other smart home-enabled devices just by getting into and out of bed. Integration options with several health applications (such as MyFitnessPal, Fitbit, Google Fit, Run keeper etc.)

Feedback:
Dedicated in-app coaching program to help reduce fatigue & improve health.

API
Withings API can be provided on request[33].

Clinical studies / Validation
No clinical or validation studies could be found using the Withings sleep tracking mat.

3.1.7. Emotional wellbeing

Next to the monitoring of physical activity, nutrition and sleep, getting insights on the emotional wellbeing of the older worker can greatly improve the SmartWork services. For example, within the myWorkAbility service, monitoring of emotional wellbeing might lead to early detection of stressful situations, enabling early intervention through targeted real-time coaching and eventually preventing burn-out situations. Therefore, in this section we provide examples of unobtrusive sensing of physiological parameters associated with stress (e.g. respiratory rate) and for services that require direct input from the user.

3.1.7.1. Experience Sampling Method smartphone applications

The Experience Sampling Method (ESM), also known as Ecological Momentary Assessment, was introduced in 1987 and concerns the assessment of feelings or activities at the current moment that they happen [43]. It started with messaging service, through SMS technology; however the spread of smartphones gave place to a whole set of applications with more complex reasoning and data mining. ESM gained a lot of interest more recently, with the spread of smartphones and mobile technology in general. When compared to conventional used diary report methods, ESM has the advantage that it reduces the recall bias as individuals are asked what they are doing at the current moment [44], [45]. Secondly, it consists of short questions designed to avoid disturbing the individual and allowing collection of data for long periods of time.

[33] http://developer.withings.com/oauth2/#

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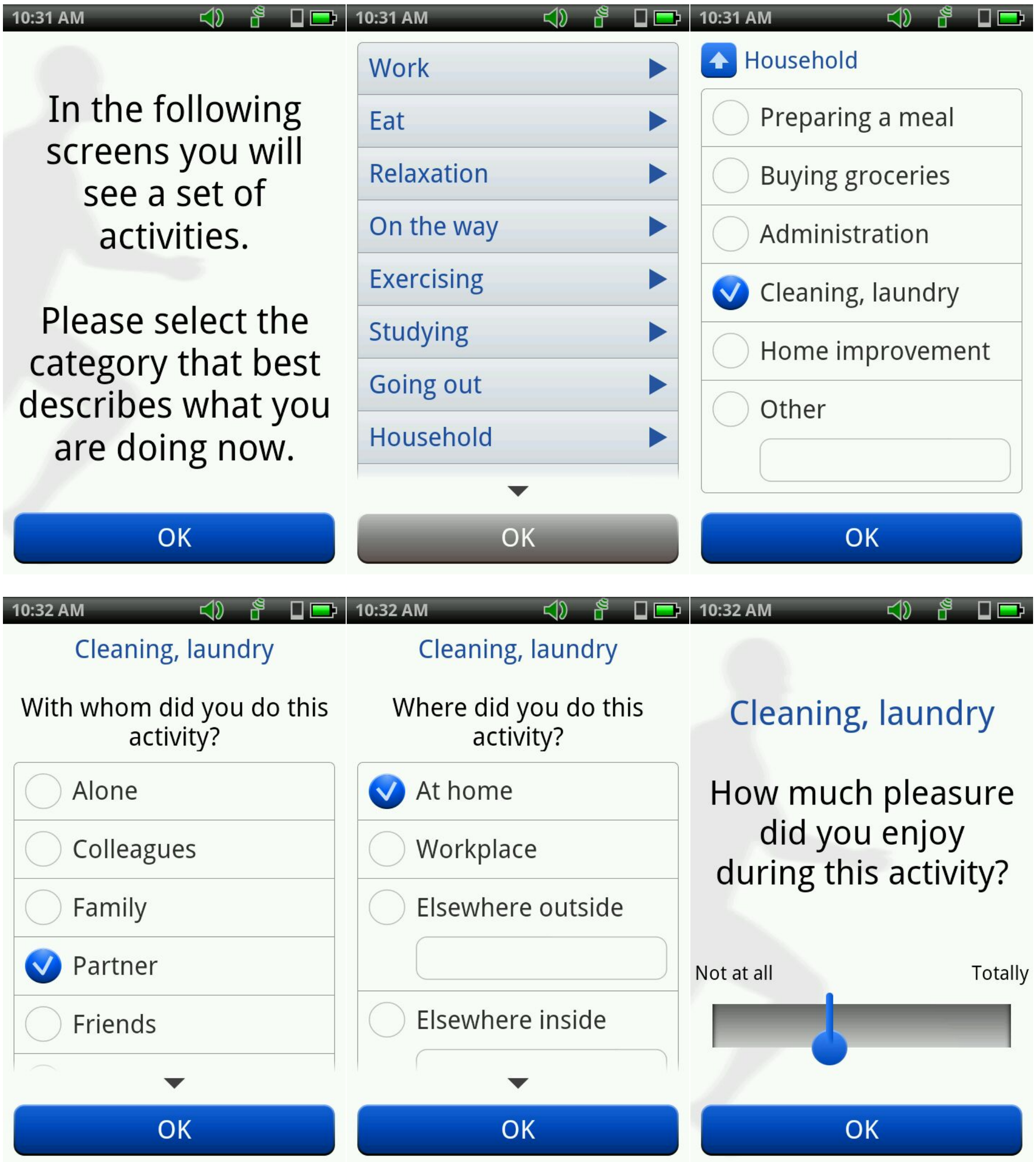

FIGURE 29 EXPERIENCE SAMPLING METHOD AS DEMONSTRATED IN THE ACTIVITY COACH APPLICATION – PART OF THE CONTINUOUS CARE & COACHING PLATFORM

By using a smartphone application for ESM, the researcher can tailor the questions and timing to the exact study. In this section, we bring ESM related to emotional wellbeing monitoring, but we can also use the same method to elicit information about the context of the individual. For example, in the context of wellbeing of the older worker, within the AAL Funded project PEARL, ESM was applied to investigate the physical activity, fatigue and satisfaction associated to several work activities (e.g. emailing) and contexts (e.g. alone vs. with colleagues) [46].

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3.2. Environment and context parameters sensing technologies

3.2.1. Environmental Monitoring

3.2.1.1. Sparks Environmental Monitoring Devices

Cost: €100

Environmental comfort is of extreme importance to both office and home buildings. It is important to ensure that the occupants of a building are feeling as comfortable as possible inside their living and working spaces. The SPARKS environmental comfort meter focuses on monitoring the thermal, visual and aural comfort of occupants. Additionally, it also monitors occupancy, to better understand different activity levels throughout the day. The latest version of the meter uses digital sensors to collect data for its surroundings and can be equipped with different radio modules to transmit such data to a cloud service (i.e., over WIFI, IEEE 802.15.4, or LoRA) or a nearby device (via Bluetooth). In some installation scenaria, the device needs communicate with an additional gateway device to ensure that the data collected are forwarded to the cloud infrastructure of SPARKS (i.e., when using IEEE 802.15.4 or Bluetooth). The monitored parameters are the following:

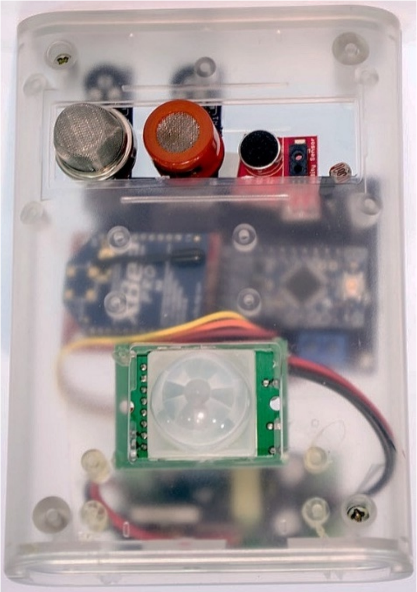

FIGURE 30 SPARKS ENVIRONMENTAL COMFORT METER

- Noise Exposure: a sound pressure level sensor is used to detect the noise level of the environment in two stages: (1) capturing noise samples using a simple electret microphone characterized by a specific sensitivity, and, (2) using an amplifier to provide output that can be read by the microcontroller used.
- Thermal Comfort: temperature and relative humidity (percentage of water vapour in the air) is measured using the digital THO2 I2C sensor. This sensor integrates both sensors and an analog-to-digital converter, signal processor, and calibration data together with an I2C host interface. It provides reliable readings for humidity between 0–100 %RH and 0-70°C, more than enough for indoor environments.
- Luminosity: the TSL2560 photodiode I2C sensor is used to measure the ambient luminosity in the installation area. This sensor offers a sensing range of 0.1 to 40,000 lux with 16 bit digital resolution, as well as lower quantification errors and reduced noise interference when compared other solutions.

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- Occupancy: a PIR Sensor is used to detect motion inside the room of the installation. The PIR sensor outputs an event that is used as an interrupt trigger to the microcontroller each time a hot object moves (like the human body) moves inside the room.

Technical specifications:

- Output: Temperature; Relative Humidity; Luminosity; Occupancy (Motion Detection); Noise
- Communication protocol: Bluetooth Low Evergy, IEEE 802.15.4, USB, LPWAN

API

SPARKS environmental comfort meter comes with a REST API that allows to retrieve information and data for all installed Environmental Comfort Monitoring Devices of a user. This API provides access to both the latest sensed measurements from the devices as well as the historical data stored in the platform. Users can also group their sensors and generate aggregated data on demand in cases where a single sensor is not able to cover a larger area (i.e., a PIR sensor has only a limited angle of motion detection around 90 to 100 degrees).

3.2.1.2. SmartThings[34]

Cost: depends on the product

SmartThings is a technology company and its primary products include a free SmartThings app, a SmartThings Hub, as well as various sensors and smart devices. The SmartThings native mobile application allows users to control, automate, and monitor their home environment via mobile device. The app's SmartSetup area, accessible from the app's dashboard, facilitates the process of adding new devices. Customers can use the app to connect multiple devices at once or follow a dedicated path to configure one device at a time. The hub connects directly to a home's internet router and is compatible with communication protocols such as ZigBee, Z-Wave, and IP-accessible devices. It serves to connect sensors and devices to one another and to the cloud, allowing them to communicate with the SmartThings native app. SmartThings sensors lineup:

FIGURE 31 SMARTTHINGS SENSORS

- Water Leak Sensor

[34]https://www.smartthings.com/

- Tracker
- Arrival Sensor
- Motion Sensor
- Multi-purpose Sensor

Technical specifications:

- Output: Water Leaks, floods; Temperature; Presence; Motion; Vibration
- Communication protocol: WIFI, Zigbee and Bluetooth (depending on the device).
- Battery: AA batteries (depending on the devices).

API

SmartThings API enables users to integrate their own IoT devices and services into SmartThings Cloud. Furthermore, SmartThings API provides methods to control and monitor a variety of IoT devices.

3.2.2. Smart Lighting

3.2.2.1. Phillips Hue[35]

Cost: €20-€120

Philips Hue offers a wide line of color changing LED lamps and white bulbs which can be controlled wirelessly. The Hue system was marketed as the first iOS controlled lighting appliance. It uses the Zigbee lighting protocol to communicate, and can be controlled via smartphone apps over cellular network, Ethernet or Wi-Fi via a Zigbee–Ethernet bridge wired to a router. It also features HomeKit compatibility. The Hue Bridge enables the user to control lights through smartphone, voice assistants and smart accessories like motion sensors and wireless switches. It also unlocks smart features like setting schedules and routines or controlling lights when the user is away from home. Phillips offers the following devices:

FIGURE 32 PHILIPS HUE SMART BULBS

- Smart Bulbs, Lightstrips and Lamps

[35]https://www2.meethue.com/en-us

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- Motion Sensors
- Outdoor Sensors
- Dimmer and Tap Switches

Technical specifications:

- Output: Motion; Luminosity; Lamp and Lights status
- Communication protocol: WIFI, Zigbee and Bluetooth (depending on the device).
- Battery: Wall powered and LiPo batteries.

API

The Philips Hue API is a public API, which allows developers to access and integrate on Philips Hue with other applications. Some example API methods include managing lights and light attributes, managing light schedules and configuring lights and accounts.

3.2.3. Smart Thermostats

3.2.3.1. Nest[36]

FIGURE 33 NEST SMART THERMOSTAT

Cost: €150-€210

Nest is a manufacturer of smart home products including thermostats, smoke detectors, and security systems including smart doorbells and smart locks. The Nest Learning Thermostat, Nest's flagship product is a self-learning Wi-Fi-enabled thermostat that optimizes heating and cooling of homes and businesses to conserve energy. Nest video doorbell with HD video streaming uses motion, sound and person (including face recognition) alerts to inform the user about potential intruders. Nest's indoor and outdoor weatherproof and tamper-resistant cameras can detect a person up to 50 feet away, and alert with a photo of who's there. It also offers a close-up tracking view which zooms in and follows the action in the app. Nest Protect is a smoke alarm with a humidity sensor and custom algorithms in order to distinguish steam from smoke. Nest currently offers the following devices:

- Thermostat (Learning, E)
- Temperature Sensor
- Indoor/Outdoor NestCam

[36]https://nest.com/thermostats/nest-learning-thermostat/overview/

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- Aware
- Video Doorbell
- NestSecure
- NestProtect

Technical specifications:

- Output: Temperature; Humidity; Proximity; Luminosity; Motion; Face recognition; Tampering; Magnetic Proximity; Air Quality
- Communication protocol: WIFI, Zigbee and Bluetooth (depending on the device).
- Battery: Wall powered and LiPo batteries.

API

The Nest API allows users to control the Nest Thermostat and Nest Protect as well as display their current configurations. By using the API, developers can integrate Nest Thermostat and Nest Protect with their own products, applications, or services.

3.2.3.2. Ecobee[37]

Cost: €70-€210

Ecobeeis a home automation company that provides temperature, humidity, proximity and luminosity monitoring devices and thermostats suitable for residential and commercial use. Ecobee4, their voice-enabled smart thermostat, comes with Room Sensors which helps to manage hot or cold spots and to save a considerable amount of the annually heating or cooling costs. It comes with built-in Amazon Alexa, which allows to control your thermostat using your voice. Ecobee's current product line offers:

FIGURE 34 ECOBEE SMART THERMOSTAT

- Thermostats (ecobee4, ecobee3 lite)
- ecobee Switch+
- Room Sensors

Technical specifications:

- Output: Temperature; Humidity; Proximity; Luminosity

[37]https://www.ecobee.com/

- Communication protocol: WIFI, Zigbee and Bluetooth (depending on the device).
- Battery: Wall powered and AA batteries.

API

The ecobee API provides an http-based interface for control and access to the ecobee thermostats. Allows read, update and poll information about thermostats. Ecobee's APIs can be used by 3rd party developers to create web or mobile applications that integrate with Ecobee's thermostat platform.

3.2.4. Air Quality Monitoring

3.2.4.1. Netatmo[38]

FIGURE 35 NETATMO MONITORING DEVICES

Cost: €100-€150

Netatmo offers health, physiological, security and energy efficient monitoring products. Its stationary devices provide a wide range of sensor measurements. Netatmo offers the following devices:

- Smart Indoor and Outdoor Camera
- Smart Smoke Alarm
- Smart Video Doorbell
- Smart Indoor Siren
- Smart Door and Window Sensors
- Smart Thermostat
- Smart Radiator Valves
- Smart Home Weather Station
- Rain and Wind Gauge
- Smart Indoor Air Quality Monitor

Technical specifications:

- Output: Motion; Vibrations; Smoke; Face Recognition; Sound; Energy Consumption; Temperature; Luminosity; Air Quality; Barometric Pressure; CO2 levels

[38] https://www.netatmo.com/en-row

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- Communication protocol: WIFI, Zigbee and Bluetooth (depending on the device).
- Battery: Wall powered and AA batteries.

API

Netatmo Connect (APIs suite) enables third party apps and services to interact with Netatmo products. Netatmo Weather API offers customized weather services and integrates real time weather data. Netatmo Smart Home API understands users' habits and home environment to create tailored services. Netatmo Enterprise API analyzes users' behavior and offers them custom-made services. The 3available APIs:

- Netatmo Weather (Available data: Temperature, Pressure, Humidity, Rain and Wind strength, Wind angle, Gust strength and Gust angle within a specific area. Details about the location of the Weather Stations)
- Netatmo Smart Home (From the Weather Station: Indoor: Temperature, CO2, humidity, noise Outdoor: Temperature, pressure, humidity, rain and wind strength, wind angle, gust strength and gust angle From the Thermostat: Temperature, schedule, setpoint From Welcome (indoor camera) and Presence (outdoor camera): Events, timeline of events, snapshots of events, videos of events, live stream User information: metric units preferences, language and geographical region Device specific data: id, firmware, battery status, radio status, location, Wi-Fi status)
- Netatmo Enterprise (Available data: From the Weather Station: Indoor: Temperature, CO2, humidity, noise Outdoor: Temperature, Pressure, Humidity, Rain, Wind (strength and angle) and Gust (strength and Angle) From the Thermostat: Temperature, schedule, setpoint Device specific data: id, firmware, battery status, radio status, location, Wi-Fi status)

3.3. Existing cross-platform infrastructures with physiological and behavioral sensors

3.3.1. Fitabase[39]

Fitabase is a platform that supports researchers collecting and analyzing data from consumer devices. It provides tools to monitor the participants in real-time, easily export data and perform analysis and store the sensitive data. With more than 500 research studies using Fitbit, Fitabase has

[39] https://www.fitabase.com/

recently announced collaborations with Garmin and Dexcom, showing that the company is opening to other brands of devices.

FIGURE 36 - FITABASE IS A CLOUD-BASED DATA AGGREGATION PLATFORM BUILT TO SUPPORT RESEARCHERS TO EXTRACT AND AGGREGATE DATA FROM CONSUMER DEVICES.

3.3.2. Continuous Care & Coaching platform

The Continuous Care & Coaching platform (C3PO) is the proprietary eHealth service platform developed by Roessingh Research and Development. C3PO is, at its core, a database management system – a set of secure APIs for transferring data to and from a server side database. The main supported data types are time-based data series (i.e. sensor data) and questionnaire results. Data can be accessed by authorized users – including the originating user, and/or his/her care professionals and system administrators.

Besides a database management system, the C3PO platform includes user interfaces and applications for end users, typically those that are present in any Telemedicine or eHealth application. A mobile smartphone application (Android) has been developed for end-users (e.g. patients, older adults), and a web portal is primarily targeted at health care professionals. The smartphone application is developed using a flexible Android platform, that is aimed at collection data either through direct interaction from the user (e.g. questionnaires) or through Bluetooth connected sensors (e.g. activity trackers, heart rate sensors, blood pressure sensors). Sensor manufacturers that do no open their sensor's Bluetooth protocols are integrated into the C3PO platform through the backend server, as is the case with e.g. Fitbit and Withings (see section 3.1.1.2).

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The C3PO platform has been used in several national and international projects over the past 10 years. The services are being used as the basis of several European research projects (e.g. Holobalance, Council of Coaches) and have been tested extensively over the course of multiple past projects (e.g. FP7 PERSSILAA and H2020 InLife). The C3PO platform is currently commercially delivered as part of regular care to Rehabilitation Centres and Care and Nursing Centres. These services are also presented as good practice within the European Innovation Partnership – Active and Healthy Ageing (EIP-AHA) framework.

3.3.3. universAAL[40]

universAAL is an open source semantic platform started from a European project. It was originally designed for Smart Living Environments, and its main objective is that through universal IoTm all compatible products and devices can connect and collaborate to the benefit of the user. Its defining feature is a semantic matchmaking based on ontologies, providing seamless communication between services, user interfaces and context providers and consumers. Several devices (sensors) exist that are compatible with the universAAL platform.

3.4. Data Management

The SmartWork Project is based on the design of a prototype which will unobtrusively sense physiological, behavioral, and environmental parameters thus composing a wellness index and provide personalized and proactive hints to the users on how to adjust their current daily working behavior to a more health-friendly and productive way. Besides listing common practices and describe state of the art mechanisms and strategies, the scope of this deliverable is also to properly identify certain components, partially track the initial development process as well as describe the main steps towards integrating the SmartWork sensing prototype platform with the rest logical entities of the overall platform architecture.

As already stated in the description of work, the SmartWork sensing prototype is a holistic solution which allows precise sensor orchestration, data acquisition, handling, manipulation and storage, paired with algorithm execution for advanced analytics and result extraction from all available information and datasets. The prototype's design will be heavily depending on the prerequisite analysis which will lead to the proper definition of the most essential components of the prototype, thus resulting to the first draft of its architectural diagram.

Moreover, a preliminary evaluation phase of common practices is crucial to obtain a basic idea for the prototype in a bottom-up approach, starting from the necessary modules that will compose the

[40] https://www.universaal.info/

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final sensor network and its auxiliary services, the underlying algorithms that will facilitate data handling and analytics, the communication protocols and the corresponding interfaces that should be implemented and most importantly, the main coordinating node, its role and how this node can be efficiently exploited for deploying a robust, near production-ready prototype. Since the available spectrum of choices for each sensor and hardware component is considerably wide, before defining a conclusive prototype architecture, all different options need to be evaluated and the most appropriate will prevail. The final choices must be made in distinct cycles involving specification analysis, development, integration testing, field evaluation and reporting.

3.4.1. Applications and Online Services

The SmartWork sensing prototype consists of distinct, yet fully integrated, modules and entities, capable of interacting and exchange vital user-related information. The prototype must support a wide variety of wearables, sensing devices as well as connectivity with online content services and data repositories. Thus, the SmartWork sensing prototype can be divided into four generic subsystems each with a unique role, set of features and functional requirements:

- The **SmartWork Data Aggregation Subsystem** retrieves information from every available source, namely the environmental sensors, the user's wearables, as well as the sensors located in auxiliary equipment, for instance inside the user's smartphone. In addition, it can connect to online repositories for retrieving relevant information (i.e. weather data, additional cloud repositories for sensing information retrieval) and lastly, is responsible for initiating the necessary channels of communication for uploading all retrieved datasets to the SmartWork Cloud Storage Repository when user demands it.
- The **SmartWork Processing Pipeline** which receives the data from the previous subsystem and performs the appropriate analysis based on the configuration of the system.
- The **SmartWork Storage Repository** which stores the reports and historical data for further distribution and processing, while allows members of the project to access, review and process them in a secure manner.
- **Third-Party online application repositories and services,** which will provide additional information details and is automatically accessed through the SmartWork Data Aggregation Subsystem.

3.4.2. SmartWork Data Aggregation Subsystem

In the rest of this section we intend to provide some insights and details on the operation and necessary building blocks of the SmartWork Data Aggregation Subsystem, along with the sensor and wearable equipment it mustsupport.The SmartWork Data Aggregation Node must support multiple services which can be divided in four distinct categories:

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- Input Services
- Pre-Processing Services
- Data Publishing Services
- Communication Services

Input Services are responsible for data collection, regardless of its source. Each source is represented by a dedicated service instance and can be either phone sensors, wearables, or external APIs.

Pre-Processing Services can transcode the data collected by Input Services to any predefined format required for the project and most importantly, generate additional data from local processing. Generated data are values computed locally based on retrieved information from all the data sources. Local caching and data aggregation processes are also part of the specific category and precede data upload to the central SmartWork Cloud Storage Repository.

Data Publishing Services are used for uploading the recorded datasets to the external storage repositories used in the context of the project. It is possible to upload the data onto multiple external repositories or share them inside or outside the scope of the project (i.e., with the worker's doctor via and email report).

Communication Services are responsible for managing connections to external services or authentication credentials to ensure the proper operation of the SmartWork applications.

It is therefore expected that several modules belonging into all categories will operate in parallel in the SmartWork Data Aggregation Subsystem. In more detail:

- **The Sensor Data Management Modules**. This module oversees sensor-originating information accumulation and is responsible for tasks related to process, filtering, clearing or converting these data to more suitable information for the application, if necessary.
- **Real Time Analysis**. This module is part of the necessary DSS (Decision Support System). It oversees information gathering from the sensors and generates notifications, alarms and additional information to warn users. This module could be active or not, based on the user decision, for instance when in the office or during a separate event worth tracking.
- **The Server Communication Module** oversees sending and receiving information from external servers. The data captured by the sensors and the data generated during the gaming sessions will be managed by this module. Furthermore, the data calculated by the Offline Analysis module or stored in the database will be sent to the application using this module. Since the server controls the access to the information, this module will need to be registered with a user and password.

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3.4.3. SmartWork Processing Pipeline

Some of the most popular frameworks which could be used in the implementation of the SmartWork Processing Pipeline are Apache Storm[41]and Apache Flink[42]. Apache Storm is a free and open source distributed real-time computation system which makes it easy to reliably process unbounded streams of data, doing for real-time processing what Hadoop[43] did for batch processing. Storm is relatively simple and the data analysis can be implemented in multiple programming language. Some of the use cases of Apache Storm include real-time analytics, online machine learning and continuous computation. Apache Storm is fast, scalable, fault-tolerant, guarantees data processing over a well-defined pipeline, and is easy to set up and operate. Storm integrates with multiple queuing and database technologies widely available. Apache Flink operates in a similar way, offering developers the ability to process datasets, stored in an HDFS cluster, and data streams, similarly to Storm. While its operation is similar to Storm, it applies the implemented data aggregations mainly on time-based windows of data, while Storm leaves more freedom to the developer on how to split and handle the data that arrive to the system. Based on these two frameworks and any other that may be used in the project we can define two main submodules of the Processing Pipeline:

- **The Continuous Computation Engine**: A real-time processing engine provides fast, and reliable processing of an unbounded number of streams of data collected from IoT devices, smart phones and web-services. The implemented SmartWork computation engine must be capable of processing and merging a large amount of data collected from sensor nodes within just seconds to generate simple analytics from the original data streams.
- **The Online Analytics Engine:** Data collected from the streams and the output of the continuous processing are easily selected, extracted and analysed to support business intelligence. An effective online analytics engine will allow the organization to apply techniques like machine learning and artificial intelligence on the large data volumes and extract the important insights that SmartWork should offer to its users.

3.4.4. SmartWork Storage Repository

The SmartWork Storage Repository must handle sensitive user-oriented datasets in a way that prevents misuse, modification, leakage and unauthorized access by any third-party individual or entity. This necessity derives from the dataset context which involves personal and medical

[41]http://storm.apache.org/
[42]https://flink.apache.org/
[43]https://hadoop.apache.org/

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information, thus is protected by special legislation within the EU. It is therefore of paramount importance to use a tailor-made identity management module for efficiently monitoring and responding to potential threats. The aforementioned module, hence defined as the SmartWork Authentication and Authorization Infrastructure must be based on the OAuth2.0 authorization protocol [47]. The main component of the SmartWork AA Infrastructure is the Authorization Server, which hosts the user accounts and authorizes other entities or third-party services to access protected resources linked to a specific user account. The SmartWork AA Infrastructure must also integrate authorization flow support for web and desktop applications, browser-based applications and mobile applications.

The SmartWork Storage Repository service, as part of the overall SmartWork platform infrastructure, must be designed with the Internet-of-Things paradigm in mind, thus enabling easy and fast implementation of applications that use an IoT-related stack. It should be implemented to support the highest possible scalability both in terms of users, number of connected devices and volume of data processed. Moreover, it is important to accommodate real-time processing of information collected from mobile sensors, smart phones and support fast analytic services.

