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FIT4WORK

SELF-MANAGEMENT OF PHYSICAL AND MENTAL FITNESS OF OLDER WORKERS

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1. Introduction

The current document summarizes the work done in Task 3.1 of the Fit4Work project. This task dealt with analyzing the available sensing and wellness devices in order to select the equipment base to be used for the system. The equipment base in the context of this report means the device package maintained by the end user, referred to in this document as the user device package. The selection done following the performed analysis is treated by the consortium at the time of publishing this report as the working user device package selection. This package will require appropriate testing (together with a Fit4Work system prototype) with the participation of end users within a field test. Only then we are able to confirm the appropriateness of the choice.

The report starts with a short presentation of the Fit4Work system and its assumptions as they were at the start of the project. We also list the criteria against which we verify the usefulness of the existing devices. This is included in Chapter 2.

Further on, in Chapter 3, we detail some of the system features, discussing the envisaged sensing scenarios taking place within the system. These scenarios relate to sensing biosignals from the end user body, as well as ambiental parameters of the workplace environment. The primary purpose of this chapter is to define a list of essential and supporting parameters which the system must (essential) and could (supporting) measure to provide the envisaged functionality.

Chapter 4 is devoted to the summary of requirements. This relates to summarizing the requirements of the sensing scenarios (i.e. what kind of values the Fit4Work system must dispose of) and any relevant findings from the user requirements analysis conducted within WP2.

Chapter 5 looks into various devices and analyzes them against the criteria defined in chapter 2.

Finally, in Chapter 6, we discuss the results of the analysis of the existing devices and present the final selection of the user device package. This package will consist of four devices including an Android-based smartphone, a wrist band, a mobile body motion capture device and an all-in-one device for sensing the environment conditions.

2. Fit4Work System overview

The proposed system aims to deliver an innovative easy-to-use and unobtrusive product that will support older workers and the relevant stakeholders in reducing and managing physical and mental stress resulting from their occupation and daily duties. By incorporating state-of-the-art ICT building blocks, the system will provide ambient ways of monitoring physical and mental activities at work. Smart algorithms will use the information thus collected to provide context-sensitive personalized recommendations for adjusting the workplace and behavior at work, as well as define long-term individual lifestyle plans to meet the demands of the work taking into consideration the worker's age.

2.1. User stories

The main objective of the project is to create a system that helps older workers improve their health or maintain it in the best possible condition. Older workers have very different problems depending on their profession starting from back pain to physical and mental stress. Understanding these problems is a key factor to Fit4Work's success. Therefore, typical stories of potential users had been presented to understand which problems will be address in Fit4Work.

2.1.1. Story 1

Helena is a 63 years old accountant living in the suburbs. Two years ago her husband Stephan had a stroke and now he is partially paralyzed. He has problems with clear speech and daily activities. Helena decided to give up work in order to take care of her husband. Every day she must help Stephan during eating, dressing and moving around the house. What is more, all household duties fell on her shoulders. She is a strong and loving woman, but more often than not, fatigue and stress show on her face.

Stephan often cannot clearly express what kind of help he is expecting from her and that causes lots of stressful situations at home. After the accident Stephan became a bit more bitter and grumpy affecting Helen's mood as well. She rarely goes out because she is afraid to leave her husband alone at home.

The total dedication to the care of husband and the excess duties make Helena forget to find some time for herself, or to focus on anything other her husband needs. The stress which she experiences every day more and more affects her own health.

2.1.2. Story 2

Anna is 55 years old and has been working as a professional caregiver for 27 years. She loves her job because she always wanted to help other people.

Her working day begins with helping patients in getting washed and ready for the day, and changing their bed sheets. After that she is supporting them during meals and making sure they take their proper medications on time. The whole day she is giving them her helpful hand, starting from adjusting their pillows to supporting their rehabilitation. Sometimes it requires lots of physical effort. Patients who are paralyzed cannot move by themselves, and she needs a lot of strength to help them. There are also patients who just do not want to cooperate with her. Such situations require even more work from Anna, not only physically, but also mentally. She is proud of what she is doing but admits that it is a very demanding job.

She is nearly the same age as her patients and with each passing year Anna feels the increasing tiredness in her whole body, especially in her sore back and joints.

2.1.3. Story 3:

Charles is 72 year old retired psychologist and has been working socially in a call center from 7 years. He spends eight hours every day at his desk answering calls, trying to solve people problems. He is so dedicated to his job that he simply forgets about taking breaks, changing positions, or doing some stretching. Even during meal breaks he does not leave his chair and phone.

When he was younger he was leading an active lifestyle, but today he is slightly overweight and suffering from back pain. It is probably because of his sedentary type of work and lack of upright body position. What is more, poor working posture affects not only his physical fitness, but also on his motivation to be more active.

2.2. How does it work?

User stories show typical problems which seniors (potential users of Fit4Work) have to cope with every day. In order to solve these problems, the project assumes that users will be equipped with sensor-packed devices capable of monitoring parameters such as heart rate, skin temperature, physical activity, body motion. A smartphone will be used as a gateway, performing the first analysis of the data coming from those sensors. The analysis will provide real time feedback to the user with information about immediate actions which may be performed by the user to avoid stress (physical or mental) or to increase their activity level. At the same time the smartphone will send the data to the cloud where it will be stored for further, long term analysis. The phone will also serve as a geolocation device and movement sensor. Furthermore, the workplace may be equipped with ambient sensors for detecting undesirable conditions, such as high levels of noise, inadequate quality of air or poor lighting. Based on the stored biosignals and ambient data smart algorithms will provide recommendations and guidelines for the user. In order to increase efficiency and motivation, an individual fitness plan will be proposed to the user. The plan will consist of physical and mental exercises and the system will monitor how well the user performs them, giving him/her feedback on their performance. Sensing biosignals and performing exercises from the individual fitness plan will be a constant process accompanying the user at home and at work, helping them avoid physical and mental occupational stress and increase physical activity levels to keep the ability to work.

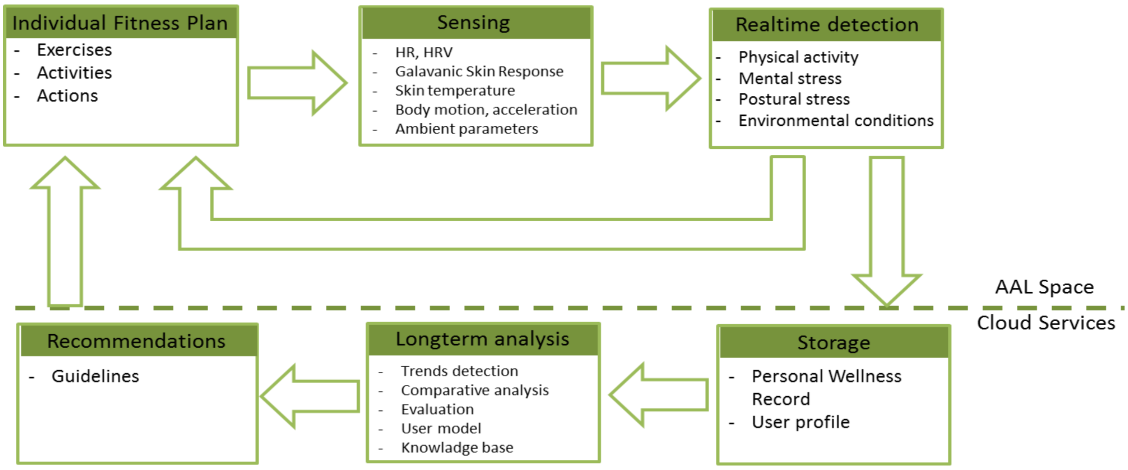

Figure 2.1. The block diagram of the Fit4Work system

2.3. Criteria for selection of devices

To select the ideal Fit4Work user device package, we decided to analyze the devices available off-the-shelf for purchase. The selection process was based on defining several criteria against which we matched the features of devices. These criteria were of two types:

- Critical, which means that devices included in the Fit4Work user package must (as the package) match the needs;
- Supporting, which means that there were some features of devices that could work in favor of one model of the other in case the 'critical' (core) features are brought by both (or more) such devices.

In this section we define these criteria.

2.3.1. Criteria 'critical'

Criterion 1: Measured parameters
Selected set of devices must contain all the necessary sensors enabling to measure all required parameters.

Criterion 1 constitutes the basic functional requirement for the Fit4Work system, discussed in detail in Chapter 3 of the current document.

Criterion 2: Budget
The market cost of the full user device package should ideally not exceed €1250.

The initial cost-benefit analysis we performed at the proposal stage assumed that a targeted monthly cost for the use of the system should not exceed €50. Having this in mind, we secured a targeted budget of €1250 per one (pilot) user device package, which is covered by 25 monthly installments of €50 paid for the system use, i.e. one month beyond 24 months, which is set the maximum initial commitment period for contracts concluded between consumers and undertakings providing electronic communications services according to Directive (2009).

Criterion 3: Availability of measurements through an API
In order to read raw sensor data, an adequate API for each device is needed.

Criterion 3 is a basic functional requirement for the Fit4Work system, which is a system built with the use of off-the-shelf devices. Ability to read raw data from all sensors integrated into the system is a must.

2.3.2. Criteria 'supporting'

Criterion 4: Platform independence
The Fit4Work system should ideally be compatible with the most popular operating systems (Android, iOS, Windows Phone), thus increasing the potential market of the resulting product.

According to IDC (2015) Android devices had 82.8%, iOS devices 13,9% and Windows Phone 2.6% worldwide market share in 2015. At the same time, in Europe Android devices had 68.4%, iOS devices had 20.3% and Windows Phone 8.2% share in the market (Kantar World Panel, 2015). These figures show that Android is the absolute market leader, however a significant and non-negligible share is owned by iOS and Windows Phone. It might be therefore essential for the successful business model to provide the final Fit4work product for all these platforms.

Criterion 5: Minimization of the number of devices in the user set
Reduction of the number of devices to a minimum should provide the maximum comfort of using the Fit4Work system.

While Criterion 5 can be intuitively assumed true by us, it must be noted that adequate proof can be also found in literature. Authors argue in (San Kim & Yoon, 2009) that nowadays the tendency of user expectations is for single devices to encapsulate as many features as possible. They also underline that it is easier for users to adapt to one interface than to a number of them.

Criterion 6: Ergonomics, usability and design
Selected devices should be simple and intuitive, require low physical effort and be 'trendy'. To ensure high level of usability of sensors used by the Fit4Work system, it is highly recommended that the communication between the sensors and devices gathering the data produced by those sensors happens wirelessly to avoid problematic cables that may constrain daily activities.

According to the study reported in (Martin et al, 2008) users must be able to use the equipment safely, effectively and with a minimum of discomfort. Devices should not interfere with users daily activities and limit their moves (cables are undesirable - it is preferred wireless communication).

Taking into consideration the fact that system must be used every day, devices should not require any special preparation from the users. Users want products with high usability and comfort. Selected devices should not be complicated to use and should come with clear instructions.

Most of home medical equipment is used by non-professionals. Additionally, the Fit4Work system is designed for use by older adults who have different experience and knowledge of new technologies, as well as physical and mental fitness.

Besides the technological and ergonomics issues, home healthcare devices should be adjustable to user style, aesthetics and home interior. According to Bitterman (2011) fashionable things work better. What is more, people choose equipment which follows current trends and looks more like jewelry than medical devices.

3. Sensing scenarios in Fit4Work System

Criterion 1, as defined in Chapter 2 above, is related to selecting such sensing devices that allow to create such an equipment base for the Fit4Work system to enable the system to effectively monitor physical and mental activities of the users. Therefore, in this chapter we describe the sensing scenarios foreseen to be performed by the Fit4Work system in order to create lists of essential parameters and supporting parameters to sense. Essential parameters are those key parameters without which the system will not be able to achieve its core functionality. Supporting parameters, on the other hand, are those parameters that are not necessary for delivering the core functionality, however can make the system better, more accurate and more usable.

Fit4Work sensing scenarios were grouped into three categories: smart biomonitoring (monitoring of physical activities, postural stress, mental stress and fatigue detection), monitoring of physical exercises and mental stress relief exercises, and monitoring of workplace conditions.