SmartWork Infrastructure in general, needs to support real time processing and analysis of unlimited IoT data streams with minimal delay and processing costs. Storage services use state of the art solutions like Not Only Structured Query Language (NoSQL)[44] and time series[45] databases to ensure maximum scalability and minimal response times. Access to data retrieved from IoT installations connected to the SmartWork framework must be granted through OAuth2.0 authentication in order to provide the easiest integration with external services. Therefore, the SmartWork platform must be designed in order to deliver a set of services that are critical for all IoT installations as listed below:

- **End-to-end security:** Communication across the components and entities of the SmartWork architecture and all types of supported services must be compliant with current standards for Internet security. Communication throughout the service infrastructure should always be encrypted using data encryption standards like AES and TLS/SSL technologies.
- **Access management:** Authorization of users and access to data must be easily managed in real-time down to specific user, device or time of day.
- **Storage & Replay:** Data entering the SmartWork system must be handled in a manner persisted to their original format and always remain associated with the output of the continuous processing engine. Data streams can be later to different components.

[44]https://en.wikipedia.org/wiki/NoSQL
[45]https://en.wikipedia.org/wiki/Time_series_database

Offline data processing is facilitated for archiving services or for benchmarking different versions of components.

Moreover, the SmartWork platform should provide a unified API for retrieving data from multiple resources and hardware platforms.

3.5. Conclusion

In this section, we provided details on a large set of devices and services that represent the state-of-the-art options to monitor various physiological paramenters, the environmental conditions of indoor home and work spaces, as well as the activity of users and workers during their everyday lives. Most of the devices are already available on the market as consumer ready devices and can be also used by the workers individually while the price tag in most of them is also relatively low and their data can be integrated into a larger ecosystem using the APIs provided by their manufacturers. We also provided a brief preliminary description of the methodology that can guide the data collection protocol in the SmartWork system.

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4. Data-Driven Functional and Cognitive Modelling of Office Workers

Currently many assistive devices are available on the market either for in-house installation or to be used on the move (wearable) by people living with a chronic condition or ageing people, and details are provided on such devices in section 3 of this deliverable. Most of these systems have some lower level of processing and local storage performed on the device itself (embedded processing), but for heavier tasks require intensive data transmission, long-term storage and advanced processing to be performed at system/application level (e.g. on the cloud). The data generated by healthcare devices are often semi-structured or unstructured and have the 3Vs characteristics of big data: Volume, Velocity and Variety. As such, being difficult to be directly interpreted by healthcare professionals or the user itself, the data provided directly by the monitoring devices is not of much use. In a first step, in order to deal with the 3Vs, for efficient transmission, storage and preparation of the data for further meaningful processing, their low-level processing is required (see section 4.1). The second step involves encapsulation of the data into higher level of complexity units (e.g. models), which provide a representation of certain features/aspects of a health condition (patient models), lifestyle attitudes of a specific user (e.g. personalized nutrition model) and can go as far as trying to represent the human organism as a whole (e.g. virtual user models). Further details on such representations, with accent on the functional and cognitive modeling, and the derived work ability model of office workers, are provided in sections 4.2, 4.3 and 4.4. However, building and updating the models is still of not much help to the users (office workers, health carers, employers), as a final step is required in order to simulate and predict potential risks (e.g. health, work ability) and enable self-management through decision support at various levels (e.g. lifestyle, work management, training). Further details on current research on predictive tools and Decision Support Systems (DSSs) are provided in section 4.5.

4.1. Low-level processing of heterogeneous data

Generally, since a single sensor can only perceive limited or partial information, multiple similar or dissimilar sensors might be required to provide sufficient information with different focus in an integrated manner. Information from heterogeneous sensors can be combined using data fusion algorithms to obtain observable data [48]. A multi-sensor system has the advantage to broaden perception and enhance awareness of the state of the environment compared to what could be acquired with a single sensor system. Therefore, they are perfectly suitable for the increasingly learning nature of the environment to be sensed.

With regards to a specific purpose or task, a sensor management system should specify sensor parameter values and configurations to achieve active perception, with the basic purpose of adapting sensor behavior to a dynamic environment. However, sensing resources may not be able to serve all the desired tasks and achieve all their associated objectives. As such, a reasoning process must be conducted, and more important tasks should be given higher priority in their competition for resources. The sensor management system should utilize evidences gathered to decide which information is of interest and to prioritize which inputs to look at in the time following. Thus, in order to achieve some sort of decision-making, it is necessary to assess the contextual information [49]. To that end, for this learning process, classification techniques are needed.

Therefore, low-level processing of heterogeneous data is deeply rooted in the concepts and models of Artificial Intelligence (AI). In some cases this type of processing takes place directly at sensor level (embedded processing), while in most of the cases additional low-level processing is required at system level. In the following an overview of various low-level processing technologies and methods is provided.

4.1.1. Toward Embedded Intelligence

One of the fast-growing areas of AI, due to advances in Smart devices and Internet of Things,is the Embedded Intelligence (EI). The main idea consists in the implementation of intelligence in an embedded system, designed to perform a dedicated or narrow range of functions with a minimal user intervention and react to a change of inputs without an intervention [50].

Despite the main challenges for intelligent solutions in embedded systems, like dependability, real-time requirements, cost, size, and power consumption, several chip manufacturers have introduced their own version of low powered embedded DL products, such as Qualcomm with the Snapdragon Neural Processing Engine and Intel with Nervana Neural Network Processor and the Movidius Myriad Visual Processing Unit. The work of Xing et al [51] analyses the capability and potentiality of EI in performing some real-life applications.

4.1.2. Data Reduction Methods

The main goal of data mining and analysis is how to extract knowledge from different subsets of a dataset and modify this generated knowledge from structural aspect in order to optimize the input data streams' usability. However, in many cases data sets are too large and their processing is not efficient with respect to time and resources requirements. In order to fulfil this challenging task,well-established statistical and computational approaches have been proposed to examine only a subset of the available or to transform the data vertically or horizontally to a smaller size data representation. Sampling, load shedding and sketching techniques represent the former approach while synopsis data structures and aggregation represent the latter.

SAMPLING METHOD

Sampling refers to the process of probabilistic choice of a data item to be processed or not. Boundaries of the error rate of the computation are given as a function of the sampling rate. The problem with using sampling in the context of data stream analysis and structuring is the unknown dataset size. Sampling also does not address the problem of fluctuating data rates.

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LOAD SHEDDING

Load shedding refers to the process of dropping a sequence of data streams [52]. Load shedding has been used successfully in querying data streams. It has the same problems of sampling. Load shedding is difficult to be used with mining algorithms because it drops chunks of data streams that could be used in the structuring of the generated models or it might represent a pattern of interest in time series analysis.

SKETCHING

Sketching is the process of randomly project a subset of the features [53]. It is the process of vertically sample the incoming stream. Sketching has been applied in comparing different data streams and in aggregate queries. However, it is important to mention that this method suffers from lack of accuracy.

SYNOPSIS DATA STRUCTURE

Creating synopsis of data refers to the process of applying techniques that are capable of summarizing the incoming stream for further analysis such as wavelet analysis [54], histograms, quantiles and frequency moments. Since synopsis of data does not represent all the characteristics of the dataset, approximate answers are produced when using such data structures which means the method cannot be considered totally reliable.

AGGREGATION

Aggregation is the process of computing statistical measures such as means and variances of the input dataset. Using this aggregated data could be used by the mining algorithm. The problem with aggregation is that it does not perform well with highly fluctuating data distributions. The effects of this drawback could be mediated in case the input stream rate coming from the sensing devices, which are responsible for monitoring the patients' health state, is set to a constant value.

4.1.3. Knowledge Extraction Methods

Low-level processing also refers to the various AI methods employed to extracting knowledge (sorting, feature extraction, classification) from incoming monitored data which are further processed at higher levels of abstraction to enable various functionalities or adaptations of system and services. Artificial Intelligence is a very general and rather difficult concept to define precisely. Despite several attempts of defining it, the successful definitions splits in two dimensions, firstly related with reasoning (thought) or behavior (action), and secondly related with human or ideal (rational) behavior. AI can be related with the ability of think and act like a human being or the capability of thinks and acts optimally. Based on that, Artificial intelligence can be defined as the study and developments of intelligent machines and software that can reason, learn, gather knowledge, communicate, manipulate and perceive the objects.

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Different AI techniques, which are currently most adopted for knowledge extraction include: Artificial Neural Networks (ANN), Fuzzy Logic (FL), Evolutionary Computing (EC), Probabilistic Methods (PB) and Hybrid Artificial Intelligence.

ANN is an information processing paradigm that is inspired by the way biological nervous systems (i.e. the brain), process information. In brief, ANN may be seen as a massively parallel distributed processor that has a natural propensity for storing experiential knowledge and making it available for use. ANNs are composed of interconnecting artificial neurons (programming constructs that mimic the properties of biological neurons). One of the most important advantage of the ANN is the fact that it can actually learn from observing data sets, thus being possible to use it as a random function approximation tool. As such, it helps estimate the most cost-effective and ideal methods for arriving at solutions while defining computing functions or distributions.

Fuzzy logic is a form of many-valued logic or probabilistic logic. It deals with reasoning that is approximate, rather than fixed and exact [55], being based on the fact that humans make decisions based on imprecise and non-numerical information. In contrast to the two-valued traditional logic (true or false), fuzzy logic can have varying values that range in degrees between 0 and 1.

Evolutionary computation (EC) is an AI technique, which consists of a group of problem-solving techniques based on the theory of biological evolution. Despite the fact that several methods exist, Genetic Algorithms (GA), Particle Swarm Optimization (PSW) and Tabu Search (TS) are the three methods more developed in EC investigation. The main key concept of EC resides in the idea that the next-generation exhibits the intelligence or quality (capability to solve problem) better than parent or at least equal to parent generation.

Probabilistic Methods (PB) includes a variety of models that were designed to deal with uncertainty of measures and control actions. These are widely adopted in robotics and control field and find numerous applications, from classification algorithms, predictive systemsand decision-making systems. Most used models include NaïveBayesian Networks (NBN), Kalman Filters (KF), Hidden Markov Models (HMM), Markov Decision Processes (MDPs) and Partially Observable Markov Decision Processes (POMDPs).

Hybrid Artificial Intelligence consists in using two or more AI techniques in order to create a hybrid system. The implemented techniques can be used in series or in integration, and communicate with each other with cooperative interactions.

The intelligent capability of a system based on AI techniques can be measured using the Turing Test Approach [56]. This test relies on the premise that if a computer or system possesses artificial intelligence, it can mimic human responses under certain circumstances. To test that, a human interrogator interacts with a human and a machine, and has to be capable of distinguish the human person from the computer based only on the responses of both entities. The computer passes the test if the interrogator cannot tell whether the written response is coming from human or from the machine.

Such AI methods can be used not only in the low-level processing of data, but also in further steps where patterns identification and classification is performed in simulation and prediction tasks. Thus, further details on the most well-known used classification methods are provided in section 4.5.1.

4.1.4. Time Series Analysis

A large volume of the health data generated by continous monitoring sensing technologies is represented by time series. By definition, a time series is a sequence taken at successive equally spaced points in time. Consequently, time series analysis methods are those suitable for analyzing time series data in order to extract meaningful statistics and critical attributes of the incoming data and especially the evolution of those characteristics over time. These methods are based on the calculation of approximate solutions using stochastic processes for fulfiling the error bounding to two problems in time series analysis, namely relaxed periods and average trends, and have a long tradition in the data processing research. The purpose and simultaneously the main benefit of these methods is the dimensionality reduction they accomplish via sketching techniques [57]. This process begins with computing the sketches over an arbitrarily chosen time window and creating what is known as sketch pool. Using this pool of sketches, relaxed periods and average trends are computed. The algorithms have shown experimentally satisfying efficiency in accuracy as well as execution time. Zhu and Shasha have proposed techniques to compute some statistical measures over time series data streams, which is also a pretty interesting approach [58]. The proposed techniques use discrete Fourier transform and the overall system is called StatStream and is able to compute approximate error bounded correlations and inner products. The system works over an arbitrarily chosen sliding window offering the possibility of changing the size of the sliding window over time. Lin et al. have adopted the use of symbolic representation of time series data streams, using a philosophy apparently different, though resulting in the same goal as this representation allows dimensionality/numerosity reduction as well [59]. They have demonstrated the applicability of the proposed representation by applying it to clustering, classification, indexing and anomaly detection. The approach has two main stages. The first one is the transformation of time series data to Piecewise Aggregate Approximation followed by transforming the output to discrete string symbols in the second stage. Finally, knowledge-based event detection in complex, multi-channel and high frequency time series data has also started over 2 decades now [60] with a large interest of the medical informatics community in establishing new methods taking into account computational resources, real-time processing requirements, efficient transmission and storage, etc. [61], [62]. Particular role in the in the process of handling and processing time series has the establishement of robust methods for completing missing values in time-series, with a double scope: (1) handling errors in data collection/transmission, and (2) recovering the time-series data sets after on-purpose reduction (e.g. for efficient transmission). In the following, additional details are provided on such methods.

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4.1.4.1. *Methods for completing missing values in time-series*

The large volume of data collected in SmartWork project in the real-life context of the office workers is prone to potential occurence of missing values in the time series. At the same time, efficient transmission and local storage under certain conditions (e.g. on the move) imposes requirements for reduction and recovey of data for advanced processing on the server side. Despite the alleged ubiquitous philosophy of sensing characterizing the selected monitoring devices, the problem of missing values frequently occurs in data recording processes [63]. Conventional methods, such as mean and mode imputation or deletion, and other methods are not efficient enough to handle missing data values coming up through sensing devices. Estimating imputation to the missing data with the values which comprise output of novel algorithmic procedures can be the most appropriate solution to minimizing the bias effect of the conventional method of the data. Through these procedures, datasets that were produced from the monitoring processes mentioned above will be available for reliable analyses. Dealing with the missing values issue is many times included in the preprocessing stages of a complete data analysis process with the input data being obtained by sensor recording. The problem of missing values is usually caused by observation devices' breakdown or even human errors. Time series data are the category of data which appears most likely to have missing values in it. For this reason, data measurements are conducted several times under different conditions and the loss could present significant variability in what is known as "missingness mechanism":

- Missing completely at random (MCAR): a variable is missing completely at random if the probability of missingness is the same for all units, or in other words the is no dependencies of the missingness probability related to the variable itself
- Missing at random (MAR): a variable is missing at random if the probability of missingness is depending only on available information.
- Not missing at random (NMAR): the missingness probability is depending on the variable itself

It is notable that the selection of the considered 'missingness mechanism' could be indicated by the selected way of data collection. Several methods have been introduced to solve missing values problems according to its missing mechanism or even a universal solution for any given missing values mechanism, ranging from those which adopt a conventional approach to the most modern ones. To overcome the additional flaws emerging from conventional methods' philosophy, the most modern way of handling missing values, namely imputation methods, were introduced.A common characteristic, though, of all types of methods is that they tend to aim at detecting some patterns concerning the missing values of a provided dataset, which are usually described by two patterns of missingness, namely the monotone and the arbitrary one. The first pattern of missingness is observed when we can detect a specific pattern among the missing values while the second one describes a situation where data are missing totally arbitrarily without providing the analyst with the possibility of obtaining a relation between the missing values even in case of reordering or

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rearrangement of the dataset structure. It is also critical to mention that most researches use datasets of largely varying missing values percentages to confirm the validity of the proposed data completion methods, which is a commonly ignored parameter but still of serious significance. Some papers consider missing values' percentages of 5%-50% [64] while others go further to somehow extreme variety of percentages ranging from 1% to 80% [65], making the usual percentage's definition a rather controversial issue. Focusing on time series data analysis, which will be the type of data mostly produced by the sensing devices utilized in SmartWork project, it should be stated that the importance of SmartWork monitored data that are about to be processed does not permit the preference of simple methods such as ignoring, deleting, zero or mean or mode estimation methods. These techniques are extremely effective but only in case of low percentage of missingness or loose reliability requirements while in datasets with higher percentages of missingness, they seem to be hugely inefficient [66].

Therefore, the implementation of SmartWork will mostly turn to more synchronous techniques known as imputation methods, which appear to behave more efficiently when handling the missing values problem. Imputation procedures provide the user with the opportunity to produce a complete sample of data but ignore the ramifications of their fundamental side effects. Imputation (or estimation) is a procedure that handles the missing values' problem by replacing each of the missing values by some specific values whose source is usually different from one method to another. This source is being defined by a variety of statistical regression models characterizing every single method. Some of the most widespread imputation techniques are Hot and Cold Deck Imputation, Mean and Mode Imputation and Multiple Imputation.

Hot and Cold Deck Imputation methods have the philosophy of using another dataset of similar structure to the one being under examination to fill in the missing values. These two types of methods are really simple but have the drawback of affecting the output in a negative way when the dataset has a large amount of dataset or when the assumption made of the missing data is MAR [67]. Mean imputation, on the other hand, utilizes the most apparent approach one would immediately think of to estimate missing values to form a complete sample, which is the replacement of each of the missing values with the mean of the observed data for that variable. This techniques is also called unconditional imputation and has some slight differences compared to the median and mode imputation with which it presents extensive structural associations.

Another noticeable method for dealing with the missing values is the multiple imputation method, which applies imputation n-times to missing values for expressing the uncertainty of possible values that are about to be imputed.The n-times imputed values are subsequently analyzed in order to come up with a single combined estimation for each value.

To overcome the deficiencies that statistical methods, such as the previous ones, bring about to missing values estimation, numerous methods have been proposed in a variety of studies. These methods have been created through adaptation of methods mostly utilized in other fields of research to the necessities and requirements of the problems being examined in our field. The most widespread group of techniques apart from statistical approaches is the ensemble of methods known as soft computing ones. The main feature of soft computing techniques need to go through a learning process to be able to estimate missing values effectively.To this point, it is important to mention the most frequently used methods of this category.

Autoregressive model-based least-square (ARLS) impute method proposed by Sridevi is a technique that focuses on an autoregression-based model to estimate missing values [68]. It is mainly advantageous in situations where a particular time point contains many missing values or where the entire point time is missing.

A principal category of the aforementioned methods are the ones whose function is based on genetic algorithms (GA), which have been applied in several domains, such as data mining or optimization problems. Genetic algorithms appear to be advantageous when:

- exploring large search spaces while exploiting optimal solutions
- the GA is relatively easy to implement and adapt to different types of problems
- the GAs paradigm is scalable and can be effectively parallelized

Lobato et al. introduced a multi-objective genetic algorithm method based on NSGA-(ii) (Non-Dominated Sorting Genetic Algorithm version 2) called Multi-Objective Genetic Algorithm Imputation (MOGAImp) [69]. In several problems, GA operators are extremely simple and do not have a considerable impact on processing time while in others fitness calculation is likely to cause a decline in the system's performance. To overcome this decline, it is preferable that multithreading be occupied for parallelizing the process without interfering with other parameters of the algorithm. An additional use of GAs was applied for optimizing Fuzzy C-means as a clustering method as suggested by Tang. GAs were used by Tang to assure that the optimal solution (the one with minimum errors) is obtained. The last study made on GAs needed to be pointed out is the one conducted by Azadeh et al [70] which involved testing of GA estimation method's efficiency when applied to RCBD (Randomized Complete Block Design) tables [71]. The correlation between estimated data and actual data emerged GA approach as the most appropriate method for estimating values missing values in RCBD tables.

Least Squares Support Vector Machine method is a technique equally noticeable with the previous ones (autoregressive and GAs) and its philosophy is based on the main concept of Local Time Index (LTI) which totally ignores the missing values and adopts temporal information combined with training patterns. It is widely acceptable that methods responsible for handling missing values may cause additional problems to the existing time series data through the data manipulation process. LTI concept adopts the ignorance of missing values as an approach but, in contrary to other methods, focuses on maintaining the continuity of existing data sequence. The principal hypothesis this method turns to is that a pattern of temporal information could be obtained through forecasting models and, subsequently, this temporal data is going to be used for replacing the missing values.

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An additional category of methods of major importance is the one including the interpolation methods, such as the one suggested by Shao et al. which is based on NURBS geometry modelling algorithm [72]. Shao apply a window interpolation adjustment having made the assumption that the time series data examined present some cyclical characteristics or, better, periodic correlation sequences. The S-NURBS introduction on the interpolation process provides a flexibility as well the capability of extracting unique mathematical expressions for time series. The window adjustment mentioned above improves the initial interpolation result to a significant extent. Another interpolation method worth analyzing is the one proposed by Dhevi, known as Inverse Distance Weighted (IDW) [67]. IDW method calculates missing values through the measured data of the dataset being under examination. The estimation is conducted taking into account the missing values' distance from known values in the temporal dimension with the weight increasing as the missing valuesget closer to the measured values and vice versa.

A very interesting method, based on the maximul likelihood criterion, was introduced by Banbura et al. who focused on imputation in datasets of arbitrary patterns of missingness [73]. The steps of the method include filling in the missing data during the expectation step and optimizing the expectation step during the phase of maximization. The main advantage of maximum likelihood method compared to other similar methods is the possibility of imposing adequately restrictions on a parameter in a straightforward way.

The last type of techniques of time series data completion worth mentioning is the fuzzy-rough set of methods, such as the one proposed by Amiri et al. [74]. The main motive for using this method sources from the user-friendly character of a framework this method provides for dealing with uncertainty which is ubiquitous in imputation problems. The algorithm calculates the fuzzy similarities of instances and has the benefit of being insusceptible to noise. The fuzzy-rough methods are being utilized as both lower and upper rank matrices approximators with the prediction method being assigned to KNN algorithm.

It is critical to point out the importance of fully comprehending the problem's nature for picking a specific completion method as the appropriate choice is largely dependent on the given problem. It could be claimed, though, that estimation techniques are the most suitable options for missing values handling since most pursued goals in the field need a complete dataset for being accomplished. In addition to this, the correlation between different variables makes deletion impossible to apply as it could disrupt the measured data itself.

4.2. Functional Modeling

The aforementioned techniques comprise useful tools for processing and handling the monitored data in order for them to acquire meaning for a given low-level system (e.g. physiological parameter monitored). The following step is to encapsulate these data entities into more complex units, which provide representations of the human organism functions as a whole or of parts of it (e.g. cognitive

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capacity). Such complex units are usually refered as virtual user models, and their level of complexity depends on the system level representation and the target application. The extremely compound nature of human organism does not permit an efficient representation and simulation taking into account all aspects of human body operations (e.g. structural, molecular), thus a compromise needs to be made by integrating in the virtual model the details of these operations that are crucial for the specific application/system. Particulary, in the case of SmartWork, the virtual user models could take a large variety of forms ranging from any physical, cognitive, behavioral and lifestyle user characteristics of office workers, including factors related to chronic conditions, disabilities, personality, identity, social environment, as well as broader physiological, mental and emotional state. A truly holistic approach, however, is not easy to implement, thus the main focus is to integrate the heterogeneus lower level representations that are providing a holistic approach for the work ability modeling of office workers. Apparently, an effort is made to integrate and emulate as many modelling features as possible aiming at a representation physically realistic. A comprehensive overview of generic user modelling approaches, and their applications in the context of the adaptive web, was carried out by Kobsa [75]. Although a wide variety of design patterns have been introduced, a mixture of them is commonly applied. These can be discriminated along the following four dimensions: (i) user type, (ii) gathering approach, (iii) time-dependency data and (iv) updating method. More specifically, the model representation may be tailored either to a specific user or to a user group (e.g. stereotype) designed to cover the majority of users with the maximum accuracy. The modeling system may acquire information (also known as user profiling) explicitly by means of a user-completed questionnaire or implicitly, by observing user actions and making inferences based on the stored knowledge [76]. The user model may depend on the time sensitivity of the acquired information since it may include from highly specific information (short-term) to more general information (long-term) data. Finally, user models can be categorized depending on their update strategy into static models, where the main data is gathered once and normally not changed again; and dynamic models, which implement additional techniques to update the representation of user's characteristics.

Extensive studies have led to the development of advanced modelling frameworks, for simulation of users in real-world scenarios, called Virtual User Models (VUMs). The main aim of such models is to pipeline as much information as possible to the corresponding modelling application that will be designed, providing an accurate simulation platform of use cases as well as intelligent and productive consultation to the target group of users.

Modelling virtual users accurately has also been proposed as a tool to solve several human-computer interaction (HCI) issues, including usability, utility and accessibility not only for general users but also for social groups with specific characteristics and needs such as older people or patients in order to overcome certain functional limitations they may have. Towards this direction, numerous attempts to develop and test virtual user models with the goal to predict user behaviour, to gain knowledge of a particular user in order to tailor interactions to that user, etc. For example Segkouli et al. [77] are atempting to simulate expected increased cognitive impairments in relation to age, by embodying novel specific modules into cognitive models, configured according to approximation of various parameters related to cognition. Simulator testing showed high correlation between actual users and their respective VUMs, indicating the success of the approach. This way, the significance of VUMs in the design process of any application or system is further established, especially with concern to accessibility and usability for users impaired by some form of mental or physical disability.

Human functional modelling has been challenging the scientific community throughout the last couple of decades. The extremely complex structure of human organism fully justifies all possible difficulties presented when trying to model its function, which are further enhanced by the large diversity between humans (both at group and individual levels) and the contextual differences (e.g. different phenotypes of a disease). Consequently, it is of utmost importance to first define what are the aspects of the "system" that must be captured by the virtual user model.

Recent efforts in the European Union (e.g. VERITAS[46], VICON[47], MyUI[48] projects) to develop virtual user models have focused on several user characteristics, in order to enable simultion tasks along with automated or semi-automated update of user models in various interactive scenarios. As a result, a formal Extensible Markup Language (XML) and Web Ontology Language (OWL) representation of patient models of people with disablities, chronic conditions and functional limitations has been proposed, and its standardization is on going [78]. More specifically, Kaklanis et all in VERITAS project developed a framework for automatic simulated accessibility and ergonomics testing of virtual prototypes using virtual user models [79]. They examined geometric, kinematic, physical, behavioral and cognitive aspects of the user affected by possible disabilities or incapacities coming about as the age of workers progresses in order to adequately represent users with functional limitations. Hierarchical task assignment and interaction models were also proposed in order to describe the user's capabilities at multiple levels of abstraction.

Evolving medical systems are grounded to the Electronic Health Records (EHR), which in fact can be considered as patient models, including a wide range of patient information, from demographics to very detailed and very specific medical information (e.g. physical, kinematic, disease specific, behavioural, cognitive). However, the heterogeneity of such systems is large, and although many standards and specifications have been defined (e.g. HL7, DICOM, CDA, EN/ISO13606), there is no single system that can be used "out of the box". One of the most coherent standards, along with a self-consistent platform and clinical models, is the openEHR[49], which also works closely with classing standardization groups (i.e. ISO13606, HL7, OMG and CEN) to integrate many of the standards issued by these organizations.

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[46] https://cordis.europa.eu/project/rcn/93725/factsheet/en
[47] http://vicon-project.eu/
[48] http://www.myui.eu/
[49] http://www.openehr.org/

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The principal components that have to be considered in SmartWork project are related to the capturing aging office workers in real conditions, accounting for potential chronic diseases (e.g. older people are much more likely to be affected by one or more chronic conditions), for their work environment, their lifestyle attitutes, as well as their preferences and needs when it comes to interacting with ICT devices. The most common chronic conditions upon which the viability of people belonging to 55-65 age group is heavily dependent upon are: (1) the cardiovascular system's condition, as heart strain during workers' daily routine is a critical parameter concerning older workers' well-being, (2) the respiratory system condition, as the possible presence of diseases like asthma or Chronic Obstructive Pulmonary Disease (COPD) is much higher; (3) overweight and obesity due to sedentariness especially in the case of office workers; and (4) diabetes, which is a very common chronic condition for the target age group, and it is closely related to overweight and obesity. Moreover, the neurological system could have a determinant impact in individuals' health as its malfunction could bring about some kinds of paralyses (e.g. limbs total or partial paralysis), especially after sudden health episodes, such as strokes. In addition, neurological system's lack of complete plausibility is highly possible of bringing about serious cognitive deterioration (e.g. partial dementia). Further details of existing research on modelling approaches for most relevant chronic diseases for the SmartWork target age group and specific work conditions (e.g. sedentary work) are presented in the following section.