3.1. Smart biomonitoring

Smart biomonitoring focuses on three aspects relevant to the elder employee: physical activity monitoring, physical stress (postural stress and fatigue) detection and mental stress detection. All of

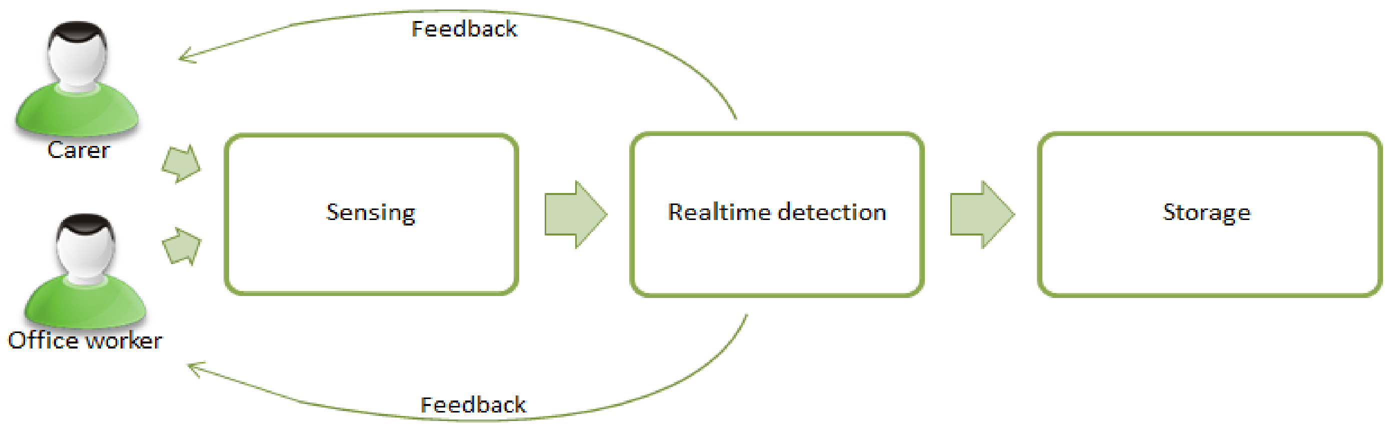

Figure 3.1. Smart biomonitoring scenario in Fit4Work

those three aspects are based on a common workflow, as presented in Figure 3.1. First, the system needs to sense relevant biosignals from the user body. The next step is the real time detection when measured signals are constantly processed and analyzed in order to find out significant events allowing to provide the user with adequate feedback. All data are stored in a long-term storage for further analysis.

Smart biomonitoring scenarios relate to detecting physical activity, physical stress and mental stress.

Physical activity is a key part of a healthy lifestyle, especially for older workers. It is essential for proper physical and mental health. Limiting daily physical activity, which increases with the development of civilization and an aging population, poses a real threat to human health and reduces job opportunities.

Regular physical activity, tailored to the individual needs of the people directly translates into efficiency at work. Therefore, it is important to encourage older adults to undertake physical activity.

Physical stress (postural stress and fatigue) in office is another factor which influences worker's health. The majority of office work time is spent sitting down (82%). Only 5% of the time is spent in the upright body position such as standing or walking (Mörl & Bradl, 2013). Poor working postures are among the factors that affect human performance in a workplace. These factors can lead to performance deterioration and introduce musculoskeletal disorders, feelings of discomfort can reduce efficiency and job satisfaction of workers. It has been mentioned that each year around 2 million workers suffer from musculoskeletal disorders, in particular, the number is increasing in the developing countries (Basahel, 2014).

Physical stress (postural stress and fatigue) at the bed of the patient. Studies have shown that elderly patients under the care of family caregivers with better physical and mental health would enjoy better outcomes in performing activities of daily living, better rehabilitation outcomes and better health-related quality of life (Liu et al, 2015). Providing a good physical and mental caregiver health by using the Fit4Work System, will improve both patient and caregiver condition.

Mental stress reduces performances in daily life, and is one of the first causes of cognitive dysfunctions, cardiovascular disorders and depression (Castaldo et al, 2015). It also has a significant negative impact on the employee and the organization in which they work. Effects of stress for the employee include problems with concentration, difficulties in making decisions, decreased involvement, nervousness and sleep problems. Stress also negatively affects the whole organization. The most common effects of occupational stress for the organization are an increase in employee absence, decrease in efficiency and productivity, increase in the number of accidents, a decline of the company's image. Therefore, it is very important not only for the employee, but also the organization to prevent stress. This may be achieved by analyzing body parameters in order to detect stressful situations. When people get stressed their heart beats faster, muscles tighten, blood pressure rises, breath quickens, and all senses become sharper. During mental stress there are also changes in skin conductance and skin temperature.

3.1.1. Sensing scenario 1A: Physical activity monitoring

Where: home and workplace

Goal: monitoring the level of physical activity and suggesting appropriate exercise

Description: The Fit4Work system needs to measure biosignals which are related to physical activity and estimate user fitness (measure the level of physical activity). Based on this estimation the system will provide feedback to the user with information on how to improve user's health and what he/she should do to increase their level of physical activity.

Physical activity monitoring is composed of two tasks: (i) the activity recognition, which recognises the current activity of the user and (ii) energy expenditure estimation, which estimates the intensity of the recognised activity. These tasks may be tackled with use of consumer devices in the form of wristband or armband for tracking fitness activities, which correlate the amplitude of measured acceleration and measured heart rate with the expended energy. More advanced devices also include additional sensors for measuring skin and near-body temperatures, galvanic skin response, etc.

We have seen from our previous research that activity monitoring can be accurately performed utilising only acceleration sensor embedded in an average smartphone, which most people already have and an optional heart-rate monitor (Cvetković, Janko & Luštrek, 2015).

Walking detection, location detection and activity recognition are done in essentially the same way, using machine learning, based on the data read from the accelerometer sensor. The accelerometer sensor may be located in any device worn (or carried) by the user. This may include the smartphone as discussed above, a wristband or other device. The method foreseen to be used by the Fit4Work system allows to potentially build algorithms for all these devices.

Energy expenditure estimation is performed on features calculated from the stream of acceleration data, the recognized activity from activity recognition is included and the average and maximal heart rate if a device providing this measurement exists.

The summary of the physical activity monitoring scenario is presented in Table 3.1.