4.2.1. Chronic diseases modelling

4.2.1.1. Cardiovascular Diseases and Hypertension

Cardiovascular problems and hypertension are two concepts bidirectionally dependent on each other. Cardiovascular disorders or even strokes are, more often than not, related to an individual's chronic suffering from hypertension issues. This relation, which has been repeatedly discussed among experts, has been extensively analyzed by Banach et al. [80] who also aimed at taking a deeper insight into the association of systolic blood pressure (SPD) levels with all-cause mortality apart from cardiovascular events exclusively. The survey included people in the US aged 45+ years older, covering the Smart Work's age group of interest (older pople in the agre group of 55-65 years old). The research found that among participants aged 55 to 64 a linear association was present between high SBP categories and all-cause mortality risk which is a conclusion that, provided it is valid (the authors claim that the confidence interval of the study's statistical analyses reach 95%), should be taken into serious consideration in the functional modelling design of Smart Work, especially concerning the manipulation of the input data streams coming from SBP measurements. Another study similar to Banach's is the one conducted by Dena Ettehad et al., which analytically examines the advantages of blood pressure lowering treatment for prevention of cardiovascular disease with respect to the patient's baseline blood pressure, the possible presence of comorbidities as well the administered drugs' class which could play a major role in the overall results of treatment strategy through review andanalysis [81]. For the purposes of the study, MEDLINE-included randomized control trials of large-scale blood pressure wasutilized and no trials were excluded due to the existence of baseline comorbidities among them. Summary-level data about study characteristics and the outcomes of major cardiovascular disease events, coronary heart disease, stroke, heart failure, renal failure and all-cause mortalitywere extracted. Subsequently, variance weighted fixed effects meta-analyses were employed for accumulating the estimates extracted. Data from 123 studies were collected and manipulated for the meta-analysis. Meta-regression analyses showed relative risk reductions proportional to the magnitude of the blood pressure reductions achieved. A drop of 10mmHg in systolic pressure caused the frequency of cardiovascular events, such as coronary heart disease, stroke and heart failure, to diminish to a considerable extent, as well as a fall of 13% in all-cause mortality. Similar proportional risk reductions were observed in trials using higher values for mean blood systolic pressure as baseline pressure as well as in trials with lower values respectively. It was unclear whether proportional risk reductions in cardiovascular diseases was modified from a specific baseline disease to another, except from diabetes and chronic kidney disease for which the observed risk diminishment was significantly lower, but yet noticeable. The survey's conclusions imply that causing blood pressure values to fall below 130mmHg of systolic blood pressure and providing a complete lowering pressure treatment to patients with a history of cardiovascular events of any type or even chronic kidney disease is essential for the well-being of those groups.

A more complete study, looking at the issue from a wholistic view, was conducted with the initiative of the Hypertension Canada organization, with the goal of contributing to prevention, detection, assessment as well as individuals' management of hypertension [82]. It establishes evidence-based guidelines for the diagnosis, assessemnt, prevention and treatment of hypertension. The study indicates that antihypertensive therapy should be considered for all individuals with elevated average systolic non-AOBP (non-automated office blood pressure) readings 140 mmHg, while for individuals with diastolic hypertension (with or without systolic hypertension), fixed-dose single-pill combinations are currently suggested as an initial treatment suitable to adopt. The ensemble of guidelines provided by this survey are intended to provide a framework but should not replace clinical judgement. Special emphasis should be placed on measuring blood pressure accurately using standardized measurement techniques and validated equipment no matter what the selected measurement model is. The measurement model mentioned as preferable is AOBP model. The criteria of diagnosis of hypertension are fully defined and analyzed and recommendations for treatment follow-up are also provided. A diagnostic algorithm is also presented, the flowchart of which is depicted in the picture below:

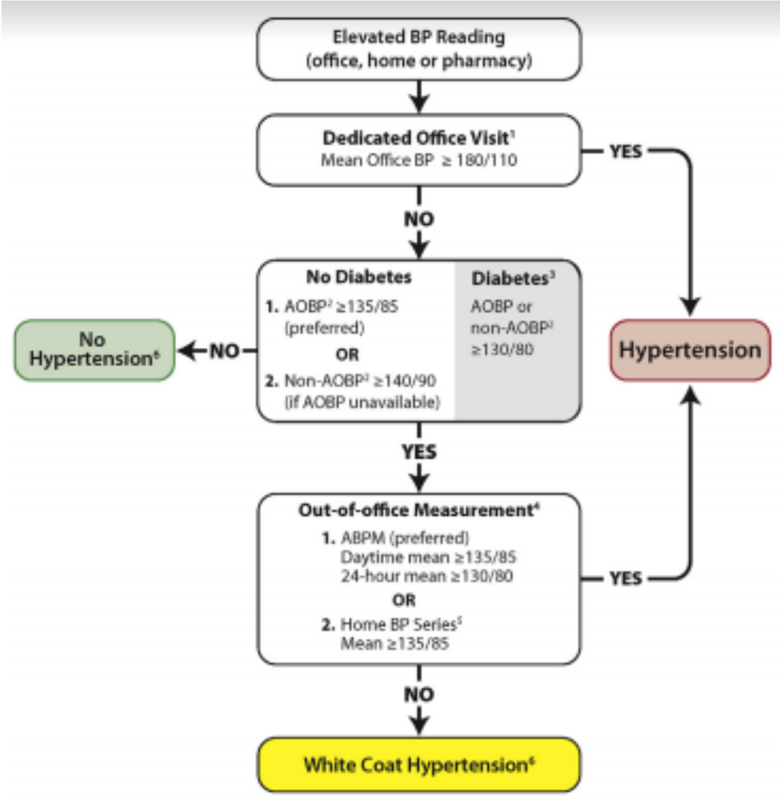

FIGURE 37 DIAGNOSTIC ALGORITHM FOR HYPERTENSION (BY THE HYPERTENSION CANADA ORGANIZATION)

Furthermore, the study includes detailed guidelines for measuring blood pressure efficiently both at home and on-the-move by presenting specific protocols for pressure's monitoring. Emphasis is placed on the assessment of overall cardiovascular risk to patients who have been recorded with high hypertension values as well. Firstly, global cardiovascular risk should be assessed through the utilization of multifactorial risk assessment models appropriate for predicting accurately an individual's global cardiovascular risk and using antihypertensive therapy more efficiently. Background and diagnostic criteria are analyzed for more specialized and rare forms of hypertension such as endocrine and renovascular hypertension. Moreover, the study examines and suggests proper ways of health behavior management through daily habits like physical exercise and possible weight loss, which are dependent on each other to a considerable extent, as well as limited alcohol consumption and a more balanced diet. Last but not least, stress management is a pivotal pylon of adequate health behavior management. Another noticeable and rather expected suggestion made by the survey is that patients without macrovascular target organ damage or other cardiovascular risk factors should be considered for hypertension therapy prescription for higher values of average DBP and SBP readings (100mmHg and 160mmHg respectively) in comparison to the category of people who live in the presence of a macrovascular organ damage or a possible cardiovascular risk factor as their proneness to their baseline frailty is significantly different. In addition to all the above, the authors are occupied with the issue of the most appropriate choice of therapy for adults with hypertension without compelling indicators for specific agents by making a segregation between adults with diastolic hypertension (regardless of

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their systolic blood pressure status which could be either hypertensive or not) and those who present exclusively systolic hypertension. Finally, recommendations are made concerning the global vascular protection therapy for adults with hypertension without compelling indications for specific agents focusing on smokers who ought to be advised to quit smoking and, especially the ones who aim at giving up smoking, to be prescribed an additional pharmacotherapy (e.g. nicotine replacement therapy).These recommendations are further analyzed and modified from one category to another based on the patients' history of vascular deficiencies such as ischemic heart disease, strokes or heart failure.The heterogeneity of all the irregularitiesmentioned above turnsthese adaptations from optional to imperative.

Another study aiming at defining an ensemble of standard directives concerning the pharmacological aspect of hypertension treatment was conducted by the American College of Phisicians in association with American Academy of Family Physicians [83]. They provide clinical recommendations based on the benefits and drawbacks of higher versus lower blood pressure targets for the treatment of hypertension in adults aged 60 years or older, which is partly covering the SmartWork's target group. Similar to the approach of the study previously analyzed [82], evaluated outcomes included mortality and morbidity related to occurance of strokes as well as major cardiac events, such as myocardial infarction. The principal recommendations the study makes are related to the threshold values of systolic blood pressure that, when exceeded, should be considered as a signal for the initiation of treatment as well as the need for intensification of an already applied treatment to people aged 60 or more with a history of as a stroke or an ischemic attack, so as to accomplish the goal of lowering systolic blood pressure, and to people belonging to the same age group who have been estimated to be at high cardiovascular risk through an individualized assessment so as for them to prevent a possible cardiac event. The basic parameters taken into accountinto this survey were the benefits and harms of dealing with increased blood pressure aiming at different targets through the lowering treatment, namely the intensity of each treatment approach. People with multiple chronic conditions were not included in the study. However, it is claimed that the adoption of a suitable treatment approach for this group of older people is complicated and rather ambiguous. On the one side, more aggressive BP treatment is needed for reducing the increased cardiovascular risks. On the other side, they are more susceptible to harm from higher rates of syncope and hypotension which are likely to come up due to the implications created by the variety of drugs administered that frequently interact.

The modelling of the association between cardiovascular system's malfunction and increased arterial blood pressure, which is apparently bidirectional, presents a bidirectional nature that has been examined and analyzed in depth by numerous studies with one of the most noticeable being the one carried out by Kaess [84]. **A** critical component of the cardiovascular system's robustness is the maintenance of vascular elasticity as it is has been observed that the vascular stiffness increases with advancing age in numerous cases, being a crucial risk factor when talking about age-related morbidity and mortality. **A** major challenge that has arised lately in cardiovascular system's modelling, and it is yet to be met, is the temporal association between vascular stiffening and pressure steep elevation due to blood flow's pulsatility. As a result of this condition, Kaess attempted to describe the temporal relationship among vascular stiffness, central hemodynamics and blood pressure evolution. More specifically, temporal relationships among blood pressure and 3 measures of vascular stiffness and pressure pulsatility derived from arterial tonometry, namely Carotid-Femoral Pulse Wave Velocity (CFPWV), Forward Wave Amplitude (FWA) and augmentation index, which were the secondary outcomes of the survey. The primary outcomes were blood pressure and incidence hypertension during examination cycle 8, during which the secondary outcomes were extracted as well. The results were exported through the employment of a multivariable-adjusted regression model. The principal and most interesting conclusions produced concerned the temporal associations between the examined quantities, namely among peripheral blood pressure, vascular stiffness, central hemodynamics and wave reflection aiming at demonstrating that aortic stiffness, central FWA and wave reflection are strongly associated with future systolic blood pressure, pulse pressure and incident hypertension. These findings act as evidence proving that vascular stiffness is undoubtedly a precursor of hypertension and not vice versa as many people assumed.

An additional major study analyzed the causes leading to increased prevalence of cardiovascular diseases and especially coronary heart disease was conducted by Maryam Kavousi et al. [85]. The study's objective was to assess novel risk markers for Coronary Heart Disease (CHD) risk prediction and layering upgrade Framingham Risk Score (FRS) predictions [86], which is the most commonly used CHD risk prediction instrument in clinical settings. The measurements made for the purposes of the study involved traditional CHD risk factors used in the FRS, such as age, sex, systolic blood pressure, treatment of hypertension, lipoprotein cholesterol levels, smoking and diabetes, along with newer CHD risk factors, such as N- terminal fragment of prohormone, B-type natriuretic peptide levels, fibrinogen levels, chronic kidney disease, uric acid levels, coronary artery calcium scores as well as indicators mentioned either explicitly or implicitly in previous paragraphs such as peripheral arterial disease, carotid intima-media thickness and pulse wave velocity.The statistical analyses performed aiming at assessing the effect of each marker in CHD incidence independently on all the other markers, which was attempted by using Cox proportional hazard models. Results indicated that the integration of new markers to FRS prediction model increased the reliability and accuracy of the predictionsto a significant or lesser extent, with the inclusion of Coronary Artery Calcium (CAC) scores being the most important intervention, the incorporation of N-terminal fragment of prohormone B-type natriuretic peptide being also noticeable and the addition of the rest of the markers being characterized as marginal. The reliability of the results, according to the authors, is more valid in older cohorts which is to our advantage.The most useful conclusions involve the proclamation of CAC score integration as the statistically and clinically most significant intervention for risk prediction and reclassification upgrade. On the other hand, the accuracy upgrade coming up from the incorporation of newer risk markers in risk assessment models is probably less significant. It is also necessary to mention that, despite seeming an adequate improvement worth trying, the integration of CAC score needs further investigation before being widely applied as it has not been yet assured that it leads to a considerable change in clinical outcome. Generally, the inclusion of a novel test in a risk prediction algorithm requires detailed

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analysis concerning its financial costs with respect to the difference it is expected to make for both people and health systems.

Cardiovascular risks and, subsequently, hypertension appearance risk is determined by numerous factors during an individual's life with the most pivotal one being nutrition habits. Jing Sun et al. have examined in depth the relationship between dietary patterns and cardiovascular risk factors in Chinese older adults [87]. The value of this study is reinforced due to the increasing prevalence of age-related chronic conditions which creates obstacles for the daily routine of those age groups and, especially, of older workers.For the purposes of the study, older adults with either one or more cardiovascular risk factors currently present or with a history of cardiovascular diseases were randomly selected through Chinese health records. Exploratory factor analysis, cluster analysis and multiple logistic regression analysis were employed to extract dietary pattern factors. Log binomial regression analysis was used to profile the relationship between dietary patterns and chronic disease related risk factors as well the sensitivity of Food Frequency Questionnaires (FFQ) to differentiate between individuals who suffer from chronic diseases and those who do not.Four different components were assessed through the factorial analysis. A high value of internal consistency was obtained with a high Cronbach's alpha coefficient of 0.83. Cronbach's alpha will generally increase as the intercorrelations among test items increase and is thus known as an internal consistency estimate of reliability of test scores. Three dietary patterns were recognized via cluster analysis, namely the healthy diet, Western diet, which is widely perceived as the most harmful one, and the balanced diet that is partially aligned with Mediterranean nutrition. Findings seem to confirm the expectations, clearly implying that a Western diet is significantly related to an increased likelihood of suffering from hypertension, cholesterol, metabolic syndromes and, apparently, obesity. The identification of these three distinct dietary patterns is reflected to a significant extent in the nutritional status of people with chronic diseases displaying a considerable level of discrimination among them. The study validates the usefulness of FFQ as an assessment tool of the nutritional habits of individuals as long as it addresses to small or medium cohorts. Additionally, and most importantly, the study's outcomes confirm the existence of a strong association between dietary patterns and cardiovascular disease risk factors including body mass index (BMI), blood pressure, triglycerides and metabolic disorders.

4.2.1.2. Diabetes

Diabetes might be the most frequent chronic condition putting people around the globe into serious inconvenience from both long-term and daily routine points of view. Several surveys have been conducted focusing on the basic features of diabetes as well as on the ways of fighting against it and mediating its immediate effects in individuals' life day in and day out. People aged over 50 years old that are diagnosed with diabetes are expected to lose an estimated 8.8 years of their lifespan according to Gregg et all [88], who attempted to provide updated estimates for the lifetime risk of development of diabetes and to assess the effect of changes in incidence and mortality on lifetime risk as well as the expected life-years lost as mentioned before. Concerning the implementation, data about diabetes incidence was provided by National Health Interview Survey and data about mortality for the period 1985-2011 were linked to them into a Markov chain model to estimate remaining lifetime, diabetes risk, years spent with and without diabetes diagnoses. Subsequently, logistic regression models were employed to estimate the incidence of diabetes and a Poisson regression model to estimate mortality. The research indicates that overall increases in new cases of diabetes have been driven mostly by cases diagnosed in middle and older age groups, where the SmartWork interest will be focused. Diabetes of type 2 rather than type 1 appears more frequently in these age groups. Estimates of lifetime diabetes risk provide a significant perspective and their use is increasingly being encouraged for being utilized in decision support systems and to prioritize public health interventions. Concerning the aforementioned modelling techniques, logistic regression and Poisson regression models employed for the estimation of diabetes' incidence and mortality respectively were expressed as a function of age, race or ethnic origin. The predictive model of age-specific mortality included a quadratic term for age with interaction terms for time period, sex and status of prevalent diabetes, which is the part of the modelling process of our direct interest. On the basis of parameters' estimates from these analyses, annual probabilities were entered into a discrete-time Markov chain model with an interval length of 1 year during which individuals moved from one of three states (remaining non-diabetic, diabetic, dead) each year, to predict the remaining lifetime risk of diabetes by baseline age; the mean length of time that an individual is expected to live with and without diabetes and the number of life-years lost due to diabetes, calculated as the difference between life expectancies by diabetes status at the age of diagnosis.To generate confidence intervals for the primary estimates of lifetime risk, transition rates were being utilized and their vacancies were estimated from the regression models to simulate the transitions of 100000 individuals of specified race, sex and baseline age with the Monte Carlo method. Results indicated that diabetes increased across three decades in both men and women with the greatest absolute increases noted in middle-aged and older adults. For example, in 60–64 year group,incidence increased from 0.73% to 1.65% in men and from 0.71% to 1.51% in women. The findings imply that the combination of increasing lifetime risk with decreasing life-years lost somewhat proves the simultaneous successes in care and secondary prevention in the face of an inability to reduce diabetes incidence in the past two decades, despite impressive evidence from various clinical trials for the primary prevention of diabetes. Increasing incidence has been attributed ecologically to an increasing prevalence of central obesity, total dietary intake and a shift in the ratio of refined versus unrefined carbohydrates and simple sugars, increased portion sized and decreases in energy expenditure [89]. Decreasing mortality in the general population and in the population with diabetes is mainly due to restrictions in cardiovascular disease mortality which have been attributed to a diverse combination of medical treatment, preventive care and risk factor modification [90].

In recent years, there have been developed several new methods for diabetes modelling in order to provide an aid at the increase of models' reliable as well as at the validation process, such as the one proposed by Duun-Henriksen [91]. More analytically, models based on ordinary differential equations (ODEs) present a difficulty in the validation process using standard statistical tools. On the other hand, stochastic differential equations (SDEs) provide a stronger potential in building models that can be validated statistically and are capable of making predictions with negligible errors not only for realistic sets of values but also for the uncertainty of the prediction. It should be highlighted that in an SDE, the error prediction is split into two noise terms, which ensures the errors are uncorrelated. A standardized model of the glucoregulatory system in a type 1 diabetes mellitus(T1DM) patient is acts as basis for development of a stochastic-differential-equation-based-grey-box model (SDE-GB). The optimal SDE-GB is determined from likelihood-ratio tests through a parameter fitting process. The results showed that the transformation of the ODE model into an SDE-GB resulted in a noticeable improvement in the prediction and uncorrelated errors. It was also confirmed that using SDE-GBs in diabetes modelling has an enormous potential as model predictions were considerably more accurate after the separation of the prediction error. Finally, SDE-GBs offer a solid framework for using statistical tools suitable for validation and development.

The research conducted by Mansell aims at establishing pure diabetes' modelling techniques and examines the phenomenon of grey noise appearance in patient-specific approaches [92]. This study indicates that except for the difficulties of glycaemia modelling process for patients with diabetes provoked by the sparse data nature and inter-/intra- patient variability as well other factors, in model-based control strategies, an additional problem comes up due to non-random grey noise appearance which can cause irreparable damage to patient-specific models' predictive potential and reliability. Mansell attempts to compare and analyze models that capture the glycaemic grey-noise impact of nutrition and stress and, subsequently, exercise and circadian rhythms are compared and considered in the context of practical application to model-based outpatient diabetes management. Candidate models to capture glycaemia in outpatients with diabetes must be considered in the context of the ddata needed to identify the models, each model's adaptability to the patient state and the practical identifiability of models for a specific level of data quality. In addition to this, the candidate models should also be capable of capturing inter- and intra- patient variabilityinthe heterogeneous metabolism of individuals with diabetes. A last component of the models needed to be seriously considered is the identifiability over a clinically admissible period of time so that the models be fruitful in the domain of diabetes management. Clinical literature strongly claims that sources of variance around nutritional habits, emotional stress, physical activity and circadian metabolic rhythms are the pivotal physiological factors affecting glycaemic outbursts of diabetics and, in case they are ignored through the modelling process could bear significant amounts of grey noise to both analytical and predictive modelling outcomesas well as to its overall management. Therefore, there is important potential benefit from including these factors in models as long as the relevant stimuli is measurable.

Surveys on diabetes care related processes as well as diabetes self-management, which are known to be indispensably linked, have also been performed by Fernandez-Llatas [93]. The aim was to find an implementation method of a holistic diabetes care system, using newly-inspired ICT for deploying cares on the philosophy of Evidence-Based Medicine, which could be an adequate solution to provide an effective and continuous care to patients suffering of diabets. However, the manipulation and classification of data inflows aiming at turning them into a readable format to take full advantage of the potential provided by ICT is a compound task. The research suggests using Pattern Recognition techniques for analyzing the problems of using mining techniques to infer care flows and how to cope with the resulting so called Spaghetti Effect. More specifically, applications and systems for supporting adherence, insulin control, exercise plans or balanced diet are examples of daily control systems providing the data inflow mentioned above. The selection of the correct communication method with the user for improving their treatment adherence or the adequate diet and exercise plan for motivating a personalized healthy lifestyle to patients are equally important to a complete treatment design. With the arrival of Evidence Based Medicine, the use of protocols and guidelines to lead the way in health care delivery is increasing in hospitals. These care protocols have been described in the form of careflows. Careflows, which were also mentioned above, are care protocols defined by experts that describe in an explicit way understandable by both computer systems and humans the expected care process of a specific illness and the expected progress of a patient. Careflows appear to be superior to traditional care methods concerning the involvement of patients into the caring process and the definition of a personalized healthy lifestyle. This definition is conducted through the so-called Life Assistance Protocols (LAPs), which consist of computer-interpretable care flows that take into account medical criteria as well as patients' personality and preferences to define care protocols. All this data is employed for setting up a holistic care processaround the dailyroutine of diabetics. In this way the use of ICT for deploying diabetes Life Assistance Protocols can support patients in the self-management of their illness, which will be further analyzed in later sections.In summary, the design of personalized health protocols through LAPs is a complicated task that can be eased by the utilization of Pattern Recognition techniques. The employment of Process Mining Technologies for handling the input data of PR frameworks used can enable the iterative design of care protocols but it is crucial that mechanisms be provided for the reduction of Spaghetti Effect in order to make the system usable by experts, which is not easy but the result is worth the time spent for developing novel algorithms diminishing this effect.

Finally, a major factor that should be accounted for when developing a model for patients suffering of diabetes, is the individuals' possible overweightness or even obesity, especially for those who suffer from diabetes of type 2. This parameter is also also heavily associated with cardiovascular diseases and disorders which will be extensively examined in the forthcoming subsection. Recently, Grover et al. focused their interest on estimating the years of life lost and the life-years lost from diabetes and cardiovascular malfunction related to excess bodyweight [94]. A disease-simulation model was developed aiming at the estimation of the annual risk of diabetes, cardiovascular and mortality for people with BMI of 25–<30 kg/m^2 (overweight), 30–<35 kg/m^2 (obese), or 35 kg/m^2 (very obese), compared with an ideal BMI of 18.5 – 25 kg/m^2. After validation of the model projections, the years of life lost and healthy life-years lost associated with each bodyweight category was estimated. Findings demonstrated that excess bodyweight was positively associated with risk factors for cardiovascular diseases as well as for type 2 diabetes. Furthermore, the effect of excess weight on years of life lost presented its maximum value for younger individuals and showed a strong tendency to decrease with increasing age.

4.2.1.3. Frailty

An additional aspect of cardiovascular diseases, and other relevant chronic conditions such as hypertension that has not been yet examined so far, concerns the frailty and deficiency that usually escorts this type of diseases, affecting largely the effectiveness of older people to cope with the chronic condition, and further more, the functional capacity of older workers when they are required to fulfil a work task. Afilalo et al. attempted to define a model suitable for being applied in clinical practice which would have as a primary goal the inclusion of frailty in the evaluation process of older adults suffering from any kind of cardiovascular disease (CVD) [95]. An integration of the realistic impacts of older people's frailties on their functional capacity has as a prerequisite the development of efficient frailty assessment tools. Numerous tools of this type have been suggested with the majority of them revolving around the core phenotypic domains of frailty such as low marching speed, weaknesses, inactivity, exhaustion and shrinking as measured by physical performance tests and questionnaires. Epidemiological studies have consistently demonstrated that frailty carries a relative risk of >2 for mortality and morbidity across a spectrum of stable CVD, acute coronary syndromes, heart failure and surgical interventions. Frailty acts as a valuable prognostic indicator contributing incrementally to existing risk models and aiding clinicians in their efforts to find the most appropriate strategy for designing their patients' treatment and deliver it in a more patient-centered fashion. An additional incentive for occupying with frailty assessment is the optimization of resource allocation so as to prevent patients from receiving costly but meaningless interventions. The authors demonstrate the existing body of evidence for frailty assessment need in patients with diverse forms of CVD and offer a perspective on integrating frailty into current clinical practices. As previously mentioned, the value of frailty as a prognostic marker is well proven by numbers (risk ratios often exceed 2 and dwarf juxtaposed predictors in multivariable models). After strongly supporting the statement that the value of frailty as a therapeutic target has already emerged and its utilization is expected to significantly expand in near future to improve patient outcomes, Afilalo concludes that the principal challenge needed to be met in the domain is the creation of a validated tool set that will provide experts with the opportunity to merge the results exported by a variety of studies in order to promote a frame of reference when evaluating novel frailty markers either separately or in combination with each other.

A similar study, focusing on the relationship of frailty observed among older patients with the presence of diabetes mellitus and hypertension rather than cardiovascular diseases, was carried out by Castrejon-Perez et al. [96]. The aim of this analysis was to sketch the association between frailty with diabetes and hypertension in Mexican older adults, proportionally to the previous study analyzed mentioned, with the sole difference being the type of disorder examined. The implementation involved the acquisition of data on diabetes and hypertension along with some critical associated parameters, such as time since diagnosis. A 36-item frailty index was constructed and rescaled to z-values (individual scores minus population mean divided by standard deviation).

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For the performed statistical analysis, multiple linear regression models were employed, adjusted appropriately using as principal criteria age and sex. The prevalence of diabetes was recorded as higher than that of hypertension. The definition of an independent association between diabetes, hypertension or both conditions simultaneously present (correlation coefficients 0.28, 0.4 and 0.63 respectively) with frailty was accomplished. The number of years since diagnosis was also included in the association with frailty estimation for both conditions. Apart from the fundamental association of diabetes and hypertension with frailty, an incremental association was also profiled when both conditions were present or with worse association features bringing about complications. The survey's main outcome is that frailty should be of particularconcern in populations with a high prevalence of this type of conditions.