Table 3.1 . Biosignals related to physical activity

Parameters		**Smart biomonitoring**
		Physical activity monitoring
Basic body parameters	Accelerometer	essential
	Heart rate	essential
Derived parameters	Type of activity	essential
	Energy expenditure	essential

3.1.2. Sensing Scenario 1B: Postural stress and fatigue detection – office

Where: workplace

Goal: detecting if the user is exposed to postural stress or fatigue due to sitting work and suggesting breaks or other relevant actions.

Description: The system will aim to detect prolonged sitting position of the user in order to recommend them to stand up. To this end the goal is to detect that the user is in the sitting position and measure the continuous time the user sits. This can be done using the same algorithm for recognition of activities as described in 3.1.1 above. Therefore the only parameter that needs to be measure is body acceleration (Table 3.2).

Table 3.2. Biosignals related to postural stress and fatigue - office

Parameters		Smart biomonitoring
		Postural stress and fatigue detection - office
Basic body parameters	Accelerometer	essential
Derived parameters	Time spent sitting	essential

3.1.3. Sensing scenario 1C: Postural stress and fatigue detection - at the bed of the patient

Where: workplace (including home of the patient, e.g. for informal carers)

Goal: detecting if the user is exposed to postural stress or fatigue due to physical exertion and suggesting breaks or other relevant actions.

Description: The system will aim to recognize prolonged times of standing, walking and other physically demanding positioning of the users. As it was with the scenario 1B, this can be done using the method described in section 3.1.1. Therefore, body acceleration is again the only parameter required for measurement.

It must be noted that according to the user requirements analysis performed by WP2, the target users do not report undertaking physically demanding tasks at work.

Table 3.3. Biosignals related to postural stress and fatigue - at the bed of the patient

Parameters		Smart biomonitoring
		Postural stress and fatigue detection - at bed pf the patient
Basic body parameters	Accelerometer	essential
Derived parameters	Time spent in physically demanding position(s)	essential

3.1.4. Sensing scenario 1D: Mental stress detection

Where: home and workplace

Goal: detecting mental stress and suggesting relief exercises when needed

Description: For mental stress detection we propose a machine-learning method which will be applied on raw data collected from bio-sensors (blood volume pulse, heart rate, R-R intervals, galvanic skin response and skin temperature) and acceleration sensor. This raw data is processed using signal processing techniques in order to provide numerical features relevant for stress, e.g., numerical features extracted using heart rate variability analysis – it uses R-R intervals (Castaldo et al 2015; Tan et al 2011), numerical features extracted using blood volume pulse analysis (Keshan, Parimi & Bichindaritz, 2015; Zhai & Barreto, 2006) , numerical features extracted using galvanic skin response analysis (Braithwaite et al, 2013; Healey & Piccard, 2005).

Recently, similar approaches have been proposed for stress detection (Hovsepian et al, 2015; Muaremi et al, 2014; Ramos, Hong & Dey, 2014) with chest belts which are impractical to use (see section 5.1.2).

The summary of the mental stress detection method is presented in Table 3.4.

Table 3.4. Biosignals related to mental stress detection

Parameters		Smart biomonitoring
		Mental stress detection
Basic body parameters	Blood Volume Pulse (BVP)	essential
	Heart rate	essential
	Heart rate variability (HRV)	essential
	Galvanic Skin Response	essential
	Skin temperature	essential
	Accelerometer	essential
Derived parameters	Type of activity	essential

3.2. Monitoring of exercises

Smart biomonitoring produces various data related to physical and mental stress of the user. Based on these data the system is able to prepare fitness recommendations and guidelines, in the form of an Individual Fitness Plan (Figure 3.2). Within this plan the system proposes a set of physical exercises – related to both, the overall physical activity and to the functional fitness, as well as mental stress relief exercises. Relevant sensing devices are used to monitor execution of each type of exercises, with real time analysis providing necessary feedback to the user.

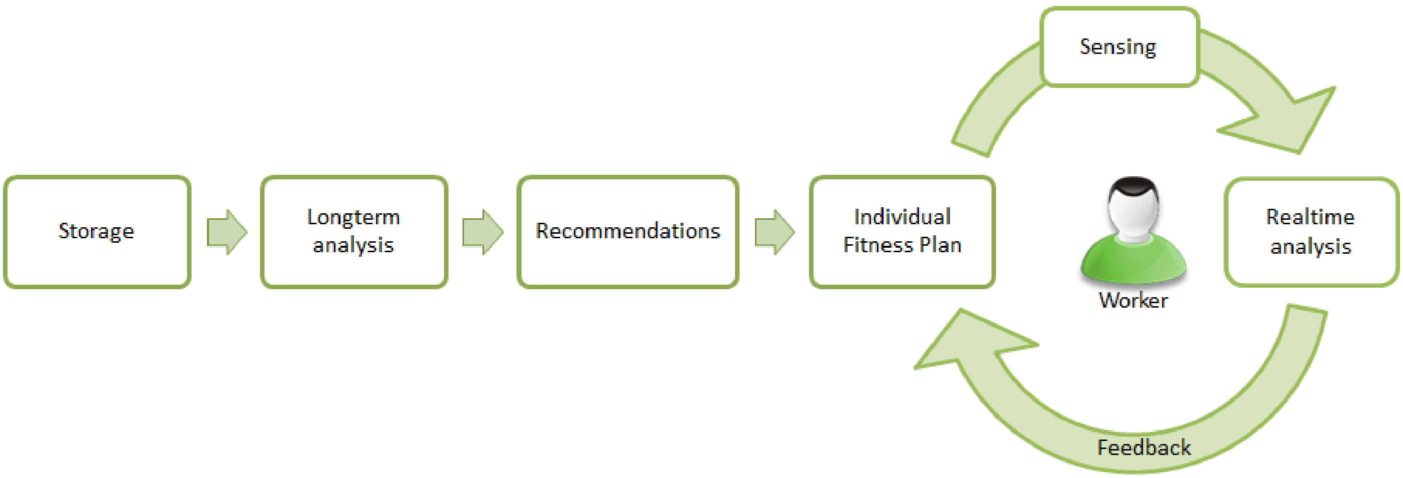

Figure 3.2. Monitoring of Individual Fitness Plan exercises within Fit4Work

3.2.1. Sensing scenario 2A: Functional physical exercises: 3D body sensing

Where: home

Goal: performing functional physical exercises according to personalized plan

Description: The Fit4Work system will monitor physical exercises to evaluate performance of the user against their personal plan. The plan is foreseen to contain a programme of functional exercises that incorporate the context of tasks and areas meaningful to the users, with an overall goal of functional independence (O'Sullivan, 2007). This kind of exercises can be monitored by tracking the motion of the user body, as the key indicator of how well the given person executes the exercises is the precision of movement.