4.2.1.4. Asthma and COPD

Chronic diseases and disorders do not only affect the cardiovascular system's function, as extensively analyzed in the previous sections, but also other systems that play a major role in individuals' well being such as the respiratory system. This type of life-long disorders sources primarily from malfunction caused by inflammation of the airways, the most renowned of which are asthma and COPD.

Asthma is a chronic inflammatory disease of the lungs characterized by repeated episodes of wheezing, breathlessness, chest tightness and coughing. The diagnosis and severity classification of asthma condition are performed through measurements provided by various pulmonary function tests [97]. However, this approach of diagnoses has proven to be relatively insufficientand not reliable enough. A novel philosophy expected to be fully adopted takes advantage of respiratory diseases' principal feature, which is the narrowing of lung airways, also known as bronchoconstriction. Bronchoconstriction has as repercussions the deformation of the airways as well as the distortion of their mechanical properties. Consequently, the quantity of oxygen transferred through the airways is reduced, posing difficulties on patients' breathing process. Bronchoconstriction is probably the leading cause of asthma. In addition to this, the way the pharmaceutical therapy of asthma is administered to patients (inhalation) poses an extra challenge due to the fact inhaled medication's effectiveness is significantly mediated when it comes to people suffering from bronchoconstriction. Therefore, the aforementioned currently employed approach involves the development of patient specific models for deepening our understanding of lung diseases' creation mechanisms that will provide us with the opportunity to define measures of assessment leading to more reliable and accurate diagnoses regarding asthma. These models introduce computational modelling techniques for the lung, based on 3D Computational Fluid Dynamics utilizing generic 3D representations of the airways structure. Both experimental and simulation studies have demonstrated the influence of geometry characteristics on functional outcomes of the breathing process and this is why numerous attempts for optimizing the modelling processes have been made, through a variety of studies.

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Burrowes et al. claim that obstructive lung diseases, like asthma and COPD, affect the lung physiology across multiple biological scales, namely tissue, cellular and sub-cellular scale by triggering signaling pathways [98]. These changes are propagated “upwards” to the organ level and vice versa. The development of an efficient modelling technique requires the integration and comprehension of theaforementioned changes occurring across each particular scale, turning multiscale computational modelling into a necessity.Advances in scanning technology such as hyperpolarized gas MRI has made possible the regional measurements of ventilation and perfusion in the lungs while novel image processing methods allow the combination of those measurements with structural imaging data -provided by Computed Tomography(CT)-leaving pulmonary function tests out on the fringe. Computational modelling practically fills the gap between imaging measurements and diseases’ appearance intensity as well as their different subtypes, aiding at the adequate definition of a mathematical association among them. More specifically, the trademark of asthma is the variable obstruction and the airway hyper-responsiveness of the Airway Smooth Muscle (ASM), which makes the capture of the physics of the human respiratory system particularly a challenging task requiring high resolution structural models as well as predictive models for the mechanical properties of the tissues and the dynamics of fluid flows. The non-linear interaction of this phenomena does not permit the development of independent models for each part of the whole system as it would lead to unexpected properties. Multiscale models are, thus, essential for the modelling process, making the modelling and imaging techniques applied rather complicated. The overall process followed is consisted of construction, parameterization and validation of patient-specific computational models.

For implementing a robust modelling technique for the lung, a principal prerequisite is a structural model of the lung, as functional outcomes are heavily affected by the quality of the input geometric structure of the occupied model. The rapid evolution of imaging techniques has provided experts with the opportunity to generate anatomically based patient-specific models, consisting of high-resolution computational meshes of the central airways and reaching up to 7-9 generations of branching. This results in millions of computational elements and this is why the branching is not extended to even more levels [99]. Computational and time restrictions arelooser currently but they still exist. Another critical component of lung modelling is the parameterization of models through imaging, which provides both structural and functional information. CT is the most common tool employed for structural lung imaging due to its high spatial resolution and adequate signal-to-noise ratio [100]. As a result, it makes possible the extraction of structural features such as geometry of airways, vessels and lobes which are essential for the development of personalized models. Airway segmentation, which is a crucial stage for the overall modelling process, is performed via threshold-based region-growing methods to detect the airway lumen while the centerline is determined using local properties of the image or skeletonization. The computational mesh coming from the airway segmentation could be used directly in Computational Fluid Dynamics (CFD) simulations. The wall thickness may be extracted and is needful for the assessment of inflammation effects of the disease. Vessel segmentation has also been performed using Hessian-based approaches.

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Functional imaging has provided experts with volumes of regional, the utilization of which can significantly aid at parameterization and validation. The most important developments in this field lately concerns the hyperpolarized gas MR imaging (HP MRI). Measurements for static and dynamic ventilation are currently possible, fueling with information on the distribution of diseases attributes such as ventilation defects [101]. Concerning the availability of functional models of the lung, and especially models for ventilation and tissue mechanics, it is widely accepted that there is a lack of truly multiscale respiratory models. An efficient model of this style and philosophy investigating lung diseases and their causes is that of Donovan et al [102]. They have investigated the impact of bronchoconstriction on lung function taking into account and combining events occuring across cellular, molecular and organ level. This model considers patient-specific lobes and central airways and includes distal airways created using the Volume Filling Branching (VFB) method. The airway model is integrated within a 'breathing' mechanics model. The tissue model for each airway is linked to a model of the cross bridge mechanics in the ASM. A plethora of modelling studies have presented novel outcomes through a combined imaging approach along with a modelling approach. These models, apart from incorporating patient-specific airway branching geometry, also include the prescription of functional defects from images. In general, the structure of models is manipulated in order to replicate the function brought about from the images.This can act as a way to figure out structural properties of the smaller airways which are impossible to extract through imaging. The ensemble of these studies has provided efficient evidence that the ventilation defects observed in asthmatics are universally provoked by severe constriction of small airways.

4.3. Cognitive Modeling

Part of the aim of the SmartWork project is to develop a Cognitive State Estimation module (CSE), as part of a prediction and decision support system (DSS) that, on one side will assess long-term risks of cognitive capacity decline, and on the other side will assess short-term efficiency and will inform the user when the user's estimated cognitive state is unfavourable for optimal work performance. Example of suboptimal cognitive states include high cognitive workload, frequent change of visual focus, frequent task switches, cognitive fatigue, inattention, and externally induced distractions, for example, by a cluttered computer screen or a noisy work environment.

More specifically, we will use Deep Neural Networks (DNN) for cognitive state estimation. Input to the CSE will be received as a continuous stream of biosensor data. Research into how the CSE should be implemented gives rise tothe following research questions:

- What kind of cognitive and cognitive states can be estimated given a sparse, unreliable stream of real-time sensor data?
- What form of learning is most viable to use for the given data?
- How well does cognitive-model-based cognitive state estimation perform compared to model-free state estimation?

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4.3.1. Cognitive states

The cognitive states that would be useful to detect in office workers include cognitive workload, fatigue, vigilance, inattention and distraction. In addition, directly work-related metrics might include time-on-task and task switching frequency. Foreseeably not all of these states can be directly mapped from biosensor data. Part of the aim is therefore to investigate to what extent the use of a cognitive model can aid in estimating the user's cognitive state.

4.3.2. Computational cognitive models

There is a potential benefit of utilizing a cognitive model as part of a cognitive state estimation (CSE) and decision support system (DSS). A cognitive model could help to achieve more explainable advices to the user, in this way increasing the transparency of the system. Also, the addition of a cognitive model introduces constraints that can help to narrow down the number of possible mappings from biosensor data to estimated cognitive states, thereby guiding and speeding up training of the system. By using a cognitive model in the CSE the system would more closely resonate with the human user: cognitive states in the model would reflect the cognitive states that arise in the human somatic and cognitive systems.

As opposed to theoretical "box-and-arrow" models, computational cognitive models are models that can be implemented on a computer and can be run to simulate various aspects of human cognition and behavior. Historically, there has been a gap between high-level symbolic architectures, such as Soar [48], [104], and ACT-R [105], [106][107], and lower-level, biologically-based modeling frameworks, such as emergent [108], [109].

A practically useful middle road is to apply architectures and learning techniques that are loosely inspired by the human biology but are fore mostly computationally optimized towards a given task. These approaches would belong to what is called weak AI, where a detailed correspondence with the human biology is not desired. The most famous example of this approach is the hierarchically structured neural network of Fukushima [110]–[112], called the Neocognitron, which was introduced in the 1980s and which eventually led to the advent of Convolutional Neural Networks (CNN). These networks are loosely based on the neural structure of the human visual system and they perform exceptionally well on visual tasks. Various extensions of the basic CNN have proved to outperform other techniques in the area of computer vision and image classification [113]–[116], and are now also being widely applied to tasks beyond image classification (e.g. signal processing using 1D CNN, biosensor classification, video processing, graph structure classification).

4.3.2.1. Models of memory

Computational models of working memory rely on Recurrent Neural Networks (RNN), where recurrent (self-looping) connections can be used to remember previously stored information. The key to working memory is a mechanism that can store information, but can also let go of old content, when it needs to be replaced with new information (REF O'Reilly). There is a loose

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correspondence between *executive control* in the classical non-computational model of working memory [117], controlling when memory should be updated, and *gating* in computational models. Gating is used to open or close particular connections leading in or out from working memory cells, in this way determining when a memory cell should be updated. Gating can either be algorithmically controlled, or be learnt from task demands, as is the case in Long-Short-Term Memory (LSTM) [118].

At a larger scale, working memory can be conceived as one of three different memory systems in the human brain [119]. The three memory systems are suggested to have complementary characteristics and serve complementary purposes. First, working memory functions as an activation-based memory, where activation patterns function as temporary holders of information. These activations can be preserved via self-connections or updated dynamically via gated in/out connections. Second, semantic long-term memory is a weight-based, memory, using distributed representations, where weights are updated through slow, incremental learning over several exposures to the same or similar input. Third, episodic memory is also weight-based, but uses localist representations, with fast learning, so that each exposure to a given input gives rise to a new representation that is separate from previously stored information [119]. These memory systems are tightly interconnected and work together in storing each input that the human cognitive system is exposed to.

4.3.2.2. Models of perception and motor actions

Biologically-based models of perception and action include visual-motor interactions during visual learning of object affordances [120]and bootstrapping of object learning through spatial selective attention[121]. In addition, there is a research filed devoted to developing detailed models of perceptual-motor actions that include an internal forward model for predicting the perceptual outcome of a motor action that is to be executed, and an inverse model, that helps to choose an appropriate motor action, given a desired outcome. These two internal models are presumed to be key components in the human perceptual-motor systems, and are trained together, laying in a sequence, during the planning, execution, and follow-up of motor actions [122]–[124].

4.3.3. Recent advances in using sensor data for user cognitive state estimation

Biosensor data have been used for quite a while for estimating user state, user activity [125], [126], and affect and attitudes [127]. With the emergence of affordable wearables (smart watches, fitness bands, etc.), biosensor-based applications for user activity recognition and user state estimation is booming. Wearable biosensor data have been used with machine learning to diagnose neurological conditions [128], [129], to recognize human activity [130], [131], and to predict stress and productivity [132]. Current approaches are not cognitive-model-based, but rather base their estimations on a direct mapping from (pre-processed) sensor data to user state estimate.

Surveying the literature, there are several practical issues to consider in biosensor-based application. First, when dealing with complex data, a choice must be made whether to extract features manually, and feed these to a simple classifier, or to let useful features be extracted automatically during a more complex classification task. While handcrafted features can be efficient together with a simple classifier, it can be laborious and time consuming to manually find the optimal feature set. Also, more complex features—such as the combination of signals at a specific frequency and within a specific time frame—may not be possible to extract manually. The alternative, namely, to automatically extract features using deep learning (see below), improves performance, as a feature set that has been extracted during training of the task is optimally adapted to the task (see e.g. the success of deep learning methods in IVRC: [133]).

A second, related issue is how to best represent biosensor data, so that readily available, well-proven machine learning techniques can be applied. Example of innovative ways to re-represent the sensor signals is described in [130], where the synchronized signals were composed into an image, which was then further processed using discrete Fourier transform of this image. The resulting 2D images showed clearly distinguishable characteristics for the various categories and could readily be classified[130]. A similar way of re-representing the sensor signals is to run spectral analysis on the data to extract the constituent frequency components, and use the resulting 2D image (time vs frequency plots) for training a deep learning network[125].

A third issue concerns how to handle streaming data, that is, the continuous flow of sensor data, for training an artificial neural network. Many of the existing machine learning approaches require a fixed data set, where the data used for training is presented to the network through many iterations (epochs), until the training error (loss) has been minimized. In contrast, streaming data can only be presented to the network once. One-exposure (one-shot) learning requires a high learning rate that allows for large changes in the neural network weights with each exposure. However, large changes would also mean that previously acquired knowledge would be overwritten in the network. To solve this problem, Lee et al. [129] propose a dual memory network, where one memory system learns slowly, while the other is updated fast with each exposure. Alternatively, one could opt for collecting input from within a sliding window over the streaming data, so that each data point can be used for training several times, potentially up to the window-size times. This could on the other hand hamper real-time performance. With a relatively large window size and a small stride (large overlap), the number of exposures with each data point could be enough to allow for moderate weight update rates, and in this way preserve old knowledge in the network. Using this latter approach, one would be able to apply off-the-shelf deep learning techniques that are normally used for fixed data sets. As an example of this approach, Cogan et al.[128] used a sliding window with 50% overlap, and could apply simple standard classification techniques (k-nearest neighbor, and as hallow neural network) to detect pre-epileptic-seizure neural state in their users.

Fourthly, online learning, that is, continually training the neural network while it is being deployed for sharp cognitive state estimation, imposes an extra requirement on the training regime. In online learning, the model has to be continuously adapted to novel data. This could mean adaptation to, possibly, novel categories that have not been encountered before (which is called non-stationarity), and/or adaptation to changes in the definition of previously established categories (concept drift). Lee and coworkers [134] describe a method for dynamically adding new categories, namely to extend the partially trained network with new components.

Fifthly, to achieve real-time and on-node processing, it is necessary to minimize the need for computational resources. This is done by carefully choosing the amount of input and how it is represented, but more importantly by the type of learning technique deployed. For example, in one recent study [130], the use of convolutional neural networks seems to yield better performance (faster output calculation) than other alternatives, including simple classifiers such as SVM, and also including the use of explicit techniques aimed to decrease computational requirements, for example, elimination of features from the data set.

Finally, an inherent problem with biosensor data is the lack of labels (i.e. correct output for each input data).There are practical limitations to providing correct labels. For pre-recorded data sets, frequently, labels must be manually produced, which is a tedious, laborious process, for larger data sets often performed through crowd-sourcing. In contrast, for real-time streaming data, the collection of labels would presume some form of user feedback, which for practical reasons can only be elicited sparingly, in order not to intrude on the user's ongoing activities. In best case, this procedure will result in weakly labeled data, where most of the data will remain unlabeled. To handle weakly-labeled data elaborate learning techniques are needed, such as self-supervised learning (see below).

4.3.4. Deep neural networks

Deep neural networks (DNN) are commonly defined as having more than three layers, that is, having multiple representational (hidden) layers [135]. While deep learning has proven to be a very powerful function estimator, deep networks require big data for determining all its parameters. The deeper the network, and the more units in each layer, the more weights that need to be determined during training. Deep networks therefore require large amounts of data for training[113], [136]. Hence, in domains where (labeled) data is scarce, a moderately deep network may be preferred (4-10 layers), before an excessively deep network. On the other hand, when large data sets are available, extremely deep networks outperform shallower networks at complex tasks, such as image and video analysis [114]–[116], [137].

4.3.5. Transfer learning

In smaller application domains, where large data sets are not available, there might be a possibility to adapt an already trained network to the small data set – provided that the previous and new data sets and the two tasks do not differ significantly. For example, it is common practice to adapt an extremely deep network for image processing, trained on big data, to a smaller domain, for

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example, medical images, by re-training the last (fully-connected) layers of the already trained network.

GENERATIVE ADVERSARIAL NETWORKS

A way of handling a situation where not only the data sets are small, but where labeled data is scarce, is to use Generative Adversarial Networks (GAN) [138]. The idea behind GANs is like letting two learning agents play against each other, in order to iteratively improve both agents without human involvement. GANs consist of two parts: one classifier part where input is classified, and one generator part where a class-code is "backwards engineered" into a corresponding input. This artificially generated fake input is then fed into the classifier as input. Intermittently, the classifier also receives real input data. The aim is to train both systems, by letting them act as adversarial players in a game where the classifier is trained to classify the real inputs (and to classify the fake inputs as fake), while the generator is trained to produce better and better faked inputs that can confuse the classifier.

The architecture of GANs is very flexible in the sense that, in principle, any type of DNN can be used as classifier and generator. In other words, the classifier and generator can be designed in several ways, resulting in a GAN architecture with a training regime where only small amounts of labelled data are needed. The drawback is that GANs are complex, and that the loss (error) function might be difficult to formalize for some learning tasks.

4.3.6. Self-supervised learning

As a last resort when faced with the problem of having few labelled data available, self-supervised learning could be applied. Self-supervised learning refers to a range of techniques to train a network on tasks, other than the main classification task, that force the network to develop some understanding of the underlying classes that the input can be categorized into. Among the commonly used tasks are to fill-in missing parts of the input (or missing input), as well as to predict the next data point in a temporal sequence of data, that is, sequence learning. Sequence learning would suit a stream-processing application well and would help to reduce the need for labelled data.

4.3.6.1. Sequence learning

Predicting the next data point in a temporal sequence amounts to sequence learning, which is achieved by Recurrent Neural Networks (RNN). Generally, sequence learning requires some form of record of the network's activation state at previous time steps. This information is stored by preserving activations in part of the network, which at the next time step is fed to the network through recurrent (self-looping) connections, so that previously stored information can be used at later time steps. The network can in this way learn to relate information about what happened previously, with the current input, and use the learnt transition regularities to predict the next time step. In standard RNN, the more time steps that the network needs to remember[139], the more diluted the oldest pieces of information will become, as newer information will be overlaid on top of

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the older information. In more mathematical terms, the gradients for longer-term dependencies can either vanish or explode, which in both cases hampers learning[140], [141].

To address this problem of vanishing and exploding gradients, a variant of RNN was proposed in the late 1990s by Hochreiter and Schmidhuber[118], the Long-Short-Term-Memory (LSTM) network. LSTM avoid overwriting of old information—unless this is necessary for solving the task. This is achieved using dynamic, learnable gates that open or close connections into or out of the memory cells of the network. LSTMs, and variations of LSTMs, have proven to be very potent for a wide range of sequence learning tasks. However, as the gates need to be learnt, LSTMs are heavier than standard RNNs, in the sense that they require a larger amount of training data.

Another, potentially more light weight alternative for handling the problem of long-range temporal dependencies is to use recurrent layers at various time-scales. The Multi-Timescale RNN (MTRNN) [142], [143], lets lower layers be updated at a faster pace, to encode short-term changes in the input, while letting higher layers encode long-term temporal dependencies.

GRAPH-EXTRACTION

For the CSE to be able to inform the user about unfavorable cognitive states, the state of the underlying cognitive model needs to be extracted, and this information represented in a simplified way, preferably in a human-readable way. A localist representation, where each unit stands for one nameable concept, would be well suited for representing cognitive states in a way that can be easily communicated to the user. However, in artificial neural networks in general, and in the CSE cognitive model in particular, neural representations are distributed, so that the simultaneous activation of a large number of units stands for a concept. Hence, the state of the CSE cognitive model is represented by activation patterns over many units. The change of these activation patterns over time, as consecutive input data are processed, must be decoded into a human-readable simplified graph of localist states and transitions between these states.

Graph extraction amounts to extracting from a neural network a graph consisting of nodes, representing states or concepts, and (directed) edges, representing transitions between states or representing relationships between concepts. Each node in the graph can, for example, represent a distinct state that arises in the underlying neural network. This state can, for example, reflect the current activation pattern across all layers in the underlying network, but can also have a temporal extension, where transition between graph nodes represent changes in activation states of the underlying network.

In the 1990's, some pioneering work was conducted on rule extraction, where algorithmic approaches were used to extract the input-output mappings performed by a trained network. A fully trained network was "circumvented", by running the network and recording its input – output mappings. These mappings were then turned into symbolic if-then rules, using various algorithmic approaches[144].

In our case, the if-then rules must be replaced by graphs representing states and transitions that occur in the underlying network. In addition, the algorithmic approaches employed previously

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require a fully trained network, which is then analyzed after the training has been finalized. When using online learning on a continuous stream of data, a more dynamic approach is needed.

One viable approach would be to achieve graph extraction by applying machine learning on the activation patterns that arise in the underlying network. The advantage is that this can be done while the underlying network is still being trained. A potential inspiration for a machine-learning-based approach to graph extraction is the technique employed in inception networks, where the aim is to cluster nodes in the network layers that tend to have similar activation values when observed over a range of inputs [113]. In our case, a combination of clustering and sequence learning could be used for capturing both states and transitions between states.

An alternative to explicitly cluster units based on their co-activation, is to train two parallel, but interconnected subsystems: one using distributed representations and one using localist units. Localist representations, where each unit represent a distinct concept, are well suitable to represent a human-readable graph structure, with connections (weights) representing transitions in the graph. A similar two-system approach is used by O'Reilly and colleagues in the multi-memory-system [108], [145].

4.4. Workability Modeling

Modelling work ability is, by definition, a truly compound task due to the multiple parameters that need to be taken into account during the assessment of a worker's capacities and abilities. Functional abilities, and the possible disabilities which are likely to come up latter in life as the worker gets older, are a pivotal factor for the overall assessment. It is also obvious that cognitive capacity plays a determinant role in the maintenance of office workers' productivity to a stable level as they are getting older. However, these are not the sole factors that are expected to have a major contribution in the process of assessment. Work environment, employers' attitude towards them, psychosocial factors determined by their personal life and, last but not least, their perceived health condition (independently on what their clinical state actually is) are factors which can affect significantly the overall work ability of an aging worker either in a positive or in a negative manner. As one could easily realize, the creation of a model in which all these parameters are integrated and taken into account is a really demanding process, as the approach adopted will be characterized by high complexity. The ultimate goal of this modelling process is to integrate into our model as many details and parameters as possible while keeping its complexity to a viable level with respect to system resources (e.g. processing time, computational power, etc.).

4.4.1. Modelling Approaches

One of the most complete studies in the field of work ability was conducted by Koolhaas et al [146], who has examined the issue from many different aspects. The main research aspects conerned:

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- to determine the relation between chronological and functional age
- to examine the association between chronological age and work outcomes
- to examine the association between functional age and work outcomes

Functional age was measured with perceived health status and the presence of a chronic health condition. Work outcomes were calculated through the Work Ability Index (WAI), as well as by assessing the perspective of aging workers on the health problems they have experienced as the time passes, the barriers to perform work due to ageing problems, the facilitators in the work situation and the support needs to continue work. WAI is a metric usually calculated using a self-administered questionnaire [147], comprising seven scales:

- subjective estimation of current work ability compared with lifetime best (0–100 points);
- subjective work ability in relation to both physical and mental demands of the work (2–10 points);
- number of diagnosed diseases (1–7 points);
- subjective estimation of work impairment due to diseases (1–6 points);
- sickness absenteeism during the past year (1–5 points);
- own prognosis of work ability after 2 years (1 or 4 of 7 points);
- psychological resources (enjoyment of daily tasks, activity and life spirit, optimism about the future) (1–4 points).

The reliability and validity of the WAI are considered as acceptable, and based on this WAI score the individual's work ability is usually classified into two categories: moderate/poor (7–36 points) and excellent/good (37–49 points). Dichotomous (yes/no) questions were used for the assessment of other outcomes: problems, barriers, facilitators and support needs.

The study conducted by Koolhaas showed that association of chronological and functional age with work outcomes (decrease in work outcomes with age) is significant, especially when a chronic health condition is present. Workers with higher chronological age (50 to 64 years old) experienced more problems due to ageing and bigger support needs to continue working life in the years to come relatively to younger age groups. WAI was also decreased in relation to chronological age, but experienced barriers did not seem to present an increasing fashion. Workers between 50 and 64 years of age experienced significantly less facilitators in the work situation. These results imply that employers should find means to promote sustainable healthy working life for their older workers.

Moreover, no significant differences were detected concerning the chronic health condition between the age groups 45 to 54 and 55 to 59 years old. Based on the literature, it was expected that older workers had lower scores on the metrics related to health status [148]. Although this finding seems to comprise a paradox, it could possibly be explained by the so called "*healthy worker effect*". Healthy worker effect is a situation where workers- and especially the older ones-usually exhibit better health conditions compared to the younger generations, because those suffering from chronic illnesses or disabilities are temporarily or permanently excluded from employment. Due to the existence of this phenomenon in combination with the selection bias of the participants, the results in this report are probably an underestimation of the problems in the entire population of this specific age group. Functional age, it was, as expected, strongly correlated with work outcomes. With respect to functional age, predominantly a chronic health condition was associated with more problems, more barriers, more support needs and lower work ability scores. The impact of the presence of a chronic health condition was not mediated by other measures of functional age. On the other hand, reported problems in work functioning increased with chronological age, but for example workers in the group aged 60–64 years did not report more problems and barriers compared with workers of the group aged 45-49 years.

Koolhaas el al have also conducted another major survey [149], aiming at determining the influence of work conditions and environment, psychosocial factors and perceived health on the association between the presence of a chronic disease or malfunction and work ability defined by WAI among workers 45+ years old. Furthermore, there was an effort to examine variables correlated with work ability while segregating the ones suffering from a chronic health condition from the rest. Work ability was assessed based on the first item of WAI while presence of a chronic health malfunction was assessed through self-reporting. Independent variables in the multiparametric linear regression analysis were work conditions, psychosocial factors and perceived health status, as mentioned above as well. The study indicates that perceived health and psychosocial factors, rather than work conditions, explained the association between the presence of a chronic health condition and work ability. Substantial differences in variables associated with work ability between workers with and without a chronic disease were not found- the differences were rather negligible. Based on the lower mean scores for workers with a chronic health condition and work ability as well as for predictors, these workers are expected to significantly benefited from a policy focusing on enhancing these associated variables.

4.5. Predictive Tools and Decision Support Systems

Longer life expectancy and increasing numbers of people living with chronic conditions during the last couple of decades, while being under employment at the same time, accompany the greying of the demographic profile. The burden of meeting the needs of this growing number of people will deteriorate rapidly the already overstretched health care services that are struggling to cope with the needs of those with long-term health conditions. A solution to this problematic situation could be the upgrade of patients' role in the process of healthcare provision. The more active involvement demanded by patients is associated with keeping up with the realities of chronic diseases whereby responsibility for day-to-day disease management gradually shifts from health care professionals to the individuals. Self-management tasks, though, require the existence of an efficacious risk assessment and decision support system which will be a valuable asset to their effort of handling efficiently their daily health condition needs. Although a valid and widely accepted

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definition for self-management could not be determined, it could be stated that health self-management refers to the individual's ability to manage the symptoms, treatment, physical and psychosocial consequences and behavioral and life style changes inherent in living with a chronic condition. Self-management may be one means of bridging the gap between patients' needs and the capacity ofhealth and social care services toefficiently and timely meet those needs for the continuous care of chronic conditions.

Pattern recognition is one major approach to AI, which refers to the automated recognition of patterns and regularities in data, often being also refered as data mining and knowledge discovery. Machine Learning (ML) is currently evolving as the most used approach to patern recognition, with a good number of classical ML methods (e.g. Random Forest, Bayes classifier) for supervised learning still competing the more advanced unsupervised learning approaches usually employing Neural Networks.

The assistive capabilities of a system are (e.g. guidance for self-management of chronic health conditions) are implemented through DSSs, which are using the prediction results along with various other information sources (e.g. rules) to establish intervention paths (e.g. trigger alerts or reminders, make suggestions, etc.). The following subsections provide an overviw of currently most used pattern recognition methods for classification tasks and various DSS systems mostly used for health condition management.

4.5.1. Pattern Recognition Methods

4.5.1.1. Classical Machine Learning Methods

A lot of progress has been made in recent years in the development of data manipulation techniques as well as predictive models using ML. In contrast to most conventional potentials, which are based on physical approximations and simplifications to derive an analytical functional relation between natural quantities describing a phenomenon, ML potentials rely on simple but very flexible mathematical terms without a direct physical meaning. Classical machine learning methods are considered as the first methods being able to respond to the demanding challenge of pattern identification and, in our case, to deal with the compound and heterogeneous nature of monitored data. In SmartWork project, this type of methods will be integrated so as to discover associations between data from different sources, to perceive interactions within the data and, overall, to address the challenge of **data complexity.**

Bishop [150], and more recently Anzai [151], provide complete overviews of the existing methods with a significant impact on the domain of Classical Machine Learning, focusing on examining the principal concepts of probabilistic methods and theories, namely Bayesian graphical models, variational inference, Monte Carlo sampling methods and Hidden Markov Models (HMM). The case of kernel techniques is also considered, with the Support Vector Machine method being the most popular and widely utilized from this category. Support Vector Machine (SVM) method, which is based on maximizing the different between two different classes of objects, is in direct alignment with Random Forest approach according to Pal et al. [152]. Random Forest techniques are claimed to perform equally well to SVMs in terms of classification accuracy and training time,but they seem to outclass SVMs from the aspect of the number of user-defined parameters required in for an equally efficient classification to take place. A short overview of the most used classical ML methos is provided in the following subsections.

FUZZY LOGIC

Fuzzy logic has found widespread popularity as a method for representing uncertainty particularly in applications such as supervisory control and high-level data fusion tasks, since it provides an ideal tool for inexact reasoning [153]. For the combination step in the fusion process, the advantages of fuzzy sets and possibilities rely in the variety of combination operators, which are able to deal with heterogeneous information [154], which is usually the case in multi-source, and to avoid to define a more or less arbitrary and questionable metric between pieces of information, since each piece of information is converted in membership functions or possibility distributions over the same decision space.

In fuzzy logic, the normal properties associated with binary logic remains: commutativity, associativity, idempotence, distributivity, and De Morgan's law and absorption [155]. The only exception is that the law of the excluded middle is no longer true, i.e. $A \cup A = X, A \cap A = \emptyset$. Together, these definitions and laws provide systematic means of reasoning about inexact values. According to [156], "Fuzzy logic and probabilistic logic are mathematically similar – they both have truth values ranging between 0 and 1 – but they are conceptually distinct, owing to different interpretations. Fuzzy logic corresponds to "degrees of truth", while probabilistic logic corresponds to "probability, likelihood". As these differ, fuzzy logic and probabilistic logic yield different models of the same real-world situations."

Typically, in a basic application, subranges of a continuous variable are defined, and each defined function maps the inputs values to a truth value in the 0 and 1 range. These truth values can then be combined, using a set of rules, in order to determine the output of the fuzzy system.

BAYES ML METHOD

Machine Learning using Bayes theorem is one of the most renowned – also one of the oldest- learning methods which belongs to the domain of the so-called traditional machine learning.

Bayesian theory enables prediction of future events and provides an embedded scheme for learning [157]. The Bayesian interpretation of probability can be seen as an extension of logic that enables reasoning with propositions whose truth or falsity is uncertain. To evaluate the probability of a hypothesis, the Bayesian probabilist specifies some prior probability, which is then updated in the light of new, relevant data.

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In complex cases, the computation is usually intractable, but good approximations can be obtained using estimation techniques such as Hidden Markov Models (HMMs), Kalman Filters and Particle Filters. Through the sequential use of the Bayes' formula, when more data becomes available after calculating a posterior distribution, the posterior becomes the next prior. As in Fuzzy Logic, in Bayesian statistics, a probability can be assigned to a hypothesis that can differ from 0 or 1 if the truth value is uncertain.

Bayes' formula provides a means to make inferences about an environment of interest described by a state, given an observation. It requires that the relationship between the observation and state be encoded as a joint probability or joint probability distribution for discrete and continuous variables respectively. Therefore, the value of Bayes' rule is that it provides a principled means of combining observed information with prior beliefs about the state of the world (Portugal and Rocha, 2013). In sensor fusion, sensor models usually represent prior probabilities, and likelihood functions represent how each observation is modelled according to the expected state. Simply put, the Bayes formula is then equivalent to:

$$posterior = \frac{prior \times likelihood}{evidence}$$

Despite the fact novel methods have been introduced in the machine learning field during last years and the domination of the different structures of neural networks that constantly come about, it is widely acceptable that the Bayes method is a kind of baseline for the whole domain. More specifically, when it comes to intelligence in the medical domain and the assessment of a patient's risk of future adverse health events, there are still state-of-the-art methods introduced by recent studies tackling clinical decision making in patient-specific and preventive care, which are based to a considerable extent on Bayes method and its renewed permutations.

A characteristic example of such a study was conducted by Lin et al. [158]. They introduce a method aiming at overcoming the prevalent flaw of numerous existing methods destined for risk assessment, which typically focus on one specific event and do not predict multiple outcomes. To fulfil this goal, the design science paradigm is adopted and a principled approach called Bayesian multitask learning (BTML) is suggested. Generally, it could be claimed that the proposed BTML approach attempts to combine a set of baseline models with each model corresponding to a single health event or risk factor. The principal aim of the BTML approach is to transfer training information across the different models employed. Consequently, it provides healthcare providers with the opportunity to achieve multifaceted risk profiling and model an arbitrary number of events simultaneously. It is demonstrated through the outcomes of the survey that the proposed approach presents upgraded predictive performance compared to the alternatives that model multiple events separately, addressing the heterogeneity of health events and disorders in a clearly different philosophy. Furthermore, it is stated that this BTML approach outplays by a noticeable margin the existing learning techniques based on similar design philosophy, namely multitask learning techniques. Finally, the analysis of the suggested approach proves that potential impacts on clinical

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practice could be created via its application, concerning the reduction of the delays in preventive interventions.

Thottakkara et al. [159] included Bayes method in their study aimed at comparing risk prediction models for forecasting postoperative sepsis and acute kidney injury from performance's perspective. More specifically, naïve Bayes method was employed and compared to other techniques, such as logistic regression and support vector machines that will be analyzed in the next subsection, concerning their impact of feature reduction techniques on predictive performance. Model performance was determined using the area under the receiver operating characteristic curve, accuracy as well as positive predicted value. It should be mentioned that generalized additive models and support vector machines were superior to naïve Bayes method from the aspect of performance as risk prediction model in postoperative sepsis and AKI. Moreover, it was shown that feature extraction using principal component analysis (PCA) optimized the predictive performance of all models taken into consideration.

Kourou et al. [160] have also considered Bayesian networks (BNs) as a feasible alternative into their study on the impact of a variety of ML techniques on the modeling of cancer progression. The authors point out the significance of classifying cancer patients into high or low risk groups, which led them to studying the application of Machine Learning (ML) methods. The advantages of ML tools concern the capability to detect key features from complicated datasets. Bayesian Networks have been widely applied in cancer research for the development of predictive models resulting in efficient decision making. It is claimed that despite being diagnosed as useful tools for acquiring a deeper insight into cancer progression, ML methods, including BNs, are yet to be further validated for being applied in the everyday clinical practice. In this study, BNs are presented as one of the most reliable techniques for evaluating either cancer risk or patient outcomes. BNs are mostly utilized for classification purposes, and they output probability estimations rather than actual predictions. They are employed for knowledge representation tasks coupled with probabilistic dependencies among different variables via a directed open-loop graph. BNs have been extensively applied to reasoning purposes, except for classification tasks and knowledge representation.

SUPPORT VECTOR MACHINE

A Support Vector Machine is a discriminative classifier formally defined by a separating hyperplane. In other words, given labeled training data (supervised learning), the algorithm outputs an optimal hyperplane for categorizing new examples. To put it simple, in 2D spaces this hyperplane is, expectedly, a line dividing a plane in two parts where in each class lay in either side, while in 3D spaces the hyperplane is a 3D plane splitting the 3D space in two parts. Normally, support vector machines are supervised learning models with associated learning algorithms that analyze data used for classification and regression analysis purposes. In addition to performing linear classification, SVMs can be utilized for non-linear classification producing efficient results by using the well-known kernel trick, implicitly mapping their inputs into high-dimensional feature spaces.

SVM is a hybrid technique of statistical and deterministic approaches. This means that to find the best space for a classification hypothesis, a probability distribution is determined from the input

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space. In the case of a linear space, it is necessary to determine the hyperplanes of separation through an optimization problem; in the case of non-linear space, a kernel function is applied and the new space obtained is denominated the feature space.

An important generalization aspect of SVMs is that frequently not all the available training examples are used in the description and specification of the separating hyperplane. The subset of points that lie on the margin (called support vectors) are the only ones that define the hyperplane of maximum margin. The implementation of a linear SVM assumes that the multi-spectral feature data are linearly separable in the input space. In practice, data points of different class memberships (clusters) overlap one another. This makes linear separability difficult, since the basic linear decision boundaries are often not sufficient to classify patterns with high accuracy. On one hand, a high capacity set of functions may lead to a low training errors, but overfitting will inevitably occur. On the other hand, a very simple set of models will lead to low complexity and quicker separability, but high training error.

In nonlinear classification, the resulting algorithm is formally similar except that every dot product is replaced by a nonlinear kernel function. This allows the algorithm to fit the maximum-margin hyperplane in a transformed feature space. The transformation may be nonlinear and the transformed space high dimensional; so even though the classifier is a hyperplane in the high-dimensional feature space, it may be nonlinear in the original input space. There are several popular kernels that can be used in nonlinear classification such as polynomial, Gaussian radial basis function or hyperbolic tangent.

Several studies have been conducted on the exploitation of support vector machines for medical classification purposes. Karstoft et al. [161] tried to develop a method for predicting Posttraumatic Stress Disorder (PTSD). They aimed at identifying interchangeable sets of risk indicators that were possible to increase the efficiency of early risk assessment. To achieve its goal to uncover interchangeable, maximally predictive combinations of key risk indicators, supervised machine learning techniques are employed. The present study demonstrates that data depicting the traumatic event and subsequent emergency department admission related to PTSD improves the prediction of early symptoms. Six classification algorithms were found to perform equally and better predictability of the non-remitting PTSD symptom trajectory relative to diagnostic status was demonstrated. Based on these findings, the authors selected support vector machines as their needed classification algorithm and a non-remitting PTSD symptom trajectory as the predicted outcome.

Diabetes early screening and diagnosis play an important role in effective prevention strategies. Tapak et al. [162] examined the possibilities of applying machine learning techniques for early screening and diagnosis purposes which are dependent on the design and implementation of effective prevention strategies. The study employs and compares four machine learning classifiers (neural networks, support vector machines, fuzzy c-mean and random forests) to classify individual sufferers from diabetes and non-sufferers. Ten risk factors that are commonly associated with diabetes were chosen to compare the efficiency of the classifiers examined in terms of sensitivity, specificity, total accuracy and area under the receiver operating characteristic (ROC) curve criteria. The results comprise a piece of evidence that support vector machines present the highest total accuracy (0.986) as well as area under the ROC (0.979). In addition to this, the method showed high specificity (100 %) and sensitivity (82%), being importantly superior to other methods, especially in this attribute. It is clearly argued that the support vector machine ranks first among the considered classifiers tested in the prediction of diabetes as its overall classification accuracy is considerably higher, implying the need of being further investigated for the prediction of diabetes and other diseases as well.

RANDOM FOREST

Random forests or random decision forests are an ensemble learning method for classification, regression and other tasks which operates by constructing a multitude of decision trees at training time and outputting the class that is the mode of the classes (classification) or mean prediction (regression) of the individual trees. Random decision forests correct for decision trees' habit of overfitting to their training set. The first algorithm for random decision forests was created by Tim Kam Ho using the random subspace method, which, in Ho's formulation, is a way to implement "stochastic discrimination" approach to classification proposed by Eugene Kleinberg. A plethora of permutations of random forests have been introduced ever since. Random forests have been utilized in bioengineering to a significant extent during the last couple of years.

One of the fields to which random forests decision trees algorithm is applied is medical imaging. McKinley et al. [163] exploited Random Forest algorithm in their study aimed at conducting fully automated stroke tissue estimation and introduced a variation of classical Random Forest algorithm named Segmentation Forests destined, as its name implies, for segmentation purposes. The resulting classifier is a decision forest, in which the final classification is derived from combining the votes of numerous decision trees, each built on random samples of the training dataset. On the contrary to classical Random Forests, in Segmentation Forests, the random sampling occurs at two levels: first at the patient level, then at the voxel level. Each tree is therefore constructed on only a subset of the patient cases. This has two advantages: firstly, since voxel-wise data are clustered in a patient-specific manner, this form of random sampling produces more representative samples than sampling without patient-level orientation, reducing the variance of the classifier without increasing bias. Secondly, since each tree is trained only on a subset of the patient cases, the cases thrown out of the training set can be used to tune the classifier, by estimating the classifier's cutoff at which a metric (for instance, mean Dice coefficient) is optimized.

ADABOOST ML METHOD

AdaBoost, short for Adaptive Boosting, is a machine learning meta-algorithm formulated by Yoav Freund and Robert Schapire. It was preferred that it be analyzed among the algorithms characterized of a supervised learning philosophy as it combines attributes from a range of methods adopting a similar orientation.AdaBoost is one the most widely used classification boosting algorithm, which aims at creating a highly accurate prediction rule (or strong learner) by combining numerous inaccurate and weak rules (weak learners). Substantially, it is used in conjunction with a plethora of other types of learning algorithms in order to upgrade

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performance.The output of the other learning algorithms employed, namely weak learners, is combined into a weighted sum that represents the final output of the boosted classifier. AdaBoost is adaptive in the sense that subsequent weak learners are tweaked in favor of those instances that were not properly classified by the previous classifiers processing. AdaBoost is considerably sensitive to noisy data and outliers. However, it is advantageous, in a specific set of problems, in the sense that they present insusceptibility to the overfitting problem compared to other learning algorithms. The individual learners can be weak, but as long as the performance of every single learner is, at least slightly, better than random guessing, the final model that comes up is proven to converge to a substantially strong learner.

Every learning algorithm tends to fit some certain problem types better than others, and normally needs a variety of parameters and configurations to adjust so as to reach to the level to which optimal performance on a dataset is achieved. On the contrary, AdaBoost (with decision trees as the weak learners) is often addressed as the best out-of-the-box classifier. In other words, AdaBoost is the most universal classifier, the one responding most efficiently independently on the nature of the problem under examination. When used in combination with decision tree learning, information gathered at each stage of the AdaBoost algorithm about the relative 'hardness' of each training example is fed into the tree growing algorithm such that later trees tend to focus on harder-to-classify examples.

An additional benefit of AdaBoost algorithm is related to its attitude towards the course of dimensionality, which is one of the most common problems one has to deal with when involved with machine learning techniques. Each sample may be represented through a vast number of potential features and the evaluation process of each feature can be reduce not only the speed of the classifier training and execution but also diminish its predictive capability, per the Hughes Effect. Unlike neural networks or supervised learning techniques, such as SVMs, the AdaBoost training process selects only those features estimated to improve the predictive power of the model, significantly reducing dimensionality and occasionally improvising execution time as irrelevant features are excluded.

In a recent study, Kocsis et al [164] in an attempt to point out the significance of emerging eHealth tools for asthma self-management, assessed the potential of three classical ML approaches, including AdaBoost, Random Forests and SVMs, as predictive tools for asthma status control. The potential of machine learning exploitation in decision support for personalized self-management of asthma is highlighted, with the random forest algorithm coming up more accurate in asthma status prediction compared to respective implementations of SVM and AdaBoost classifiers.

4.5.1.2. Neural Networks

Neural networks' approach is a principal pylon of the field of pattern identification. Although the first neural networks have been restricted to vectorial spaces of low dimensionality and, consequently, few degrees of freedom due to their large computational complexity, they are currently applicable to high-dimensional systems allowing for the examination of complicated

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natural phenomena. The rapid development of different variations of neural networks has converted them into a dominant force in an extremely wide range of fields and applications, including the medical domain.

Neural Networks provide the potential of an alternative information processing paradigm that involve large interconnected networks of processing units. These units, relatively simple and typically non-linear, are connected to each other by communication channels, i.e. connections that carry data. Artificial Neural Networks have a relationship with statistics. Most neural networks that can learn to generalize effectively from noisy data are similar or identical to statistical methods. Feed forward nets with no hidden layer, including functional-link neural nets and higher-order neural nets, are basically generalized linear models. Probabilistic neural nets are identical to kernel discriminant analysis. Kohonen nets for adaptive vector quantization are very similar to k-means cluster analysis, and Hebbian learning is closely related to principal component analysis [165]. ANNs can have different types: Supervised Learning, in which the network is supplied with a sequence of both input data and desired output data (target); and Unsupervised Learning, in which only the input is given to the network, and the network should learn the system properties and reflect them in its output. Moreover, if the flow of computation is in one direction (from the network input to its output), they are referred as feedforward networks. On the other hand, recurrent neural networks are more complex, allowing data and information to flow in both directions with the presence of loops and feedback connections between units. The ANN methodology consists of dividing the sample data into the training, validation and testing sets, conducting afterwards the classification phase. In the training set, a set of examples is used for learning to fit the parameters of the classifier. The validation set is used to tune the parameters of the classifier (e.g. choosing the number of hidden units in a neural network). The testing set is used to assess the performance of a fully-specified classifier. Finally a classification algorithm, such as Fuzzy Adaptive Resonance Theory (ARTMAP) architecture can be applied [166].

In SmartWork project, the large data volume collected by the various sensing devices results in complex data sets, which are expected to be challenging for more complex predictions (e.g. work ability). For addressing this challenge, SmartWork implementation is expected to take advantage of novel machine learning algorithms for reinforcing the decision making. Deep neural networks, which usually outperform shallower networks at complex tasks when working with large datasets, could be exploited for fulfilling the goals of SmartWork, as already discussed in section 4.3.4, potentially considering fully connected neural networks (FCNs), convolutional neural networks (CNNs) and recurrent neural networks (RNNs). In the following sections, FCNs, CNNs and RNNs are analyzed separately for clarifying the reasons behind their qualification as emerging tools for the complex prediction tasks, as well as for providing an overview of the state-of-the-art studies which have employed these methods in similar or relevant tasks.

FULLY CONNECTED NEURAL NETWORKS (FCNS)

Fully Connected Neural networks are characterized as the work horses of deep learning, used for thousands of applications. The major advantage of fully connected networks is that they are "structure agnostic". This means that no special assumptions or modifications of the network need to be made about every single input. Consequently, fully connected architectures are "universal approximators" capable of learning any given function. Being "structure agnostic" which causes FCNs to be broadly applicable also brings about some considerable deficits for these architectures, the most important of which is they tend to be less efficient from performance perspective than special-purpose networks suitably modified based on the structure of a problem space. A FCN consists, as its name implies, of a series of fully connected layers and is practically a function from a real m-dimensional space to a real n-dimensional space, with each output's dimension being partially dependent on each input dimension.

However, its structure arises an obligation for importing a vast number of parameters causing the computational load to increase in an exponential manner. This happens due to the fact that, in a fully connected layer, each neuron is connected to every neuron in the previous layer and its connection has its own weight, causing the memory requirements to ascend as well. Consequently, training process is significantly slower and relatively high chances of overfitting also come up. Thus, this type of networks is highly unsuitable when it comes to computationally demanding tasks (e.g. medical image classification). Nevertheless, its general purposenature in combination with the integrationof individual fully connected layers in all other types of networks, and especially the convolutional ones which are elaborated in the forthcoming subsection.

CONVOLUTIONAL NEURAL NETWORKS (CNNS)

A convolutional neural network (CNN) is a class of deep neural networks, most commonly applied to analyzing visual imagery. CNNs use relatively minor pre-processing compared to other image classification algorithms, a field to which they are mostly applied. CNNs might be the most widely used type of networks in medical imaging due to some specific benefits they provide. What is considered most beneficial is their property of learning (on their own) the filters that in traditional processing and classification algorithms were hand-engineered. This subsequently leads to their being totally independent on prior knowledge and human effort in feature design.

Regarding its structure, a convolutional neural network consists of an input and an output layer as well as a multitude of hidden layers. The hidden layers of a CNN typically consist of convolutional layers, RELU layers ("responsible" for activation functions), pooling layers, fully connected layers and normalization layers. The description of the algorithmic process of this type of networks could be figured out by the fact its naming instantly points to convolution. Mathematically, it is expressed as a cross-correlation rather than a convolution. However, it is only significant for the indices in the matrix, defining which weights correspond to each index.

CNNs are extensively used for supporting clinical decision in diagnostic tasks, such as the study of Paras Lakhani et al. [167] which confirmed that deep CNNs are capable of accurately classifying tuberculosis from chest radiography with an AUC of 0.99, which is undoubtedly impressive.

Acharya et al. [168] proposed a framework for computer-aided diagnosis (CAD) of arrythmia, a cardiovascular disorder affecting mostly ageing people, which is making use of deep CNNs.The main data source for performing diagnostics for arrythmia is the electrocardiogram (ECG) for

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recording and interpreting ECG signals. Due to the ECGs' non-linearity and complexity, a CAD system is proposed by the authors for exempting experts from manual analysis. The CAD system performs objective and accurate assessment of the ECG signals exported. The proposed CNN is used for the detection of different ECG segments. The suggested network is an eleven-layer deep CNN with the output layer consisting of four neurons, each representing a single ECG class. An accuracy, sensitivity and specificity of 92.5%, 98.09% and 93.13% respectively for two seconds of ECG segments was reached.

In a comparable manner, a novel computationally intelligent-based ECG signal classification methodology using a deep CNN was developed by Pourbabaee et al [169]. The focus of study is patient screening and identification of patients with Paroxysmal Atrial Fibrillation (PAF), which is a type of cardiac arrhythmia, though much more dangerous. The proposed architecture uses a large volume of raw ECG time-series data as inputs and attempts to autonomously learn representative structural features of PAF for being exploited by a classification module. Thus, the features are learned directly from the large time domain ECG signals by using a CNN with only one fully connected layer.The experimental outcomes confirm the impact of the learnt features for PAF on patient screening. Through the proposed method, the feature extraction process is simplified to a great extent, corresponding adequately to diverse cardiac arrhythmias. Moreover, the necessity for a human expert intervention for defining critical features working with time-series datasets of large volume.The efficiency and advantages of the proposed deep learning classification machine are demonstrated and quantitative comparisons with an ensemble of conventional machine learning classifiers are also provided in the study.

Burlina et al [170] conducted a study aimed at developing methods for automatic detection of Age-related Macular Degeneration (AMD) from fundus images using a state-of-the-art application of deep learning methods to the automated assessment of these images and at taking full advantage of artificial intelligence remarkable progress in recent years. Deep CNNs trained explicitly for automated AMD grading contradicted an alternative learning method that applied transfer learning and universal features as well as a clinical grader. AMD automated detection was applied to a 2-class classification problem for distinguishing the disease-free from the intermediate or advanced stages. The output of the current deep learning CNN approach regarding accuracy ranged from 88.4% (with a standard deviation of 0.1%) to 91.6% (with a standard deviation of 0.1%).Finally, it was demonstrated that the application of a deep learning-based automated assessment of AMD from fundus images with a CNN acting as a baseline can produce outcomes similar to human levels.

RECURRENT NEURAL NETWORKS

A recurrent neural network (RNN) is a sub-category of artificial neural networks (ANNs) where connections between different nodes from a directed graph along a temporal sequence, allowing for dynamic behavior with respect to time. Unlike the more prevalent feedforward neural networks, RNNs can use their memory to process antecedent sequences of inputs. The term "recurrent" is utilized for referring to two discrete classes of neural networks with almost identical general structure simultaneously, discriminated from each other by the fact that the first is finite impulse

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and the second is infinite impulse. The first sub-category is a directed acyclic graph that can be replaced with a strictly feedforward neural network, while the second is a directed cyclic graph that cannot be unrolled. Both sub-categories present an extra stored state with the storage being directly controllable by the neural network. Another alternative is that the storage be replaced by a network or graph provided it integrates delays or has feedback loops. These controlled states are known as gated state and comprise a part of long short-term networks (LSTMs), which is probably the most historical type of RNNs, as well as gated recurrent units.

A recent survey on the possibilities RNNs in the domain of medical diagnosis was carried out by Zachary et al [171]. EHRs include a wide variety of data ranging from monitoring data coming from sensors to lab test results. Although it is normally expected – and it is a partially valid statement- that the volume and variation of data provide us with useful information, the process demanded for extracting useful knowledge brings about numerous complication that are owed to diverse length, irregular sampling and missing data, as was analyzed in previous sections. Recurrent Neural Networks (RNNs), particularly those using Long Short-Term Memory (LSTM) hidden units, are powerful and increasingly popular models for extracting knowledge from sequential data. They effectively model varying length sequences and represent long range dependencies. The study attempts to empirically evaluate the possible contribution of LSTMs in pattern recognitionof multivariate time series of clinical measurements. A multilabel classification of diagnoses is considered aimed training a model to classify 128 diagnoses given 13 frequently but irregularly sampled clinical measurements. The effectiveness of a simple LSTM network for modeling this type of data, namely clinical measurements, is confirmed at first place. Subsequently, a straightforward and effective training strategy in which targets are constantly reproduced at each sequence step is introduced. Using raw time series as a training dataset, the established models outclassed the majority of the existing state-of-the-art methods currently employed, including a Multilayer Perceptron trained on hand-engineered features.

An additional interesting study oriented mostly towards cognitive modelling was published by Suhara et al [172]. Having noticed the lack of diagnostic criteria for depression, which increase the possibility of signs of depression going unobserved or, worse, ignored, the authors attempted to address the challenge of predicting depressed moods leading to severe types of depression based on self-reported events as the forecast of depressed moods remains unanswered. The centerline of the suggested method employs a recurrent neural network algorithm that incorporates categorical embedding layers for defining depression indicators. Self-declared depressed people were recorded for the purposes of the experiment. Results showed that the method reliably predicts severely depressed attitudes of subjects based on self-reported history, demonstrating higher accuracy compared to other baseline methods such as SVMs. It was also shown that detailed information such as reporting moods in different parts of the day could have an immediate impact on the forecasting process optimization. The 'charisma'of LSTM-RNN to incorporate long-range dependencies of time series assisted the determination of the contribution of distant past histories in the forecast, which was proven to be largely beneficial. Overall, the integration of RNNs in the examined study is considered as the first step toward automatic depression detection.