To this end we assume using a motion capture application (MOCAP) based on computer vision technologies that are built by a sequence of image algorithms. The monitoring functionality has to compare the elements in the images with the defined anthropometric body models in order to recognize a person in the scene.

The most common MOCAP systems are composed by at least 4 high precision cameras and a set of markers placed on strategic parts of the body allowing the recognition of a human body and also tracking his/her limbs segments. These kinds of capture environments have high accuracy (under the millimeter) but also high complexity, are really expensive and needs to set them up properly calibrated and the markers position has a large influence on the skeleton tracking. This kind of setup seems inappropriate for using with the Fit4Work system due its complexity and lack of mobility potential.

Therefore, we propose to use “Kinect-like” devices that allow computing the skeleton tracking without markers, though with lower precision. The term “Kinect-like devices” refer to those digital CMOS sensor cameras, able to register the depth distance of the pixels of the resulting captured image within the field of view(FOV) of the camera.

Most often, the MOCAP applications using the “Kinect-like” devices for 3D body sensing are built with Microsoft SDK (Microsoft Kinect devices) and Open NI / NITE. The OpenNI framework provides a first semantic description of the environment at a very low computational cost. The main functionalities are the user recognition and the skeleton tracking in order to implement natural human-machine interactions: gestures or body movements. Support for OpenNI will be an important factor during the selection process for the adequate device.

The monitoring of the physical exercises may be further enhanced with monitoring the parameters related to physical activity, i.e. heart rate. This helps to assess the performance of the user in terms of their physical fitness (in addition to the precision of movement).

The requirements for the device capturing the motion within the Fit4Work system are summarized in Table 3.5.

Table 3.5. Sensing requirements related to functional physical exercises sensing with motion capture device

Parameters		Physical and mental exercises
		Functional physical exercises
Basic body parameters	Body motion	essential
Additional requirements	OpenNI support	supporting

3.2.2. Sensing scenario 2B: Mental stress relief exercises

Where: home

Goal: performing mental stress relief exercises appropriate to the level of mental stress

Description: The mental stress relief strategies range significantly from breathing therapy (Lee, 1999) through progressive muscle relaxation (Jacobson, 1925) to physical exercises (Salmon, 2001), including yoga (Chong, Tsunaka & Chan, 2011). The first two methods mentioned above require performing specific tasks according to an instruction. This does not require the Fit4Work system to monitor the performance of execution (i.e. the system will notice the mental stress level goes down). It rather requires presentation of the instruction to the user to enable them to perform the given technique. Both techniques are feasible for execution at the workplace as they do not require lots of space – they can be done at any place, including behind the desk.

As far as effect of physical exercises on the mental stress relief, this is secured by the Fit4Work system through encouraging the users to undertake physical activity in various forms. Moreover, should we decide on adding yoga exercising as a longer term mental stress relief strategy in Fit4Work, the monitoring of this could, most likely, be done using the same technique as with the functional exercises in scenario 2A (Chen et al, 2014).

Taking the above into account only the body motion sensing is a potential supporting measure enabling a richer functionality of the Fit4Work system (in the future).

Table 3.6 summarizes the needs for the monitoring of mental stress relief exercises.

Table 3.6. Parameters related to monitoring of mental stress relief exercises

Parameters		Monitoring of exercises
		Mental stress relief exercises
Basic body parameters	Body motion	supporting

3.3. Workplace conditions monitoring

Studies indicates that there is a relationship between the office ambiance and psychological well-being of office workers (Klitzman & Stellman, 1989). A number of factors such as: adverse environmental conditions, especially poor air quality, noise, humidity and bad illuminance, in addition to ergonomic conditions and lack of privacy, may have an effect on worker satisfaction and their mental health. Additional problems that may be caused by inappropriate workplace environment conditions are: lack of concentration, reduction of efficiency and (in extreme cases) serious deterioration of worker's health status. The list of negative factors may be more extensive if environmental conditions stay unhealthy for a longer period of time.

In this scenario the Fit4Work system will continuously measure a number of parameters related to the conditions of the workplace, in order to detect those that fall beyond conditions known to be good for work and/or worker's health. The analysis performed in real time will enable to provide suggestion for undertaking immediate actions aimed at improving the working environment. The data will be stored for future reference and analysis in system's long-term storage.

3.3.1. Sensing scenario 3A: Workplace conditions monitoring

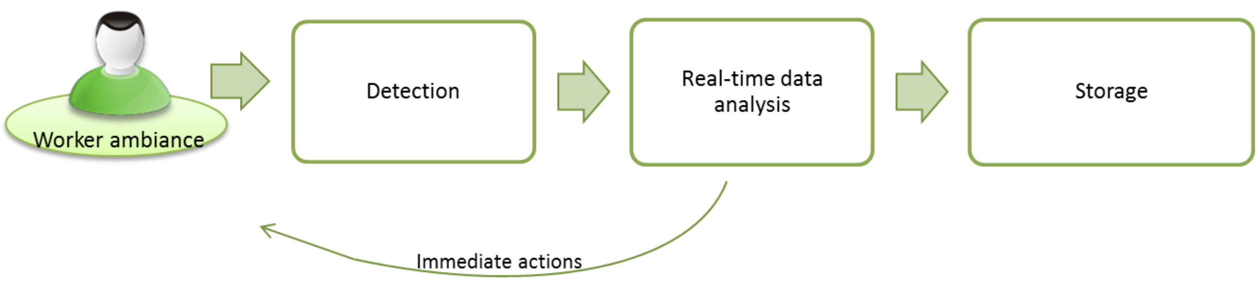

Figure 3.3. Monitoring of workplace conditions within Fit4Work

Where: workplace

Goal: detecting if conditions at the workplace are appropriate and suggesting improvements if necessary

Description: For the environment conditions monitoring, the Fit4Work system should aim to collect the following ambiental parameters: air temperature (°C), concentration of carbon dioxide - CO_2 - in the air (ppm), relative humidity (%), noise (db) and luminosity (lux). These parameters are found as important for health of the workers and their experience with working environment in a number of ISO standards (HFE Consultancy, 2016).