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Myers et al. suggested a machine learning method to optimize risk stratification after Acute Coronary Syndrome [173]. The accurate and reliable assessment of a subject's risk of adverse events remains an -almost- open question for clinical care. Commonly employed risk metrics have been developed through the utilization of logistic regression models that integrate parameters such as medical history, appearing symptoms and lab outcomes. However, more sophisticated and holistic approaches, characterized of parameterization and the possibility of constant introduction of new risk metrics, are demanded. This would yield classifiers with improved performance. For accomplishing these goals, the utilization of Artificial Neural Networks is a perquisite according to the authors. For the experimental part, two cohorts consisting of patients admitted with a non-ST segment elevation acute coronary syndrome, a RNN was constructed for identifying patients at high risk of cardiovascular death (CVD). The RNN training and testing session were realized using patient data from a cohort consisted of 4395 patients, while the validation was conducted based on an independent set of 861 patients, displaying similar results in both cases. The ANN 1-year Hazard Ratio for CVD was 3.72 with a 95% confidence interval. The novelty of the approach concerns its ability of capturing changesthat are almost negligible in the ST segment over time and are not visible by inspection. The findings of the survey certify the pivotal role RNNs are expected to play in health risk stratification in the forthcoming years.

4.5.2. Health Decision Support Systems

Decision support capabilities of a given system are determined to a significant extent by personal health record (PHR) systems which may assist patients or ageing individuals, and in this specific case the aging office workers, in managing their chronic health conditions [174]. In addition, the importance of integrated PHR systems with electronic health record systems (EHR), aiming at fully supporting improvements in patient health outcomes, has also been emphasized in several studies.The proper function of decision support systems has as a prerequisite the existence and exploitation of efficient predictive tools that will guide the employed decision systems towards the appropriate decision making. The development of this type of tools is very much intensified in recent years due to the increasing needs of handling problems brought about by the chronic conditions analyzed in previous sections, especially among older people. Older people are the most prone cohort of workforce to suffering from chronic diseases, as well as if intensified symptoms potentially due to co-morbidities. Therefore, scientific community presents a growing interest in developing support systems for assisting older people in improving the self-management of their condition, which is also in line with the SmartWork project objectives.

The large volume and variety of data collected in SmartWork imposes the extensive use of various AI methods at different levels (e.g. pre-processing at collection stage, classification at prediction stage, etc.) for the decision making to be made possible on multiple dimensions (e.g. health, work task performance, team pairing, etc.). According to Lee et al [175], there is significant ongoing interest in big data and the role it could play in decision-making systems in interdisciplinary areas of science. By employing a combination of modern artificial intelligence, machine learning and

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statistics techniques, datasets of considerable size and complexity can be 'mined' in a variety of ways to reveal associations and patterns that are not observable neither at first sight nor through standard database management tools or data processing applications. As one could easily perceive, data manipulation in the overall process of development of decision support systems is of paramount importance. In addition to this, the exploitation of AI techniques aiming at the definition of rule sets for guiding the decision making is also extremely important.

Apart from the designated therapies and their application orchestrated by the decision support systems, a factor of utmost importance is that of prevention, especially concerning the early identification of intensification of occurring symptoms. Prevention holds the promise of maintaining good health levels and Quality of Life (QoL) by testing, diagnosing and treating conditions as long as they have not led to advanced symptoms yet, or easing them in case symptoms are already there. Lee et al [176] studied the "lag time to benefit", that is defined as the time between a preventive intervention (when complications and harms are most likely) to the time when improved health outcomes are seen. **A** measure of assessing medical interventions, apart from their different magnitude of benefit, is the differentiation of lag times to benefit, ranging from a couple of months to a fistful of years, especially when it comes to preventive interventions. Numerous standardized measures such as relative risk, odds ratio and absolute risk reduction quantify the magnitude of benefit, while the lag time calculation methodologies are certainly underdeveloped. The importance of this calculation is easy to perceive making the simple hypothesis that life expectancy might be substantially shorter than the lag time to benefit from a given intervention, which makes the administration of a specific therapy rather useless as it only exposes patients to the immediate risks the therapy brings about. In addition, the factors associated with limited life expectancy, such as increased age, comorbidities and functional limitations are strong risk factors for adverse effects, further increasing the chances that prevention would harm rather than help these patients. Furthermore, treatment in older adults also has immediate risks and delayed benefits, which is a prevalent condition especially in chronic asymptomatic diseases. A characteristic example is the treatment for hypertension that can lead rapidly to orthostatic hypertension and falls, but decreased cardiovascular outcomes in later months or even years. Another such instance worth mentioning is the glycemic treatment for diabetes that might cause immediate hypoglycemia, while aiming at a macroscopic prevention of future vascular malfunction. Consequently, given immediate risks and delayed benefits, treatments or interventions should always be assessed with respect to their lag time to benefits. A general approach involves the following stages:

- Estimation of the individual's life expectancy.
- Estimation of the preventive intervention's lag time to benefit.
- In case life expectancy is much greater than lag time to benefit, the intervention is probably recommended. If life expectancy is lesser than lag time to benefit, the intervention is more likely to harm rather than be beneficial for the patient. In case lag time to benefit and life expectancy are roughly equivalent, patient preferences are dominant components in decision making.

Many guidelines use age as the main criterion for recommending preventive interventions, with specific age threshold determined by the average life expectancy for the selected age group. However, age could generate misleading conclusions. Emphasis should be placed on other key components of life expectancy, such as comorbidities or functional limitations. Focusing on age rather than life expectancy can lead to poor prevention and treatment decisions. Upgraded individualized decision making could be accomplished by improving prediction for life expectancy and, subsequently, using mortality indexes that incorporate comorbid conditions and functional status along with age rather than age alone. Furthermore, rule-induction methods are required for optimizing the choice of criteria taken into consideration when assessing possible interventions. These methods would sort the key components from the pivotal to the least important ones according to the rules a rule-induction method can provide.

Unlike the magnitude of benefit, measures of lag time to benefit arerarely reported. A method likely to fulfil this goal demands the reanalysis of original trial data using quantitative methods. In case quantitative meta-analyzed estimates are unavailable, the lag time to benefit could be estimated by reviewing Kaplan-Meier survival curves for the intervention of control groups. The point at which the curves last separate provides a qualitative estimate of the lag time to benefit for a specific intervention.

Another survey, aiming at highlighting the paramount contribution of decision support systems in contemporary clinical health care [177], tried to provide undisputable evidence for the necessity of using DSS to asteadier basis through evaluating the effect of clinical DSS on the corresponding outcomes, health care processes, workload and efficiency, patient satisfaction, cost and on implementation. Investigators extracted data about study design, participant characteristics, interventions, outcomes as well as quality from various scientific publication databases (e.g. MEDLINE, CINAHL, PsycINFO and Web of Science). They independently screened reports to identify randomized trials of electronic CDSSs that were implemented in clinical level used by providers to contribute to decision making at the point of care. They reported clinical, health care process, workload, relationship-centered, economic or provider use outcomes.Results implied that both commercially and locally developed CDSSs are effective at improving health care process measures across diverse settings but evidence for clinical, economic, workload and efficiency could be characterized as sparse. The principal contribution of this review article to the establishment of CDSSs is the demonstration of the considerable benefits CDSSs bring about in real-life situations, except for academic institutions alone.

Fathima et al examines the outcomes of clinical DSSS related to the improvement of diagnosis reliability and ongoing management of chronic diseases focusing on disorders caused by the respiratory system, such as asthma and chronic obstructive pulmonary disease, also known as COPD [178]. This is a review article,just like the previous one, aiming at reviewing in systematic fashion randomized control trials that evaluate the efficiency of computerized CDSSs in care of people suffering from the aforementioned chronic conditions. The majority of considered trials were conducted with patients suffering of asthma.The exploitation of CDSS led to considerable

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improvements in both asthma and COPD care in 74% of cases, while 45% of the examined trials showed upgrades that were characterized more than significant. The survey provides strong evidence for the effectiveness of computerized CDSS in the care of asthma patients and some slight piece of evidence for the outcomes in COPD care. While the practical improvements, such as health care process measures, these systems bring about are more than obvious, its impact on carers' and patients' satisfaction as well as its financial viability, such as user workload and costs of care, are yet to be investigated.

Roshanov et al. attempted to identify the factors that differentiate between effective and unsuccessful approaches in the implementation of computerized CDSSs in terms of upgrades either in the care process or in the impact on patients' condition [179].The authors conducted a meta-regression analysis of randomized controlled trials using data that were extracted from a database of features and effects of these DSSs derived from randomized controlled trials. The main criterion a DSS should fulfil for being 'effective' was to substantially improve primary reported outcomes of care process or patient health. Simple and multiple logistic regression models were employed for testing features for association with system effectiveness with a diversity of sensitivity analyses. The results demonstrated that presented advice in electronic charting or order entry system interfaces were not normally so successful, unlike systems providing advice concurrently for both patients and health practitioners as well as forcing practitioners to supply a reason for over-riding the advice provided, which were assessed as more likely to reach their goals compared to the systems that lacked these features. These outcomes' validity and robustness was confirmed across a variety of statistical methods. It could be stated that the principal conclusion of the study is heavily associated with the fashion the advice is delivered to the ensemble of stakeholders through the decision support system utilized.

Ontology-based health care personalization for chronically ill patients, supported from and collaborated with decision support systems, mostly at clinical care levels, demonstrated to be an effective intervention for these patients [180]. The detailed analysis of the conditions of each patient and the adaptation of evidence-based standard intervention plans to these conditions is considered as an important factor. An ontology encompasses a representation, formal naming and definition of the categories, properties and relations between the concepts, data and entities that substantiate one, more or all domains. Ontologies are one of the most successful ways of representing actionable knowledge in biomedicine with its main advantageous feature being its relatively easy application in the reasoning process performed by medical DSSs. In this sense, this research aims to introduce an ontology for the care of patients suffering from chronic conditions and to implement two personalization processes and a decision support tool for dealing with these conditions. The first personalization process adapts the contents of the ontology to the peculiarities observed in the health history of a given chronically ill patient automatically providing a personalized ontology containing exclusively the clinical information that are useful for the management of the specific patient by the health-care professionals. On the other hand, the second personalization process uses the personalized ontology aiming at automatically transforming intervention plans from general treatment approaches into a more personalized plan for individuals.

The ontology, which is called case profile ontology, is employed as a base to extract knowledge from, which is further imported into a decision support tool that helps health care experts to timely detect abnormalities such as fault diagnoses, comorbidities or related diseases not yet observed, missing information and preventive measures/actions. The overall conclusions about the DSS extracted through the implementation of the study could be summarized in the following statements:

- The set of terms managed by the tool (i.e. ontology classes) is appropriate to support physicians in diagnostic tasks as well as to make possible an adequate description of patients' multiple health conditions
- The classification of diseases allows not only for the confirmation and validation of patient diagnosis, but also for the guidance of physicians on preventing possible future health deterioration risks
- The system integrates the recommendations as new information and this integration is similar, in terms of the steps and information requirements, to the decision made by regular general practitioners

Tinetti et al consider that the most common among chronic conditions experienced by adults is multimorbidity, that is practically the coexistence of multiple chronic diseases [181]. For instance, patients diagnosed with coronary disease usually suffer from other conditions as well (83% of the cases). Almost 75% of people aged 65 years and older are being diagnosed with multiple chronic conditions. However, specialists are responsible for a single disease among the patient's many. The patients subject to multimorbidity could be prone to harm and generally adverse effects of numerous simultaneous treatments rather than being benefited from it. Therefore, the burden coming up from multiple treatments addressed to a variety of diseases is the most widely accepted and well-established challenge of contemporary clinical decision making. To successfully address this challenge provoked by the millions of baby boomers entering their years of declining health, an alignment with the clinical reality of multimorbidity is undoubtedly demanded. Care provision should acquire a patient-oriented character focused on maximizing the health benefits of individual patients with unique sets of priorities instead of a disease-oriented character it presents currently.These designated priorities can transfuse a rule-based inference character in the decision making, which is highly desirable based on the contemporary tendencies observed in the domain. Patient goal-oriented care involves the determination of the individual's health outcome goals, the identification of the components of specific illnesses comprising an obstacle in the accomplishment of these goals and the overall guidance of shared decision making through the incoming data. The National Quality Forum (NQF) recently released its framework for multiple chronic conditions. As proposed by the NQF, the measures for dealing with multimorbidity should focus on activities such as optimizing functions, ascertaining patient-important outcomes and avoiding non-beneficial care. However, modern care process remains disease-centric rather than patient-centered in a vast majority of cases. To encourage appropriate care for patients with multiple conditions, health care delivery innovations need to ensure integration and coordination of novel methods across different

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chronic conditions as well as between clinicians and settings. Otherwise, fragmentation based on individual settings and clinicians will merely be substituted with fragmentation based on a specific disease. The authors of the article also enumerate the pivotal modifications needed to be made in order for a substantial upgrade in clinical decision making to be achieved. The equipment renewal in context of tools employed, such as clinically feasible methodologies for integrating patient priorities in decision making, as well as the appropriate data provision, such as evidenceof harms and benefits of treatments in individuals with multiple chronic conditions, are critical factors towards heading to this direction. For instance, research organizations should generate evidence of a treatment's net benefit or harm within the context of an individual's particular set of risks, coexisting conditions and goals. In case this evidence becomes available to clinicians, point-of-care risk calculators will be required tocompose it so as to determine the best options for each patient. EHR will play a crucial role in the integration of this knowledge that will be exploited for personalized recommendations. This role could be concluded to the statement that EHR need to secure periodic verification of patient-specific goals and cross-disease universal outcomes related to functionality or symptom intensity.

Jung et al. examine the recent rapid progress made in the field of IT convergence technology with respect to their association to the new rules imposed in decision making when it comes to patients suffering from chronic diseases [182]. Despite the fact CDSS rule-based algorithms contribute significantly to decision making when it comes to a single chronic disease, it is yet not possible to for such systems to be equiped with specialized features of each chronic condition and, consequently, a development and suggestion of preventive tactics and guidelines for handling more complex disease is essential. The study suggests evolutionary rule-based induction for decision making through the employment of similarity based associative groups of patients, to establish baseline clinical conditions by exploiting patient-specific information and recommending guidelines corresponding to detailed conditions in CDSS rule-based inference. For the classification of patients, similarity was estimated based on the prevalence of attributes extracted from each patient. Some examples of rules employed, the considered attributes, and their evaluation from the CDSS rule-based algorithm's side, are shown in Figure 38.

Rule	Attributes of chronic disease patients	Conditions
$Rule_1$	BP	[SBP $\leq$120–130 mmHg, DBP 80–89 mmHg: 0]
		[SBP $\geq$140 mmHg, DBP $\geq$90 mmHg: 1]
$Rule_2$	BMI	[BMI < 23: 0], [23 < BMI: 1]
$Rule_3$	Proteinuria	[Negative: 0], [positive: 1]
$Rule_4$	Cholesterol	[Cholesterol < 200: 0], [200 < cholesterol: 1]
$Rule_5$	Smoking	[Non-smoker: 0], [smoker: 1]
$Rule_6$	Blood sugar	[BS < 110: 0], [110 < BS: 1]
$Rule_7$	Exercise	[Yes: 0], [no: 1]
$Rule_8$	Drinking	[No: 0], [yes: 1]

FIGURE 38 EXAMPLES OF RULES FOR A MULTI-CONDITION DSS SYSTEM (FROM YOUNG ET AL, 2015)

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Similar vectors were classified in the same category through the assessment of the degree of similarity among patients. The assessment was made using similarity coefficient. Rule-based inference is an artificial intelligence structure mainly used in CDSS to apply clinical knowledge in the actual diagnosis. Guidelines addressed to chronic patients brought about through DSS utilization can be re-established every now and then based on the ever-changing environmental conditions using the data provided by this cohort suffering from a heterogeneous ensemble of diseases.Instead of temporary recommendations, continuous feedbacks are preferable by a wide margin.

Apart from CDSS, self-management techniques have begun to play an extremely important role in health care overall process in recent years. In contrast to treatment-oriented medical services, it is the chronic diseases' inherent peculiarities that impose constant monitoring as well as the provision of behavior-based self-management. A characteristic example is the diabetes self-management model utilized in US primary care settings. This model was analyzed in detail by by Stellefson et al [183], who tried to establish the application to the Chronic Care Model (CCM) in US primary care settings, to provide care for people suffering from diabets and to describe outcomes of CCM implementation. The CCM adopts a philosophy towards reconstructing health care that is characterized of strong established connections between medical care provision systems and communities. 16 studies of heterogeneous structural design were considered, including 9 randomized controlled trials, as well as heterogeneous ensemble of settings, including academic-affiliated primary care approaches. The paper provides evidence that CCM approaches have been effective concerning diabetes management in US primary care settings. Disease registries and electronic medical records were exploited for the establishment of patient-centered goals, the monitoring of patients' condition and the timely identification of flaws in health care. Results showed that primary care physicians office–based diabetes self-management education improved patient outcomes.The outcomes reported were exclusively positive, backing the claim that CCM-based interventions are generally effective for managing diabetes. Despite the incapability of a single component of the CCM to be determinant for the health care process, it became apparent from the results that the incorporation of a diversity of components simultaneously in the same intervention can facilitate the CCM implementation to a great extent(e.g. using the decision-support component to train providers onguidelines). Another tactic adopted for efficiently handling diabetes was the modification of staff roles and the assignment of renewed responsibilities, which produced clinical benefits. It also became obvious from the results that the reorganization of careis essential for the design of more effective training programs aiming at assisting self-management on the patients' behalf. The review is very supportive concerning diabetes self-management education (DSME) and its assessed outcomes, as it is believed to be pivotal for learning about proactive diabetes self-care practices and self-management skills. Focusing on older populations of chronic disease patients, which is the focal interest in Smart Work project, the reviewers point out the importance of training programs on the exploitation of ICT for self-management purposes. The expected outcomes from this familiarization process include the reduction of anxiety and barriers to

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access that currently exist. The significant impacts of prevention efforts, social determinants of health as well as reinforced community participation are highlighted as principal components of chronic disease care. The review could be concluded in the statement that CCM's success in diabetes management is mostly owed to positive clinical outcomes, while its process outcomes, namely self-efficacy for disease management and clinical decision making, which are considered noticeable contributors concerning functional and clinical improvements, demand further assessments.

Self-management is being increasingly considered in healthcare, especially through smartphone interventions for long-term health management purposes. A recent review study shows that smartphone interventions can aid chronic condition management, thus the applications being overall beneficial for patients suffering from chronic diseases [184]. The interventions included in the review were found in five scientific publication databases and the main criteria of inclusion was that the application was exclusively developed for chronic conditions. Another inclusion criterion was the existence of outcome measures for the assessment of the intervention's impact. The survey highlights the importance of e-health as a tool for healthcare systems, as it transmits the right information from audience to audience timely and in the best ways to guide healthcare. A subdomain of e-Health is called m-Health and is practically a medical practice supported by mobile devices, such as smartphones, patient monitoring devices or personal digital assistants. The m-Health interventions considered in this review study involved communication between patients and health care providers, communication between health care professionals, health monitoring and access to information for healthcare professionals at the point of care. Mobile technologies contribute largely in the improvement of patients' health in real time, leading them to personalization of health care provision as well as to efficient progress monitoring. Real-time monitoring system improved classification accuracy and facilitated tracking of chronic patientsin most cases. In some cases, the interventions involving use of mobile phones that were evaluated seemed to strongly support telemedicine and remote health care, mostly in developing countries. This type of interventions has begun to be integrated into clinical practice for exploring the possibilities it provides health practitioners with, mostly aiming at upgraded patient-centered management of common chronic diseases. The review's focus was on evaluating effectively and in detail the outcomes of the interventions as well as the possible margins for future optimizations. Results demonstrated that smartphone interventions for long-term health management of people in chronic diseases have been effective in more than 90% of the total cases based on the primary outcomes. However, it is necessary to mention that there were no desired and expected impacts in all parameters considered. More specifically, 16 studies on chronic conditions were included in the study with the illnesses considered being diabetes, mental health problems, obesity, cancer and COPD. The only study that did not bring about significant results was the study of depression, which was totally expected. The rest of the studies proved to be truly effective in symptoms' monitoring, patients' support as well as in the management of chronic illnesses. Regarding treatment and daily activity management, 5 studies in this review focused on the specific requirements to help diabetes patients manage blood glucose, insulin dose adjustment and dietary intake. 3 studies in this review focused on the daily activities of overweight patients to assist them in calorie management, fat intake and physical activities. 1 study focused on exercise for patients with COPD to increase their endurance walking at home and inspiratory capacity. One important finding is that participanting patients declared themselves as feeling secure due to the close monitoring of their condition. They also felt that they had not been forgotten by their doctors and were treated efficiently at home, which had as a result a significant upgrade in their self-management efficiency.

Another study focusing on the impact of m-Health type interventions on people suffering from cardiovascular diseases was conducted by Gandapur et al [185]. The aim of this study was to review the role of mobile health (mHealth) tools for raising medication adherence in patients with cardiovascular diseases. mHealth is considered asa means for delivering healthcare in an automated, personalized, andcost-efficient manner by researchers.The randomized controlled trials selected for the review involved patients suffering from hypertension, coronary artery disease, heart failure, peripheral arterial disease and stroke. Data on the types of mHealth tools, preferences of patients and health care providers as well as the effect of the mHealth interventions on medication adherence were extracted and reviewed for the purposes of the survey. The mHealth tools under examination included text messages, Bluetooth-enabled electronic pill boxes, online messaging platforms and interactive voice calls and were assessed as preferable compared to other types of interventions. 10 complete studies were considered in the review process with all 10 of them improving medication adherence. The magnitude of the impact differed from study to study and from one time period to another, as expected. Characteristic examples of the considered interventions involved the following:

- Daily SMS reminders for aspirin adherence with positive feedback from the perceived increase of adherence from the patients' behalf (patients with Acute Coronary Syndrome)
- Interactive voice recognition phone calls (IVR) at one hand and IVR-enhanced (IVR+) phone calls, letters, EMR-feedback and mailed material at the other hand, for participants suffering from CVD and type2 diabetes and their medication adherence evaluated as suboptimal
- SMS and Micro Letter in arm 1 and 2 respectively for patients with coronary artery disease confirmed by CT or angiography
- Automated daily text messaging for 2 weeks, alternate days for 2 weeks, then weekly with the goal to assess patients' adherence vs. Control (no text) for patients with prescribed blood pressure

The overall conclusion of the review study is that mobile technology has the undisputable potential to upgrade health care by making it faster, cheaper and more accessible as well as raise the quality of the provided care. The results of mHealth concerning the attempt to improve medical adherence

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was promising, thus confirm its potential in becoming even more effective through ubiquitous monitoring and real-time analysis of health data.

4.6. Conclusion

A large number of AI methods and approaches are currently employed in assistive ICT systems to implement automation capabilities with respect to knowledge extraction and intelligent reasoning, enabling the systems to be capable of helping and supporting the end-users in different real-life problems. These systems must be able to interface several different sensors, which generate large volumes of raw data that needs to be robustly and efficiently collected, trasmitted and stored for further processing. Furthermore, the system must be capable of "learning", with a high degree of probability, and must be able to perform the learned actions autonomously in order to obtain information more relevant for the designed application. The low-level processing to be employed in SmartWork targets at solving various challenges to ensure robustness and efficiency in pervasive and ubiquitous data collection, making use of sensor embedded processing capabilities (e.g. as described in section **Error! Reference source not found.**) and edge processing, along with advancend techniques for features extractions and missing data completion techniques.

SmartWork functional modelling approach should combine various approaches in order to capture short- and long-term office worker characteristics, both at individual and group level. More specifically, generic models representing groups of users, will be generated and updated to take into account the long-term changes of the the specific groups. Individual models will capture short-term and long-term changes of a particular office worker on various dimensions (e.g. specific chronic condition, lifestyle attitudes, etc.), to support personalized prediction and decision support on these dimensions. Data collection for the update of these models should involve both explicit (e.g. questionnaires) and implicit information acquisition. Dynamic adaptation of models to the evolving conditions will be performed automatically, with the short-term individual user model being updated in real-time (per event), while the long-term update of individual and group models beeing regularly scheduled.

With respect to cognitive capacity modelling, which network architectures and learning techniques are most suitable for cognitive state estimation depends on what sensor data is available, how the sensor data are represented, and how the task can be framed. For (temporal) pattern detection within a sliding window, CNNs can be applied. For temporal sequence learning on row data, RNN or LSTM are better suited. In addition to these decisions, practical problems in connection with streaming data and real-time, online learning need to be addressed. There is to date no cognitive architecture that can be used off-the-shelf for cognitive state estimation based on biosensor data. For this task, an integrated architecture would be needed including perceptual-motor actions, executive control, and multiple memory systems. Model-based cognitive state estimation requires a complex learning scheme, including learning techniques for state extraction from the underlying cognitive model. Partly for this reason, it is important to investigate if a simpler approach would be feasible. In other words, it would be interesting to compare model-free and model-based approaches in terms of how well they can estimate the user's cognitive state.

When it comes to pattern recognition (classification) and prediction, depending on the desired application, there are several other AI techniques that can be implemented in an intelligent system, some of them having evolved to the point of offering real practical advantages in several different areas like Expert Systems, Natural Language Processing, Speech Understanding, Robotics and Sensory Systems, Computer Vision and Scene Recognition, Intelligent Computer Aided Instruction and Neural Computing. Several works compare different classification techniques, leading to different conclusions in distinct application domains. It is generally accepted in the literature that a decision on the classification algorithm hugely depends on the properties of the specific problem to tackle. The most widely used data fusion methods originate in the fields of statistics, estimation and control. The application of these methods in human state prediction from multiple sources of sensor data has different number of features and challenges. Assuming the availability of user historical data and common interval of parameters which are deemed as usual for each different individual, human expertise judgment beforehand can be leveraged to model relevant prior data, and consequently have an important impact on the inference process. For example, in the case of SmartWork we intend to apply Bayesian models to extract the user emotional indicators during the development of the mouse intelligent software.

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5. Accessible Interaction Interfaces

The world's population is ageing. According to data from World Population Prospects: the 2017 revision, the number of older persons - those aged 60 years or over - is expected to more than double by 2050 and more than triple by 2100. In addition to population ageing, demographic projections point to a rapid ageing of the European workforce. According to data from the European Labor Force Survey, 55+ workers are currently 16% of the total in the EU, a percentage that is expected to increase in the next years.

In 2011, the European Labour Force Survey (LFS) defined disability in employment as the one that limits people in the work they can do (and not in other areas of life) due to a long-standing health problem and/or a basic activity difficulty (i.e. difficulty in seeing, hearing, walking or communicating). According to this survey, in 2011 some 35 million people aged 15-64 (11%) in the EU-28 reported a disability in employment. Figure 35 presents the prevalence of basic activity difficulties or disability, by sex and age, EU, 2011 and 2012 (%). Figure 35 provides the following main findings: (1) women report a higher number of disabilities than men; (2) in all ages and genres, people with a disability and people who have a basic activity difficulty are greater in number than people that report a working disability; and (3) the percentage of people suffering a disability increases dramatically for users older than 45 years old.

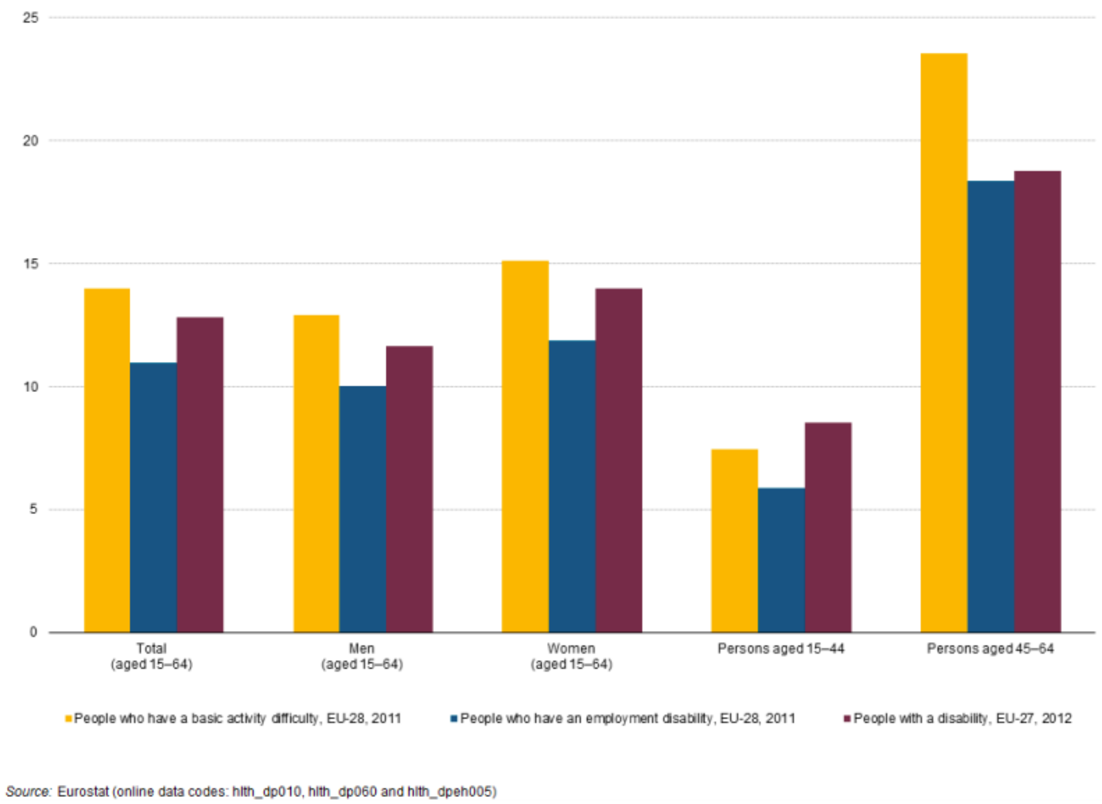

FIGURE 39 DISABILITY AT WORK BY GENDER AND AGE

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Therefore, the accessibility and usability of the ICT systems used in the workplace is a factor of paramount importance to ensure the inclusion of older workers. Standard ISO TC 159 defines accessibility as the "extent to which products, systems, services, environments and facilities can be used by people from a population with the widest range of characteristics and capabilities to achieve a specified goal in a specified context of use". Whereas accessibility focuses on people with disabilities, younger and older workers without a disability or with a temporary disability might also benefit from the use of accessible ICT systems. As stated by the W3C, people with age-related functional limitations, that they may not identify as "disability", may also benefit with the use of accessible systems. However, accessibility focuses on disability and does not try to address broader issues. Approaches such as Universal Design, Universal Usability or Inclusive Design tackle the goal of designing accessible systems while ensuring good usability of the systems.

5.1. Designing Accessible Systems

Universal Design[50] has been defined as "the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design".

Universal Design is guided by the following principles:

- Equitable Use
- Flexibility in Use
- Simple and Intuitive Use
- Perceptible Information
- Tolerance for Error
- Low Physical Effort
- Size and Space for Approach and use

The Principles of Universal Design address not only the needs of people not ordinarily addressed but also mainstream users as well. As the name implies, Universal Design means taking the needs of all users into consideration. It is important to note that there are no universal designs. That is, there are no designs that everyone can use. Universal Design is not an outcome but a process of including everyone's needs when designing a product. It is never possible to meet them all - but all would be considered and all of those that can be practically addressed would be addressed. The Principles offer designers guidance to better integrate features that meet the needs of as many users as possible, and have been the basis to develop several guidelines, heuristics and standards.

[50] https://projects.ncsu.edu/ncsu/design/cud/about_ud/udprinciplestext.htm

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However, considering the needs of all users poses several challenges. Authors like Huh et al have pointed out that one of the main problems of "Universal Design" or "Designing for All" is that extreme users (the tails of the tails) tend to be easily ignored due to their small number of simply because their existence is not always known. On the other hand, designing for specific users or situations might deal better with extreme users but usually at the expense of compromised universality/globality [186].

Since it is not possible to create one universal design for all, personalizable user interfaces can increase the range of people who can use an interface. Designing products so that they have flexible interfaces including different interface options can allow the product to be personalized and offer more optimal levels of usability and accessibility for diverse users and context conditions.

Self-adaptive user interfaces also provide flexible interface elements but combine then with algorithms that try to deduce the best setting for an individual and make the adjustments automatically. A simple example is phones or tablets that automatically adjust their screen brightness based on ambient lighting conditions. This approach can be convenient when correct but it can pose significant challenges in terms of usability, consistency and acceptability if it sometimes changes the interface in ways that are counterproductive or disruptive and the user is not able to control it. Therefore, it is of paramount importance to ensure that users can control the types and activation of the adaptations, by providing users with the ability to customize both user interfaces and their automatic adaptation capabilities.

5.2. Personalized user interfaces

There are two main approaches to personalization:

1. **Self-adaptive interfaces** dynamically adjust the interface in a way that is intended to support the user. In this case, personalization is carried out by the system without intervention of the user.
2. **Adaptable** or **Personalizable** interfaces provide customization mechanisms but rely on the user to do the adaptation.

Personalization of the user interface aims to provide:

1. Personalization of **presentation,** that includes graphical aspects such as the size of the text, the use of different colour schemes, etc.
2. Personalization of **structure**, that includes aspects such as the input and output modalities, adaptive navigation support, blocks of widgets displayed at a time, etc.
3. Personalization of **operation,** that includes the types of widgets used, and the actions of the user needed to operate them - for example by keyboard or mouse, click, double click or triple click, click while holding down a key etc.
4. Personalization of **content**, using for instance simplified content for users with cognitive problems, inclusion of captions for videos or audio, etc.

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Personalization of the User Interface can be used to adjust for several different factors or contexts of use. All can be important to optimal operation of the device, and for some people/situations all may be necessary for effective operation. Key factors or contexts of use include:

- **User**. The UI needs to be adapted to the needs and preferences of the user, which may depend on their capabilities or current physical condition. These may also change over the course of the day, when fatigued, when in different seating positions, and in different environments or when carrying out different tasks.
- **Environment**, which includes both extraneous (i.e. noisy environments, lighting conditions, etc.) or intrinsic (i.e. location - meaning whether the user is at home or at the office -, etc.)
- **Runtime platform**, including hardware (i.e. size and resolution of the screen, connectivity, input modalities, etc.) and software (i.e. to check the available accessibility solutions).
- **Task**. which may call upon the user to carry out different types, or amounts of activity or to carry them out under different time or other constraints. Turning off the house alarm for example requires both total accuracy and completion within a time limit, while logging on to a computer allows correction and can be done slowly.

Different projects have tackled the creation of user interfaces. The project AALuis[51] focuses on solutions in the domain of Ambient Assisted Living (AAL), providing an open middleware layer that allows to generate accessible and usable user interfaces for different types of services. It covers the service integration, the user interface generation and the user interface rendering. MyUI[52] generates individualized user interfaces and performs adaptations for diverse user needs, devices and environmental conditions during runtime. MyUI has addressed the provision of individualized user interfaces which are accessible to a broad range of users by the collection of information about the user during the interaction and updating the user profile accordingly. SUPPLE automatically generates concrete user interfaces from declarative models that specify what types of information need to be exchanged between the application and the user (Gajos, Weld, & Wobbrock, 2010). The Universal Control Hub (UCH)[53] implements the Universal Remote Controller (URC) technology in order to connect a set of controllers (i.e. a mobile device) and a set of targets (i.e. a smart TV), allowing the user to select between a list of remote user interfaces. User interfaces are then built from a list of resources that are available in the openURC development server.

Finally, the Cloud4all and Prosperity4All EU projects worked on developing the three pillars of the Global Public Inclusive Infrastructure (GPII), the Unified Listing, the DeveloperSpace (which included

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[51] http://www.aal-europe.eu/projects/aaluis/
[52] http://www.myui.eu/
[53] ISO/IEC, ISO/IEC 24752-1:2014, Information technology –user interfaces – universal remote console, Part 1: Generalframework, 2014

componentization of some of the technologies from the above projects) and auto-personalization of user interfaces. This latter pilar (auto-personalization) provides an infrastructure for the automatic adaptation of the presentation, structure and content of different user interfaces based on a shared personal preference set, which encompasses parameters for user interface parametrization and their preferred values for a specific user.

Some of these projects have adopted an approach named Model-driven engineering (MDE), which is characterized by a raised abstraction tactic via separation of concerns throughout all the phases of software engineering. The World Wide Web Consortium (W3C) charted the Model-Based UI Working Group (MBUI-WG, currently closed)[54] as part of its Ubiquitous Web Activity (UWA) to investigate the standardization of context-aware user interface authoring. Its goal is to work on standards that enable the authoring of context-aware user interfaces for web applications. The CAMELEON Reference Framework (CRF)[55] defines an important foundation for this type of approaches. CRF provides a unified framework for model-based and model-driven development of user interfaces.

The framework specifies a context-sensitive user interface development process, driven by an intrinsic notion of the current user context, the environment context, as well as the platform context. According to the CRF approach, an application's user interface development consists of multiple levels of abstraction. Starting from an abstract representation of the interface's task and domain model, a PSM of the user interface is subsequently generated by means of a chained model transformation based on contextual knowledge.

The CRF is an established reference architecture for model-based development of user interfaces and consists of four different layers (see figure below).

[54] https://www.w3.org/2011/01/mbui-wg-charter
[55] https://www.w3.org/community/uad/wiki/Cameleon_Reference_Framework

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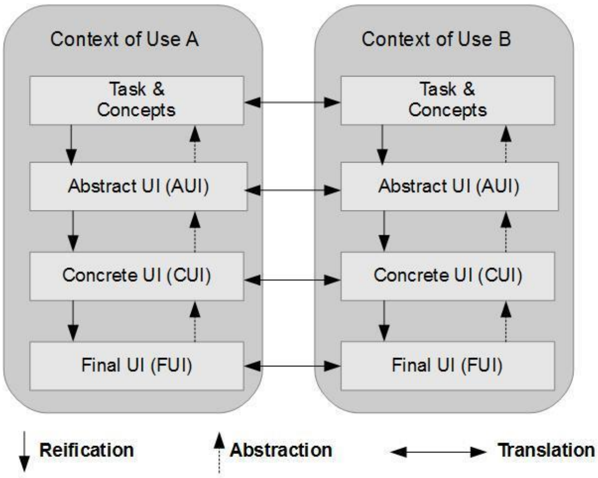

FIGURE 40: CAMELEON REFERENCE FRAMEWORK

Moreover, the World Wide Web Consortium (W3C) charted the Model-Based UI Working Group (MBUI-WG) as part of its Ubiquitous Web Activity (UWA) to investigate the standardization of context aware user interface authoring [187]. Its goal is to work on standards that enable the authoring of context-aware user interfaces for web applications. The MBUI-WG aims to achieve this type of adaptivity by means of a model-driven design approach. In this context, the semantically structured aspects of HTML5 will be used as key delivery platform for the applications' adaptive user interface.

To summarize, adaptation of interfaces is critical to products and systems being able to accommodate the variety of individuals who must use them in the variety of contexts of use they will encounter. The ability to adapt must be built into the interfaces from the beginning wherever possible, for best effect and to make it widely available. Many of the design approaches discussed above can be used in this scope, by broadening the users considered and providing flexible adaptable interfaces to address them.

For those users where the base design of the product cannot be flexible enough to cover their needs (e.g. someone who needs a braille display), information and control can be exported to them (e.g. URC) or adaptive assistive technologies can try to attach themselves to the innards of the product and provide an alternative interface. Where assistive technologies are required, Install on Demand (IoD) can be used to bring the assistive technologies to the computer under question and install it.

Once interfaces are designed to be adaptable (and any assistive technologies are installed where necessary) there are two approaches to adaptation to meet the needs of the particular user: manual adaptation by the user or clinician or assistant and self-adaptation. Both have drawbacks by themselves. If the adaptation needs to change by context of use, then adaptations by others

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(clinicians, families, assistants) will not work. This also does not work for individuals using shared computers where the settings must be returned to default values after each use. Self-adapting interfaces are helpful only if they are always correct (or near-correct) and where the changes they make are not disruptive or confusing.

Auto-personalization based on user preferences can be used to instantly configure a computer (and any assistive technologies) to each user needs. Since different preference sets can be stored for different contexts of use - this type of auto-personalization can accommodate a wide variety of contexts of use. It can also allow those users who cannot set up computers themselves for different contexts- of-use to be able to have help with configurations but then chose themselves the ones that work best for them. Auto-personalization can also be used to turn on, turn off, or adjust self-adaptive functions in the interface to meet individual users needs and preferences. Finally, auto-personalization can automatically return shared computers to their original settings.

5.3. Conclusion

This section provides a brief glimpse on the importance of accessibility and usability in order to ensure the inclusion of all users, and more specifically in the case of this project the inclusion of older workers, as well as an overview of efforts to date to address this. Although the various approaches to universal design or design-for-all are great for developing flexible user interfaces that can be adapted or adjusted to a wider variety of l workers and contexts of use, they do not by themselves directly or fully address the need to change the actual interface for different contexts of use -- or to adjust and restore the interface on shared computers. The GPII therefore provides the needed complementary functionality. Whereas the GPII auto-personalization does not itself provide an interface adaptivity or assistive technology functionality, it does provide automatic personalization of the interfaces for computer software that will be developed and used in the different services developed within SmartWork, specifically the ubiWork Service, aiming at supporting on-the-fly work flexibility through an ubiquitous computer work environment. Furthermore, the Install on Demand (IoD) infrastructure will be used to build the AnyWhere Delivery system for seamless transfer of, work materials and computer working environment settings (including on-need software and assistive technology install/uninstall), without any effort from the side of the office worker.

6. Work Flexibility Tools

This section aims at giving a summarized overview of the characteristics of work management tools (also known and referred to as project management tools, team collaboration tools or task management tools), as well as describe briefly the most prominent tools available out on the market. Furthermore, work task modelling aspects have been analysed in order to give us a wider perspective on how to model tasks related to work management and decision making. All of the above act as guiding background notes and provide an insight on the **digiTeam Service,** which is one of the main services that will be developed within SmartWork.

6.1. Work Management Tools

One of the core services that will be offered through SmartWork is addressing the provision of flexible working practices and smart work-management capabilities through a set of tools that will enable "on-the-fly" job sharing, job rotation, shifting work, daily work schedule adjustment and on-need extra leave. The aim is to build a Work Flexibility Management Module for the efficient coordination of individual office workers and optimal collaboration and team work.

Having this in mind, the number of automated work management tools (also known and referred to as project management tools, team collaboration tools or task management tools) available in the market is increasing rapidly. With significant evolution of these tools, many project managers have started using various software project management tools to manage and support their project activities. These tools are mainly used in planning, monitoring and controlling projects.

Digital project management tools have been around for a long time, but the technological development has steadily accelerated[56]. New forms of project management methodologies have also evolved while new technologies and the internet have dramatically reduced the threshold (and cost) of collaborating efficiently and effectively in complex and remote based teams. And of course, social media have also influenced the development. Today there are uncountable amounts of alternatives to choose from - ranging from extensive and expensive systems to lightweight and free apps.

Nevertheless, it is evident that the trends currently employed by many enterprises nowadays focus on online digital collaboration and project management tools either concentrated on the Agile methodology or technically based on Software-As-A-Services (SaaS) approach.

[56] http://www.wenell.se/wp-content/uploads/2018/10/digital-project-management-tools-rev-1.1

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6.1.1. Characteristics of Work Management Tools

There are a lot of features and criteria used to define and compare the work management tools. Most can be considered as important when performing such a comparison study, but we have mostly focused on the elements and characteristics that are relevant to the Agile methodology approach, which is also the main focus within SmartWork. These characteristics can be summarized as follows:

- **Integration Aspects:** In the context of a team for a large sized project, where team members can be distributed in several remote geographical areas, and customers can also be in different locations, and the flow of information exchanged between all entities involved is quite significant, integration becomes a fundamental element for a good collaboration. This may come in the form of integration with the internal communication system that company owns or another external solution, such as Skype for Business, etc. In particular for SmartWork, integration is a key and fundamental characteristic since we aim for a solution that can be seamlessly integrated with the platform developed within the project.
- **Platform Availability:** Another important element to be considered, is the ability of the tool to be available on multiple platforms like desktop, web and mobile, offering primarily flexibility and on the other hand, the possibility of integration with the cloud for storing large data and even remote collaborative work. Obviously, apart from the diverse platform availability, the number of mobile platforms that each tool has been developed for, is also an important sub-criterion i.e. iOS, Android and Windows.
- **User Stories:** This characteristic of these tools is one of the closest principles to the Agile Methodology approach. It may seem very informal and unstructured data format but it is the element that encourages all entities participating in the development process to express themselves freely, to be transparent in recognizing the problems, the solutions and the achievements. User stories are short, simple and describe in natural language the perspective of a person (user or customer) about a subject from the project, it can be a software capability or anything else.
- **Training:** This feature is closely related to the user stories mentioned above but also an important aspect with respect to the services proposed by SmartWork. Thus, for any tool to be adopted successfully by the members of a working group, certain training and learning activities need to be addressed where participants can learn and understand the functionality of the tools and how these can be used to improve their activity and the company productiveness. A successful training and learning approach take into consideration: access to documents, tutorials, webinars, time and cost of support when submitting requests, etc.
- **Task Management:** Last but not least, another critical characteristic that distinguishes these tools is the effort that eventually is required to complete the project alongside the availability of the accompanied information that must be based on transparency, so that at any given time, any participant in the development and management process, either the developer or a client,

has the ability to access this information. Due to the constantly adapting and evolving state of projects, these tools must provide automated schedulers that can send notifications about the progress of the project, deadliness and other factors involved in order to keep the stakeholders informed in all the stages of the product development cycle. Also, this feature helps the team to better organize their resources, maintain the expected cost of the project and even plan their free time depending on how the work progresses.

6.1.2. A Distinctive Selection

The increasing rate of ICT is growing and the number of tools intended for implementation of the Agile methodology is rising exponentially. Various task and project management applications and tools are employed to support team collaboration, for example, tools for knowledge management, coordination, information exchange, communication, shared authoring or co-creation and collaborative learning [188]. This section examines some well-known software tools that support various purposes for task and project management, and which are frequently used by companies operating in various domains for managing their Agile projects.

Most of the tools mentioned below, feature a detailed and comprehensive API interface for integrating to local or custom applications, therefore utilizing the capabilities offered by these tools. In certain cases, applications can also be developed for the internal deployment within these tools i.e. Slack.

6.1.2.1. Trello

Trello (https://trello.com/) is a visual online project and task management tool that provides many features for collaborative use, such as notifications, calendars, comments, file attachments and so on. Either for individual use or for teams, users can create check lists, add labels and due dates, invite people to join tasks, and connect with other applications, including Google Drive, Dropbox, Boxand OneDrive. Trello works in real time and is synchronized across devices, with apps for different mobile devices. Some advanced features include power-ups, calendar, voting and cardaging.

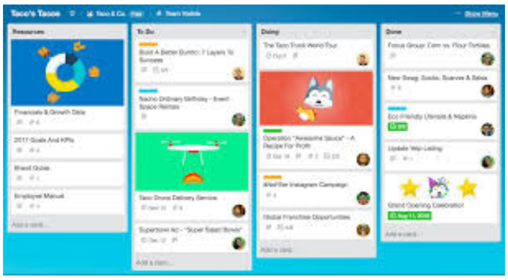

FIGURE 41 TRELLO ONLINE PROJECT AND TASK MANAGEMENT TOOL

Trello uses a method called Kanban, a project management system which allows users to move cards— representative of tasks—to create a visual representation of where a project is in development. It supports iPhone, Android and Windows 8 mobile platforms, however, its website has been designed to be accessible on most mobile web browsers. It added support for an unlimited number of tags, in the form of coloured labels that can be renamed and new ones created. Cards accept comments, attachments, notes, due dates, and checklists.

Trello provides a simple RESTful web API where each type of resource (e.g. a card, a board, or a member) has a URI that you can interact with.

6.1.2.2. Slack

Slack (https://slack.com/) is a cloud-based collaboration tool for team communication that provides an open channel to organize team conversations for a project, a topic or a team. It provides a transparent view of teamwork, as well as a private channel for sensitive information. Slack includes features such as direct messages, file sharing, comments, stars for later reference, connection and synchronization with other services (e.g. GoogleDrive, Dropbox or Box), integration with other software tools, notifications and more. All files are also automatically archived and synchronized across different devices.

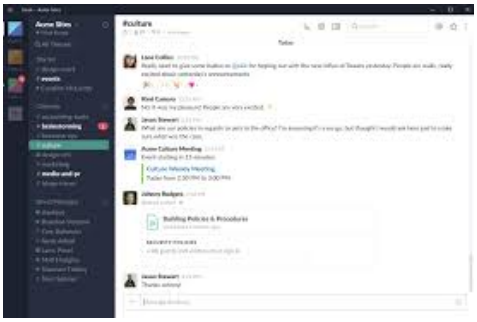

FIGURE 42 SLACK CLOUD-BASED COLLABORATION TOOL

6.1.2.3. Asana

Asana (https://asana.com/) is a personal task and project management tool with features such as tasks, projects, conversations and dashboards. It offers a quick progress view of projects at a glance without scheduling meetings and selected team updates. Some features of the tool are task and project creation, setup due dates and times, attachments and more. Advanced features include "hearts" to encourage participation in an activity, task and project conversations, a searchable archive of files, calendars, dash boards for checking progress on all projects, an inbox for automatic updates, team management features with task assignees, followers and guests, integration with other software tools (e.g. Dropbox, Slack, Chrome, GitHub, Google Drive) and more.

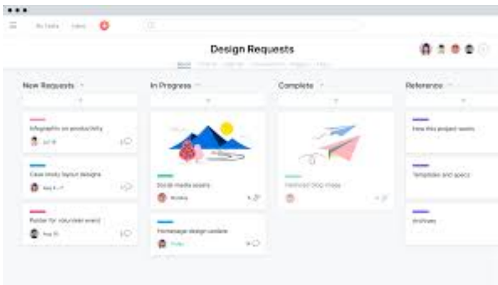

FIGURE 43 ASANA PERSONAL TASK AND PROJECT MANAGEMENT TOOL

Asana is an intuitive task management system that works best for teams seeking real-time interaction. Asana allows its users to visualize their goals, track their time, assign priority to their tasks, and get updates on the project right in the program. It also has a calendar function to graph the team's tasks right onto the dashboard. It is added an Android app, the ability to convert a task to a project, conversations, and dashboards.

In terms of integration, the Asana API is a RESTful interface, allowing you to programmatically update and access much of your data on the platform. It provides predictable URLs for accessing resources, and uses built-in HTTP features to receive commands and return responses. This makes it easy to communicate with from a wide variety of environments, from command-line utilities to browser plugins to native applications.

6.1.2.4. Todoist

Todoist (https://todoist.com/) is a task manager for personal or collaborative productivity in managing to-do lists from different devices. It supports functions such as setting up and managing tasks, projects and teams, either online or offline, across many different platforms. This tool supports collaboration on shared tasks and goals in real time and customizes the user experience. Some of its features are notifications, real-time data synchronization, visualization of productivity, comments, labels and filters.

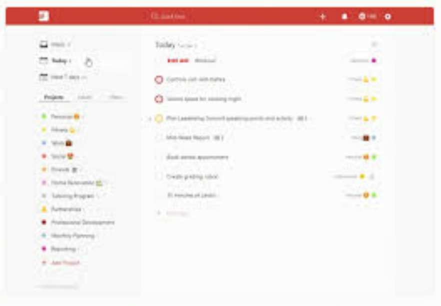

FIGURE 44 TODOIST TASK MANAGER

6.1.2.5. Teamwork

Teamwork (https://www.teamwork.com/) is an online project management platform that supports features such as time logs to keep track of work hours per project task and team member, milestones, tasks view, the ability to quickly reassign all tasks from one person to another and more. Other software tools for collaborative use – such as Dropbox and Google Docs for file sharing and Skype and Google Hangouts for communication – are also employed for project and task management.

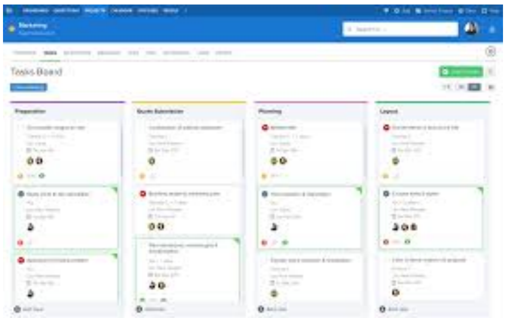

FIGURE 45 TEAMWORK PROJECT MANAGEMENT PLATFORM

6.1.2.6. Atlassian JIRA

JIRA (https://www.atlassian.com/software/jira) is an issue tracking system developed by Atlassian Corporation starting in 2002 [189]. It is most commonly used for software bug tracking, but thanks to its advanced customization features, is highly suitable for other types of ticketing systems (work orders, help desks, etc.), and project management. Emerging from the software industry, Atlassian JIRA is a generic work item tracker ("work items" which JIRA calls "issues") which is widely used for tracking software bugs and tasks and is also commonly used for Agile projects. JIRA has nonetheless a high level of configurability, which allow

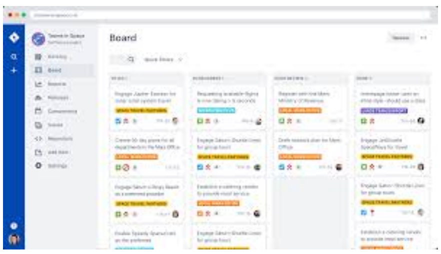

FIGURE 46 JIRA ISSUE TRACKING SYSTEM

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administrators to create legitimately all types of work items. Consequently, created work items can be requirement objects of all kinds (e.g. System Requirements, Software Requirements, or simply Requirements). All work items have a predefined set of data fields (properties or attributes), which are common to all tracked items, such as status, priority, version, etc. These properties are also configurable, and can be altered or complemented with new custom fields which can be specifically dedicated to requirements. For instance, we may want to characterize requirements with a Requirement Type, a Mode of Operation, a Source, a development Phase, a Component, a Sub-System, and so on.

6.1.2.7. Taiga

Taiga (https://taiga.io) is a project management platform for agile developers, designers and project teams, offering visual tools for management of SCRUM based projects. Taiga is an open source project management platform in beta for startups, agile developers, and designers. Taiga is a tool that aims to solve the basic problem of software usability. Designed with this sole aim, the developers claim it's beautiful to look at all day long. With a focus on agile development, Taiga has all of the required features such as a backlog, Kanban, tasks, sprints, and issues. Taiga is open source under the GNU Affero GPLv3 and available on GitHub.

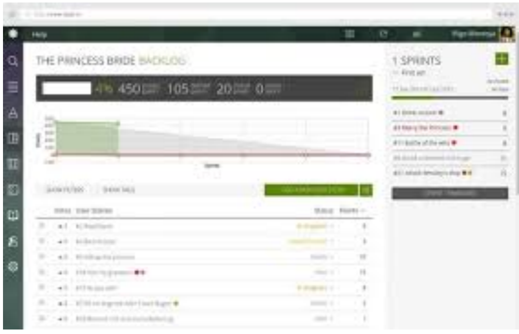

FIGURE 47 TAIGA PROJECT MANAGEMENT PLATFORM

6.1.2.8. Version One

VersionOne (https://www.versionone.com) is one of the more popular agile management tools, with a distinctive "tab" environment, and with different pages for different Scrum-driven ceremonies from product planning to sprint review. The user interface has a lot of components, so familiarization is clearly needed to fully take advantage of the features. Backlog creation, task management and other basic agile planning does not seem to lack any important features. There are also customization possibilities and traditional management features, such as forecasting.