In addition, helpful in provision of adequate recommendations will be information on the conditions outside of the office, i.e. external temperature (°C) and external relative humidity (%). This will help to decide whether it is worthy to open the window in case the temperature in the workplace is too high (opening windows during summer when the outside temperature is higher than the one in the office would not help).

The summary of parameters to be sensed during workplace conditions monitoring is presented in Table 3.7.

Table 3.7. Parameters related to workplace condition monitoring

Parameters		**Ambient**
		Ambient conditions monitoring
Ambient parameters	Air temperature	essential
	Relative humidity	essential
	Concentration of CO_2 in the air	essential
	Noise level	essential
	Luminosity	essential
	External air temperature	supporting
	External relative humidity	supporting

4. Summary of requirements

4.1. Core functional requirements: parameters to sense

Scenarios presented in Chapter 3 define the scope of core sensing capabilities that the Fit4Work system should be equipped with. These have been summarized in Table 4.1. We list also the derived parameters. This will be used in case basic parameters are impossible to monitor with the available devices, yet some devices provide these (derived parameters) values.

Table 4.1. Summary of essential and supporting parameters to sense within Fit4Work sensing scenarios

Parameters		Summary Fit4Work System	Smart biomonitoring				Monitoring of exercises		Workplace conditions
			Physical activity monitoring	Postural stress and fatigue detection - office	Postural stress and fatigue detection - at bed of the patient	Mental stress detection	Functional physical exercises	Mental stress relief exercises	Workplace conditions monitoring
Basic body parameters	Accelerometer	essential	essential	essential	essential	-	-	-	-
	Blood Volume Pulse	essential	-	-	-	essential	-	-	-
	Heart rate	essential	essential	-	-	essential	supporting	-	-
	Heart rate variability	essential	-	-	-	essential	-	-	-
	Galvanic Skin Response	essential	-	-	-	essential	-	-	-
	Skin temperature	essential	-	-	-	essential	-	-	-
	Body motion	essential	-	-	-	-	essential	supporting	-
Ambiental parameters	Air temperature	essential	-	-	-	-	-	-	essential
	Relative humidity	essential	-	-	-	-	-	-	essential
	Concentration of CO_2 in the air	essential	-	-	-	-	-	-	essential
	Noise level	essential	-	-	-	-	-	-	essential
	Luminosity	essential	-	-	-	-	-	-	essential
	External air temperature	supporting	-	-	-	-	-	-	supporting
	External relative humidity	supporting	-	-	-	-	-	-	supporting
Derived parameters	Type of activity	essential	essential	-	-	-	-	-	-
	Energy expenditure	essential	essential	-	-	-	-	-	-
	Time spent sitting	essential	-	essential	-	-	-	-	-
	Time spent in physically demanding position(s)	essential	-	-	essential	-	-	-	-

The parameters defined as essential for the Fit4Work system to sense can be now also looked at from the point of view of potential groups of devices that could help to do so. This has been summarized in Table 4.2. The presented list is an assumption made prior to the analysis based on the knowledge and/or intuition of the authors. In the table we also add a category not specifically analyzed later on in this report, yet creating an essential element of the user device package – smartphones. We list these potential possibilities as a second choice backup when no other device is capable of measuring the given parameter.

Table 4.2. Parameters essential to sense within Fit4Work vs. groups of devices to use

Sensed parameter	Device group			
	Wearable devices	3D sensor devices	Environmental sensors	Smartphones
Accelerometer	+	-	-	+
Blood Volume Pulse	+	-	-	-
Heart rate	+	-	-	-
Heart rate variability	+	-	-	-
Galvanic Skin Response	+	-	-	-
Skin temperature	+	-	-	-
Body motion	-	+	-	-
Air temperature	+	+	+	-
Relative humidity	-	-	+	+
Concentration of CO_2 in the air	-	-	+	-
Noise level	-	-	+	+*
Luminosity	+	-	+	+
External air temperature	-	-	+	-
External relative humidity	-	-	+	-
Type of activity	+	-	-	-
Energy expenditure	+	-	-	-
Time spent sitting^	+	-	-	-
Time spent in physically demanding position(s)^	+	-	-	-
Mental stress occurrence	+	-	-	-

* using microphone and an application

^ possibly as a parameter derived based on reading the type of activity (and measuring time outside of the wearable device)

The device groups (except for smartphones) are subject of more detailed analysis in Chapter 5.

4.2. User requirements

An important factor for the selection of devices to be used within the Fit4Work system are the needs of the users. These we have been analyzing through work done in WP2 within a survey performed on an international population of older adults, focus groups consisting of representative of this population and interviews with several experts active in supporting older adults. The results of this analysis have been presented in detail in (Blok et al, 2016). Herewith we extract those findings of the analysis that support or contradict the 6 criteria we defined in section 2.3.

4.2.1. Survey

The survey based on the questionnaire designed by the project team (Bussink et al, 2014) was conducted in five countries: the Netherlands, Poland, Romania, Slovenia and Spain. Altogether 277 older adults participated in the survey. Analysis of the respondents replies shows that the main user requirements related to devices support criteria 2, 3 and 6, as it is summarized in Table 4.3.

Table 4.3. User requirements survey results vs. device selection criteria

Criterion	User requirement
2. Budget	• If the product of Fit4Work was to be paid for by the target users, it must be fairly cheap so selected device package should not be very expensive
3. Availability of measurements through an API	• The devices used should be compatible with the Android operating system, because the most popular operating system among survey participants is Android
4. Platform independence	• Android is the operating system used by 62,5% of the respondents – the remaining group uses other systems
6. Usability, ergonomics and design	• The device should use big letters, be as simple as possible and contain tutorial

In addition to the findings related to device selection criteria it must be also noted that potential target users indicate that they are fine with using any type of devices helping them with their (health) needs, however they prefer wrist devices.

4.2.2. Focus group

The focus group was organized as a series of meetings with 9 persons aged 55-75. The discussion in the group was related to the following topics: motivating factors to use ICT for health, privacy, preferred device, special features and costs.

The opinions of the focus group as relates to the selection of the devices for the Fit4Work system have been summarized in Table 4.4

Table 4.4. Focus group opinions vs. device selection criteria

Criterion	User requirement
6. Usability, ergonomics and design	• Participants prefer technical devices with bigger buttons, clear screens and zoomable content on the screens; • Target users prefer to use devices which can be included in their daily routines.

In addition, the focus group confirmed that wrist devices were preferred as potential sensors, as they were found easy to wear without constant awareness of their existence (i.e. they were found pretty unobtrusive).

4.2.3. Interviews with experts

The input of the representatives of the target end users was accompanied by the opinions of four experts: a health ICT entrepreneur, a professor of occupational health, a nurse and an elderly volunteer. These experts were interviewed in order to gather additional insights into how the Fit4Work system should be constructed. Their opinions relate to the six criteria for device selection as presented in Table 4.5.

Table 4.5. Experts' opinions vs. device selection criteria

Criterion	User requirement
2. Measured parameters	• Selecting the device itself should not be a separate decision: the first thing to decide is the goal of the system
6. Usability, ergonomics and design	• Devices need to be made as simple and easy as they can be, without too many extra features; • An intuitive and efficient design of the device will help to encourage users to use the system • Older adults expect to use devices with full functionality, exactly the same as would be used by younger generations

5. Overview of devices

Having in mind the criteria for the selection of devices for use within the Fit4Work system, as defined by the previous chapters, we looked at the availability of devices on the market. To this end we assumed the analysis of pros and cons of several various types of devices, as well as detailed analysis of specific models as available for purchase on the market (i.e. off-the-shelf).

The devices were analyzed herewith in the following groups:

- Biomonitoring devices, enabling to sense key physiological parameters related to monitoring of physical activity as well as detection of mental stress;
- Body motions sensors, enabling to monitor the movement of the user's body during physical exercises;
- Environmental sensors, enabling to monitor the conditions of the workplace environment.

5.1. Biomonitoring devices

Due to the fact that the Fit4Work system needs to continuously monitor several key physiological parameters of the end user's organism, the devices used for monitoring of those parameters must be worn at all time. Therefore, in the current analysis we only take a look at the wearable devices which could be potentially equipped with relevant sensors.

In the recent years due to the increased popularity of fitness and health related technology, as well as due the increasing technical possibilities of such technology, extensive efforts have been put towards the research and development of wearable systems for health/fitness monitoring (Chan et al, 2012). There are three main groups of wearable devices which are getting equipped with sensors capable of measuring physiological parameters: wrist wearables, sensor straps and smart clothes.

5.1.1. Wrist wearables

The term wrist wearables means all types of smart bands and smart watches. They can be equipped with accelerometers, activity trackers, automatic sleep detectors, sensors which measure skin temperature, HRV, galvanic skin response, and many others. All wrist wearables communicate with other devices (eg. Smartphone) via Bluetooth. They do not require a lot of effort from the user to put on, and provide constant monitoring. What is also important, literature demonstrates that older adults show enthusiasm towards the idea of embedding sensors into clothing accessories such as a ring or a watch (Steele et al, 2009).

Table 5.1**Błąd! Nie można odnaleźć źródła odwołania.** lists a number of smart bands and watches currently available on the market. This list is not extensive. On the contrary it contains devices with the richest functionality that can be potentially close to the needs of the Fit4Work system out of those known are found by the authors. The list provides information on fulfilling relevant devices selection criteria.

Table 5.1 Wrist wearables and their assessment versus device selection criteria

															
Model		**Jawbone Up3**	**Mircosoft Band 2**	**Fitbit Charge HR**	**Amiigo**	**Empatica E4 Wristband**	**Empatica Embrance**	**Basis Peak**	**LG G Watch**	**Samsung Gear Fit**	**Samsung Gear S2**	**Polar Loop 2**	**Whitings Pulse O2**	**Moto 360**	**Apple Watch**
Criterion 1		-	+	-	-	+	-	-	-	-	-	-	-	-	-
Sensors	Accelerometer	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	no	no	no	yes
	Blood volume pulse	no	yes	yes	no	yes	no	no	no	no	yes	no	no	no	no
	Heart rate	yes	yes	yes	yes	yes	no	yes	no	yes	yes	yes	yes	yes	yes
	Heart rate variability	no	yes	no	yes	yes	no	yes	no	no	no	no	no	no	no
	Galvanic skin response	yes	yes	no	no	yes	yes	yes	no	no	no	no	no	no	no
	Skin temperature	yes	yes	no	yes	yes	yes	yes	no	no	no	no	no	no	no
	Others	air temperature + energy expenditure	luminosity of the ambient + energy expenditure	-	energy expenditure	Mental stress monitor	Mental stress monitor	-	-	-	luminosity of the ambient	energy expendit ure	energy expendit ure	-	energy expendit ure
Criterion 2		+	+	+	+	!	+	+	+	+	+	+	+	+	+
Price (€)		165 €	175 €	135 €	165 €	1 170 €	180 €	180 €	240 €	140 €	360 €	110 €	110 €	230 €	330 €
Criterion 3		+	+	+	-	+	-	-	+	+	+	+	+	+	+
API/SDK		yes	yes	yes	not yet available	yes	not yet available	not yet available	yes	yes	yes	yes	yes	yes	yes
Criterion 4		-	+	-	-	-	-	-	-	-	-	-	-	-	-
Supported platform		iOS Android	Windows Phone 8.1 iOS 7.1+ Android 4.3-5.0	iOS Android	iOS 4s+ Android 4.3+	iOS Android	iOS Android	iOS Android 4.4+	Android (4.3+)	Android (Galaxy products only)	Android 4.4+	iOS, Android	iOS, Android	Android (4.3+)	iOS

5.1.2. Sensor straps

A separate category of biomonitoring devices are sensor straps worn around the chest (chest belts). Usually this kind of wearables are designed for fitness tracking and measuring heart rate using electrodes. Electrodes are attached to a chest strap which adapts to user's body shape and positions electrodes in the right location. The use of the chest straps sensors requires special preparation, electrodes must be covered with a special gel or water before and be cleaned after each use. These preparations required before each use can be discouraging for users who would have to use the system every day. What is more, while worn sensor straps can cause discomfort and skin abrasion (Chernbumroong, Cang & Yu, 2014). This fact disqualifies them in case of ergonomics and usability.