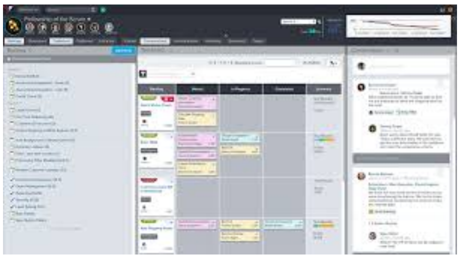

FIGURE 48 VERSION ONE AGILE MANAGEMENT TOOL

6.1.2.9. Assembla

Assembla (https://www.assembla.com/) specializes in providing Agile, online project collaboration solutions for distributed teams, with an emphasis on task management and issue tracking. The product itself is all about driving continuous delivery with a robust, but intuitive set of Agile tools: Kanban, testing workflows, task management, sprint planning and execution, backlog management, burn down charts, bug tracking, and many others. Assembla's cloud platform and strong collaboration features allow teams to work together regardless of location, keeping everyone focused on the big picture. Another core feature is unlimited software configuration management (SCM) and deployment through Subversion, Git, or Perforce, for which most other vendors require a separate add-on.

FIGURE 49 ASSEMBLA ONLINE PROJECT COLLABORATION TOOL

6.2. Work Tasks Modeling

The necessity of modelling the tasks performed at workplaces becomes even more imperative during last years, as there is an increasing need both on the side of the employers and of the employee, for adequately establishing the resources needed to complete each individual work task. A major contribution to the field, on which many of the more rencent studies base their modelling approaches, is the work of Schaufeli et al [190]. The work introduces critical novelties to the well known Job Demands - Resources model (JD-R) model, which are based on the assumption that increasing job demands leads to strain and health impairment (health impairment process) and that wealthy resources lead to ramped-up motivation as well as elevated productivity (motivational process). The research also provides new insight into the field of work tasks modelling, by discussing in detail what are the unresolved issues concerning the JD-R model approach, such as the explicit definition and distinction between demands and resources, which are normally abstract concepts with relatively unclear boundaries, the incorporation of personal resources as well as the issue of reciprocal causation.

A different and more recent approach was introduced by Arnoud T. Evers et al [191], which despite being excessively specific (e.g. focused on teachers profession), could have significant repercussions on the assessment of numerous professions, if it was adequately modified and expanded. The main scope of the research was to shed light on organizational (cultural and relational) and task factors which could potentially enhance teachers' professional development at workplace. The model employed takes into account the development of lifelong learning competencies with the workplace as a baseline, and the impact it could have on the teachers' careers worldwide. The model incorporates the relationships between organizational and task factors as predictor variables and Teachers' Professional Development (TPD) at work as the dependent variable. The findings implied that learning climate, social support from the individual's supervisor, social support from colleagues and learning value of the function could act as beneficial

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job resources for TPD at Work. On the other hand,work pressure and emotional demands appear to have adverse effects, acting as job demands for TPD at work.

Ontology-based models represent another dominant category of approaches on task assignment and sharing between members of groups at workplaces, as well as on the assessment of isolated tasks. Ontologies provide structured, readable and comprehensible knowledge for both humans and machines, and provide an influential role in knowledge representation and sharing, data manipulation, and information retrieval, among others. Schmidt et al. [192], grounded on this ontology-based philosophy, presents an ontology-based application for mobile devices which is responsible for contributing to the management and sharing of tasks assigned to groups of people. The ontology's role is the storage of the domain knowledge about collaborative tasks, which is supporting the processes of task recognition and relocation. The accumulated knowledge is exploited by a multi-agent system consisted of a group of agents representing each person in the group. For the control of task execution, the agents come up with plan recognition techniques according to the existing schedules and request task allocation if necessary. The main concepts and properties of the task ontology proposed in the present study are exhibited in the figure below. The rules steering the decision making for task negotiation is also demonstrated.

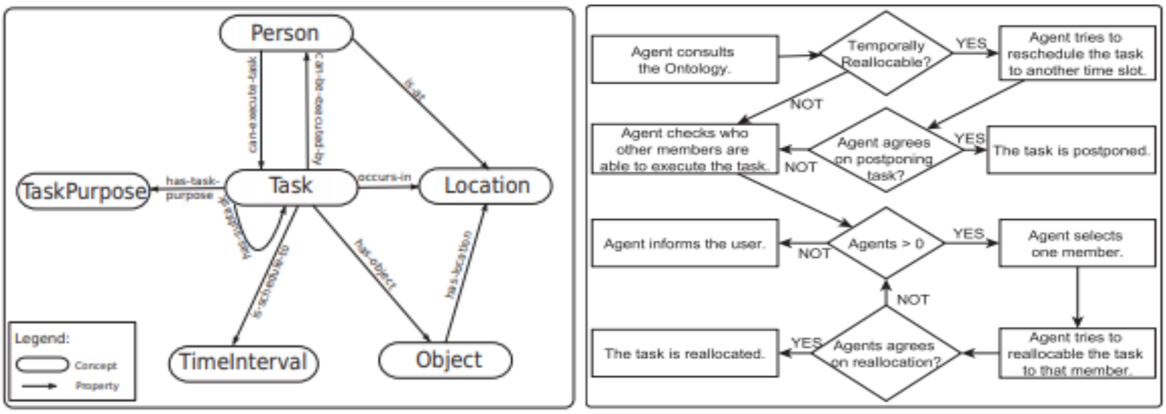

FIGURE 50 ONTOLOGY-BASED WORK TASK MODELING (FROM SCHMIDT ET AL, 2016)

The techniques presented by the study were applied in a healthcare scenario, which consists of a family group destined for nursing an elderly person. The research points out that the methodology can be applied to other contexts, provided that the ontology instantiation is adequately modified and making use of the developed software components. Applications based on ontology and agent technologies are beneficial in the context of providing adequate reasoning, as well as distributed computing.

The approaches using ontologies are rapidly propagated in the field of intelligent work task assignment in workplace environment. Mavridis et al. have conducted a study on crowdsourcing platforms, which are responsible for proposingan increasing number of tasks that require specialized skills, especially in participative science projects, adjusting individuals' competencies to the pending tasks and vice versa [193]. In other words, there is an augmented need to reason about the required skills for a task and the available set of skills in the group of workers assigned to the task, aiming at increasing the resulting work quality and efficiency. Most approaches rely on unstructured tags to model skills (vector of skills). It is suggested that a skill tree can be utilized for effectively modelling tasks and available doers (workers). A skill tree is a taxonomy of skills equipped with a similarity distance between individual skills. Consequently, the capacity of mapping doers to the respective tasks in a manner that fully exploits the hierarchy among the skills is provided. Real, as well as synthetic datasets are employed for demonstrating the efficiency of the model and the corresponding algorithms. In conclusion, the research indicates that the proposed techniques allow a simple form of reasoning about skills and participating workers contingent substitution that could be extremely useful in the optimization of task assignment quality. A plethora of heuristics for task assignment to doers are suggested and evaluated in terms of quality and scalability through constant experimentation. The introduced model could be expanded and upgraded in several ways for integrating participants whose skills are not fully and explicitly specified. For instance, by upgrading the construction of skill profiles from their answer traces, or by identifying and recruiting experts in order to maximize the expected high quality. Furthermore, the optimization of task assignments heavily based on personal preferences it is expected to boost the morale and the passion of the doers to a considerable extent. Last but not least, the modelling process of complex tasks that demand a wide range of skills in order to be successfully completed needs further expansion.

6.3. Conclusion

The analysis performed in this chapter helps expand the understanding of how task management tools could enable team collaboration in the process and through motivations, thus providing an insight on the **digiTeam Service** and the capabilities that such work management tools could provide to this service and consequently to the overall SmartWork platform. The aim of the service is to offer smart and flexible management of the workforce from the side of the employers (e.g. manager, supervisor) to increase efficiency and productivity of teams working on specific tasks, and to optimize training and knowledge management activities.

Through this service, SmartWork opens up a doorway into Industry 4.0 with respect to project management approach for the ageing population. In order to ensure the best competitiveness, the integrated management of the projects will become increasingly important and, as a result, the project teams will become more and more focused on specific objectives related with diverse elements of Industry 4.0. SmartWork will take advantage of the fact that project teams will be increasingly delocalized, with people that will interact from different places of the world and they all have their own cultural and professional identity that needs to be integrated.

SmartWork **digiTeam Service** will aim to impose a technological breakthrough, utilizing AI for changing the course of how project management tasks are delivered and controlled in the future, as well as take advantage of advances in communication technology to build project teams with stakeholders located in various places over the world.

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7. Life-Long Learning and Training of Older Workers

One of the policy concepts that is most commonly linked to active ageing is lifelong learning, which can be seen to have been originally developed to deal with the increasing rate of change in the workplace and society in general [194]. Indeed, it has been embraced by governments and educators as a concept that allows for more flexible forms of learning throughout life. One of the challenges of keeping older employees up to date and ensuring their continued involvement in the workplace is to provide them with relevant learning opportunities. Continuous learning, either through formal or non-formal means or informally through a variety of means that fosters the continuous practice of cognition, continuous social interaction and continuous physical activity, all of which can encompass an important learning component, is an integral part of active ageing. But some have argued that it might be more productive to have a separate policy focus on learning for older people as part of active ageing because the imperatives of employment and earning have, to a large extent, overshadowed the holistic dimensions of lifelong learning [195]. As a recent example, one of OECD's recommendations (2013) to improve the employability of older workers is to ensure a high level of learning throughout their working career, i.e., lifelong learning in working life. In other words, active ageing may help to provide a broader focus on the needs and aspirations of older adults, one that extends beyond an exclusive emphasis on employability. As Schuller notes however, clearly the two concepts are not mutually exclusive. Perhaps, the use of both policy concepts is appropriate simply to emphasise older workers and older adults and focus on their learning opportunities, their level of engagement at work, at home, in the community and in leisure, together with their concomitant outcomes.

It is unquestionable that learning is a key feature of participation in social and economic life, and is considered an essential strategic component for a successful personal evolution as well as a professional negotiation aspect. McClusky [196] argues upon four key areas of need that older people might meet through learning strategies compatible with models of increasing service user participation and involvement [197]: first, **coping needs**, arising from adjusting to changes in daily life such as physical fitness, economic self-sufficiency and basic education; second, **expressive needs** such as those related to adults taking part in activities for their own sake; third, **contributive needs** relating to individuals who want to continue actively contributing to society; and fourth, **influence needs** where older people take a leadership role to achieve social change.

Like any human endeavour, learning is a complex social and value-creating activity, and one that is shaped by, and that shapes, social structure and culture and that inevitably involves ethical judgements and political choices [198].

7.1. Life Long Learning (LLL) and professional learning

Policy makers turned to lifelong learning as a means to increase social cohesion, employability and, more recently, to tackle the challenge of ageing populations. It has also been hailed as the policy

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means to improve national performance in the knowledge economy. Some view LLL as a connected system that covers the whole lifecycle and includes all opportunities for learning [199]. An important aspect of LLL is that learners should take the initiative of their own learning with the support of the employer. Many factors may influence LLL, but motivation and future career plans, as well as a work environment which is conducive to learning have been identified as important factors [200].

The concept of LLL has also received criticisms. Field et al. [201] suggests that the concept has too many aims (social, economic and business competitiveness) and that it is a vehicle to stimulate innovation and novelty in the knowledge economy. The term LLL is frequently used to describe individually-motivated learning, but also learning of basic skills at all stages of life and personal development which may not be work-related. The term has also been used as a way of "repackaging" adult learning policy. Furthermore, the research points out that most European countries have indeed developed national visions of LLL, but that policy implementation is delayed and is much more fragmented.

Employers can, of course, interpret LLL in their own way and the challenge of making it happen among older employees is evident in the findings of The Programme for the International Assessment of Adult Competencies (PIAAC) which indicates declining participation in organised learning activities and declining literacy, numeracy and technological skills with age [202]. Other studies have found that older employees were more interested in learning things relevant for their current work situation and challenges, than in learning things which may or may not be useful for them in the future [203], [204], [205].

If we look at the professions more closely, we find some of the same drivers of change and thus of learning. However, we find different attitudes to learning and knowledge, as well as the importance of upholding professional ethics and norms [206]. A profession is defined as: "members of any occupational group, usually committed to public service, that defines itself as collectively sharing particular knowledge and practices and that is publicly accountable for its service" [207]. In their re-conceptualisation of professional learning, Fenwick & Nerland seek to debunk the ideas of professions based on decontextualized individual competence. Instead, they conceive learning as something which emerges in situations where there is a gap between action and expectations of the job that needs to be done. Guile highlights the importance that professionals place upon continually learning from colleagues and having time and places to meet and exchange experiences and identify ways of developing their knowledge [208]. The importance of formal education and professional knowledge at the core of a profession is acknowledged, but, as Gherardi (Chapter 1 in [207]) points out, although formal knowledge may be at the core, there is also a margin that consists of all the extra, perhaps less formal knowledge which makes the profession function as a group, enabling it to learn new things and to change and develop.

Properly practised, LLL and professional learning should ideally result in engaged and competent employees who continuously update their knowledge and learning to work in new ways as part of a learning organisation. However, by including concepts of professional learning, our attention is directed to non-formal learning and everyday informal learning, as well as the all-important formal education of professionals.

7.2. Activity-based learning

The gerontology literature tends to theorize and debate learning within the paradigm of 'activity' and 'disengagement' as potential routes in later life [209]. For example, activity theory is one emerging discipline that attempts to provide a clear series of objectives potentially attractive to professionals such as in health and social work with older people [210]. This works by encouraging the maintenance of existing activities for as long as possible or by replacing these with new ones. However, activity-based approaches are said by some to lack a theoretical basis by problematizing older people as non-productive and making their activities quantifiable and subject to measurement and regimes [209] in a vein similar to critiques of managed care [211]. Within this 'discipline', however, other forms of learning may provide adequate means by which older people can improve their opportunities, resume a neglected interest [210], reflect on life experiences leading to greater self-understanding or individual insight as well as offering limited protection against cognitive decline. Similarly, emphasis is put on the need for older people to keep up with technological and scientific advances [212] in order to take advantage of developments in self-assessment now available through interactive web-based assessment tools.

7.3. Informal learning and empowerment

Informal learning has tended to be ignored or devalued by dominant service cultures. The literature on informal learning identifies numerous dimensions of previously obscured but vitally important learning in social contexts that occurs amongst marginalized groups [213]. Older people's experience, involvement and participation as a virtue or an untapped element of formal and informal learning are becoming increasingly recognized particularly within intergenerational work programmes. Valuing experience and wisdom-based knowledge is of particular interest to those working with older people because it provides a basis for reflection on the quest for self-fulfilment and a means of achieving quality of life as well as passing it on to others. Critical perspectives within educational gerontology [214] have examined relations between knowledge, power and control where learning acts as an agent of social change. The process of learning can be painful 'incidental, unanticipated or imposed' [210], suggesting a form of reflection or review taking place in an unstructured or spasmodic way and leading to greater self-understanding and individual insight [215]. Radical educationalists argue that learners should be able to reflect critically on their own processes of socialization to enable the relation of personal learning to societal issues and structures to take place [213]. This approach would imply an examination of perspectives on the process of learning, and the learner's identity for both the learners themselves and those providing support [216]. The quality of relationships between users and professionals, for example, are identified as key to successful outcomes [217], [218]. Rogers' (1980) humanistic vision of learning

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should appeal to social work practitioners with its emphasis on participation and involvement in the delivery of services to overcome this.

Empowerment associated with social work, widening participation and life-long learning, comes from a range of traditions including civil rights, anti-racism and the feminist movements [219]. Starkey identifies competing discourses of empowerment: the consumerist model, giving people choice within professionally defined services; the liberation model, concerned with the position of oppressed groups within society and the conceptualization of empowerment as professional practice [219]. The latter outlines a process by which users gain control over and take responsibility for their lives mediated through methods used by professionals to achieve this. Empowerment is not something professionals can 'do' to people. It's a reflexive activity or process initiated and sustained by others as well as by the subject themselves, needing an appropriate climate, relationship, resources and procedural means through which people can enhance their own lives. Core aspects of this model derive from both a value base concerned with social justice, self-determination and self-actualization and a theory base emphasizing the significance of power in social relationships. It highlights the nature of oppression and the personal and social costs of belonging to a potentially disempowered group.

7.4. Conclusion

It has been evident from the literature survey above that the motivation for learning is reduced or at least fragile among older employees. The increasing challenge of motivating older employees to participate in formal learning and at the same time encourage their willingness to engage in learning which is relevant for their current task supports findings from earlier research on older employees and their attitude to LLL.

In this section we have reviewed the principles of life-long learning and the special characteristics of professional educational approaches for the older people. These finding will be critical for the design and development of the **workCoach Service** which will provide on-demand training support and new skills acquisition to support the older worker prolong his/her functional work ability and increase technology acceptance. Individual differences in qualifications are highly important for professional employability and flexibility, and these differences increase with age. Older workers (compared to younger employees) are generally not up to date with, and rarely participate in or are excluded from, training. Yet, the difference within this cohort are extreme, even more so than among youngsters. This leads to ageing being connected with reduced professional flexibility without actually causing it.

This service builds on the functionality implemented by the on-Demand Training Module and the team Training Needs Prioritizing Module to facilitate identification of individualized training needs analysis, provision of training on-demand (e.g. relevant for the completion of a specific work task), and intergenerational knowledge transfer.

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Annex 1. EPO patents on Smart Mouse Devices

Identification	Title	Patent Type	Summary	Pub. Date
CN104714669 (A)	Mouse capable of detecting female physiological cycle	A (Invention)	The invention provides a computer mouse capable of measuring a female physiological cycle. If comprises the normal functions of a computer mouse with female physiological cycle detection. The mouse can be connected to a computer via wireless or wired connection and is made out of glass. There is a temperature sensor, mounted on the surface of the mouse, constituted by multi-point electrofusion contacts When the user touches the mouse, it measures the women temperature body and sends the data to the central processing unit to obtain the female physiological cycle information. The obtained information is displayed in the d display device. Notes: Invention Patent Application deemed withdraw after publication (2018/07/20)	2015-06-17
US2014019165 (A1)	Computer Mouse System and Associated Computer Medium for Monitoring and Improving Health and Productivity of Employees	A (Invention)	This invention consists in a computer mouse with several health sensors, that are used to measure different bio signals to assess the employees current health and predict potential health issues by changing the employee behavior during the day. In order to measure the temperature when the user grasps the device, it includes an infrared (IR) sensor disposed on an exterior	2014-01-16

			surface of the computer mouse. Besides the temperature sensor, the mouse is composed by a blood pressure sensor, which consists in a blood pressure cuff including a pneumatic tube extending between a body of the computer mouse and a bladder of the blood pressure cuff, and an integrated pressure transducer configured to sense air pressure within the cuff. The output the blood pressure data is sent to the mouse wirelessly. The device is equipped with a pulse oximeter sensor located in an interior region of the computer mouse, and protected by a hinged cover that is rotatable into an open position to provide access to the pulse oximeter sensor	
CN201145887 (Y)	Mouse capable of acquiring human body physiological data	U (Utility Model)	The utility model discloses a mouse capable of collecting physiological data which comprises a USB interface mouse, a pulse sensor, a body temperature sensor and a blood pressure sensor. The three sensors are all installed in the grip part of the mouse casing, and the outputs thereof are respectively respectively and the three-module The generated signals by each one of the sensors are connected to a A/D chip. All of the 3 chips are connected to an SDRAM chip via data bus and the data bus of the SDRAM chip is also connected with the data bus of a USB chip inside the mouse. The data collected by the pulse sensor, the body temperature sensor and the blood pressure sensor are transmitted to the computer memory through the USB interface, and the physiological data is displayed on the floating window of the	2008-01-28

			display	
KR2002 006596 2 (A)	Mousewith health diagnosis sensor	A (Invention)	The main purpose consists in a mouse capable of giving an alarm to the user, about his health, by using health diagnosis sensors. The mouse can sense temperature, pulse, fat, oxygen concentration, and cardiac signals (EGC). The sensor transmits the measured data to a computer system for comparing the measured data with the standard data of the temperature, the pulse, the oxygen concentration, and the electrocardiogram and displaying the current health state, giving an alarm if necessary. The sensors can be a contact or a non-contact type, and a digital or an analogue type. Notes: Decision to refuse application (2003-07-02)	2002-08-14
CN2010 04220 (Y)	Mouse for measuring multiple body data	U (Utility Model)	The present invention is a mouse capable of measuring a plurality of data of a human body, like body temperature, body fat measuring and heart rate. The devices utilizes a measuring device capable of simultaneously measuring body temperature, body fat and heart rate, but the measuring device is at heart rate. The measurement may be less accurate, so a extra measuring device is separately provided for measuring the heart rate. The mouse is also packed with a mouse pad with a integrated wrist band and inflatable wrist strap, used for blood pressure measure. The measured blood pressure data is transmitted to the circuit in the mouse	2005-06-01

			body via wire or wireless transmission. Notes: Deemed withdrawal of patent application after publication (2007-04-18)	
CN201084113 (Y)	Mouse for monitoring human body grease	U (Utility Model)	The proposed utility models provides a mouse for dynamically monitoring human body fat and transmit it to the system host while the user uses the mouse. The mouse comprises: a displacement sensor, a moisture sensor, a pulse sensor and the respective conversion units of each sensor. The moisture sensor has two sensing heads, extended out of the surface, in the mouse body, responsible for sensing the body fat information. The monitored data is converted and sent to the host. The same procedure is used in order to measure the mouse displacement The unit also includes a body temperature sensor, located in the upper surface of the mouse, and respective conversion unit. This circuit has the ability of measure the body temperature, convert the data to digital values and send it to the host device The pulse sensor, located on the left or right side surface of the mouse, has the same process of gathering and converting the data as the other two sensors. The body temperature sensor and the pulse sensor can be used in order to make the the user physiological information more complete and perfect. Moreover, by adding a data integration unit, the physiological information of the monitoring can be integrated and directly	2008-07-09

			displayed in the mouse, so that the mouse can be used as a special monitoring terminal without the use of the computer Notes: Cessation of patent right (2012-03-28)	
CN208000552 (U)	Intelligence mouse pad and human health monitoring service system	U (Utility Model)	The invention presents an intelligent mouse pad capable of collecting physiological information of a human body and monitoring mental stress of the human body. The intelligent mouse pad, comprises a mouse pad body and a human body physiological information collecting device, wherein the human body physiological information collecting device is disposed in the mouse pad body. The physiological information module is composed by a piezoelectric film sensor, a photoelectric sensor, a blood pressure sensor, a body temperature sensor, a sweat detecting sensor and a processing unit. All of these sensors are directly connected to the processing unit, which is capable of measuring and process the gathered data, with use of a signal amplifying circuit, a signal filtering circuit, and a microprocessor. The processed data is forwarded to the communication module which mediates the data exchange between the microprocessor and the user terminal. Notes: Patent grant (2018-10-23)	2017-06-28
CN1056	Health mouse	A	The invention relates to the technical field	2016-06-

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30212 (A)	capable of monitoring human pulse and heart rate	(Invention)	of medical devices, in particular to a health mouse capable of monitoring human pulse and heart rate. In order to enable the pulse and hear rate measurent, a reflective pulse wave photoelectric sensor, a pulse wave signal filter circuit and a pulse wave signal amplification module are connected in sequence and connected with a single-chip microcomputer control module. The data is exchanged between the microcomputer and the terminal using a MicroUSB interface. The reflective pulse wave photoelectric sensor is placed at a position where the thumb is normally used when the mouse is used. The sensor is composed by an infrared light emitting diode, used as the fast light source, and a photoelectric transistor is used as the receiving tube. The single-chip microcomputer control module is composed of a pulse wave signal analog/digital acquisition module, a pulse wave signal smoothing filter module, a mouse data acquisition module, a signal processing module, and a signal sending module. The invention introduces health into the mouse, integrates health monitoring with daily life, allows the user to deliberately measure his physiological signal in daily life, understanding his physical condition Notes: Invention Patent Application deemed withdraw after publication (2018-05-18)	01
TW2012	Mouse for	A	The present invention discloses a mouse	2012-11-

43660 (A)	measuring physiological parameters	(Invention)	which is used to measure physiological parameters. The mouse comprises a body, a light source, a data processing unit and a display module, The light source and respective photocell receiver are located in an opening in the mouse body. The light generated by the light source is directed to the user hand, and the reflected light is collected by the photocell receiver, which generates a set of analog signals representing the user's heart rate information according to the intensity of the light received. The obtained hear-rate is show to the user, using the display module, which is electronically connected to the data processing.	01
CN2028 54733 (U)	Healthy mouse with blood oxygen and pulse monitoring functions	U (Utility Model)	Disclosed is a healthy mouse with blood oxygen and pulse monitoring functions. The mouse comprises a data collecting device, a blood oxygen and pulse reflection-type photoelectric sensor, blood oxygen and pulse signal filtering circuit, blood oxygen and pulse signal amplification circuit, a core control chip, an interface circuit and a power source device. The blood oxygen and pulse reflection-type photoelectric sensor are arranged on the side position of the mouse. The blood oxygen and pulse signal filtering circuit, the blood oxygen and pulse signal amplification circuit, the core control chip and the interface circuit are sequentially connected and integrated on a mouse circuit. The power source device is arranged in the inner space of the mouse.	2012-09-10

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			The mouse can serve as a general input device of a computer, and meanwhile can monitor physiological features such as the blood oxygen and the pulse of a user.	
CN2012 66358 (Y)	Mouse and device with function of measuring and regulating physiological signal	U (Utility Model)	The utility model consists in a mouse with physiological signal measurement function, comprising a USB interface unit, one or more blood pressure signal sensing unit, at least one signal conversion unit and a USB controller. The signal generated by the blood pressure sensor is sent to a signal conversion unit that converts the sensing result into a digital signal. The result signal in sent to a USB controller that integrates the digital signal into a USB signal output. The USB controller present in the mouse is capable of receiving an external control signal and starts the sensing of human blood pressure. The mouse further includes an electrocardiographic signal sensing unit, a blood oxygen signal sensing unit, a respiratory signal sensing unit, a body temperature signal sensing unit, an alcohol concentration sensing unit, a blood vessel hardening degree sensing unit, and a skin dry humidity sensing unit. All the data generated by the mouse sensors are integrated by the USB controller and uploaded to the computer. The computer can store the measurement data and perform other processing. This makes it easier for people to measure, store and manage blood pressure data to better monitor their health Notes: Cessation of patent right (2012-10-	2008-08-08

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			03)	
US2001 041845 (A1)	Stethoscope mouse	A (Invention)	The invention presents a stethoscope mouse which consists in a mouse with standard input capabilities and a stethoscope integrated with the mouse. The stethoscope mouse is connected to an on-line computer for listening to heart sounds and displaying its result, measuring a body temperature and displaying its result and measuring a skin conductivity, displaying its result and transmitting these physiological information to a physician via the on-line communication. The device includes an auscultation head and a microphone mounted therein, a body temperature sensor mounted on the outside of the auscultation head and three electrodes fixed mounted on the outside of the auscultation head for measuring the skin conductivities.	2001-11-15

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