Despite the fact that the newest straps are capable of measuring relatively wide range of data related to heart activity, such as HR, HRV, R-R intervals, and several other parameters, such as stress levels and activity levels, none provides means for measuring all parameters required by the Fit4Work system. All straps communicate with other devices via Bluetooth.

Sensor straps available in the market, have been listed in **Błąd! Nie można odnaleźć źródła odwołania.**, together with their assessment against the device selection criteria.

Table 5.2. Sensor straps and their assessment versus device selection criteria

					
Model		Polar H7	Zephyr HxM Smart	Scosche Rhythm+ Heart Rate Monitor Armband	Wahoo TICKR x
Criterion 1		-	-	-	-
Sensors	Accelerometer	no	no	no	no
	Blood volume pulse	yes	no	yes	no
	Heart rate	yes	yes	yes	yes
	Heart rate variability	yes	yes	no	yes
	Galvanic skin response	no	no	no	no
	Skin temperature	no	no	no	no
	Others	-	Energy expenditure + Mental stress monitoring	Energy expenditure	Energy expenditure + Type of activity
Criterion 2		+	+	+	+
Price (€)		80 €	50 €	80 €	100 €
Criterion 3		+	+	-	+
API/SDK		yes	yes	no	yes
Criterion 4		-	+	-	-
Supported platform		iOS Android	iOS Android Windows Phone 8	iOS Android	iOS Android

5.1.3. Smart clothing

Another category of smart wearables are smart clothes, where smart shirts are the major design used. Thanks to a large contact surface with the user's body, smart clothes allow to deploy sensors in various locations. This potentially increases the number of parameters to possibly measure (Perez-Villacastin &Gaeta, 2015). While research works show a huge potential of smart clothing, not many mature products exist in the market.

As far as comfort of use is concerned, smart clothes are closely adjoining to the body which can cause, for some people, feeling of discomfort and irritation. What is more they must be changed and washed every day, making them less usable. Moreover, people are afraid that the technology could leave marks on their body, or cause physical harms by technical defects (Schaar & Ziefle, 2011).

Table 5.3**Błąd! Nie można odnaleźć źródła odwołania.** shows smart clothing models available on the market at the current moment, and their assessment against the defined device selection criteria.

Table 5.3. Smart clothing and their assessment versus device selection criteria

				
Model		Hexoskin shirt	OMsignal shirt	Nuubo
Criterion 1		-	-	-
Sensors	Accelerometer	no	no	yes
	Blood volume pulse	no	no	no
	Heart rate	yes	yes	yes
	Heart rate variability	yes	yes	yes
	Galvanic skin response	no	no	no
	Skin temperature	no	no	no
	Others	-	-	-
Criterion 2		+	+	-
Price (€)		400 €	200 €	Not announced yet
Criterion 3		+	+	+
API/SDK		yes	yes	yes
Criterion 4		-	-	+
Supported platform		iOS Android	iOS	iOS Android Windows (including Windows Phone)

5.2. Body motion capture devices

As it was described in section 3.2.1 for body motion sensing we aim to use ‘kinect-like’ devices. Such devices consist of a standard camera and an infrared camera. The first camera is used to process visual image (face recognition, motion capture), detect color and texture of objects. The second camera, infrared is providing information about the depth (the distance of a given object from the device. Combining both cameras, the sensor is able track human skeleton and gestures.

Most of body motion capture sensors are dedicated to be compatible with computers or consoles and only a few of them are small and portable enough to be connected to a smartphone.

Currently on the market there are several 3D sensors capable of body motion capturing. They are listed in Table 5.4. All of them but Creative Senz3D come with OpenNI compatibility.

Table 5.4. Body motion capture devices

						
Model	Microsoft Kinect	Microsoft Kinect One	Structure Sensor	Asus Xtion PRO	Fotonic Astra Pro	Creative Senz3D
Criterion 1	+	+	+	+	+	+
Camera	640 x 480	1920x1080	640 x 480	640 x 480	1280×720	1280×720
Depth sensor	320 x240	512 x 424	320 x240	320 x240	640x 480	320 x240
Min depth distance	0,4 m	0,5 m	0,4 m	0,8 m	0,4 m	0,5 m
Max depth distance	4,5 m	4,5 m	3,5 m	3,5 m	6,0 m	3,25 m
Horizontal field of view	57	70	58	58	-	74
Vertical field of view	43	60	45	45	-	-
Criterion 2	+	+	+	+	+	+
Price (€)	140 €	140 €	470 €	190 €	145 €	145 €
Criterion 3	+	+	+	+	+	+
API/SDK	yes	yes	yes	yes	yes	yes
OpenNI support	yes	yes	yes	yes	yes	no
Criterion 4	-	-	-	-	-	-
Supported platform	Windows	Windows	iOS Android Windows Linux	Android (by request) Windows Linux	iOS Windows	Windows

5.3. Environmental sensors

Sensors to monitor the conditions of the environment can come in a variety of forms. For the purpose of this analysis we look into two specific groups of devices. These are all-in-one devices, where all sensors have been integrated into a single device, and distributed home automation systems, where a managing device (hub) maintains communication with a number of sensors of which each measures a different parameter of the environment.

5.3.1. All-in-one devices

The primary feature of all-in-one devices packed with environmental sensors is the fact that since they are a single device, take can be conveniently placed anywhere at home or office. They are usually characterized by excellent design and small size which makes them ergonomic and fit to most interiors. Some of the solutions may use a hub, which provides means for connecting the Internet. This connection allows the devices to store the measurements in a cloud storage.

The environmental all-in-one devices are listed in Table 5.5, where their assessment versus the defined device selection criteria is also summarized.

Table 5.5. All-in-one devices with environmental sensors and their assessment versus device selection criteria

							
Model		Neoji	CubeSensors	KotoAir	Netatmo	Birdi Smart	Elgato Eve Room
Criterion 1		-	+	+	+	-	-
Sensors	Air temperature	yes	yes	yes	yes	no	yes
	Relative humidity	yes	yes	yes	yes	yes	yes
	Noise level	yes	yes	yes	yes	no	no
	Luminosity	no	yes	yes	no	no	no
	Concentration of CO_2 in the air	no	no	no	yes	yes	no
	External air temperature	no	no	no	yes	no	yes
	External relative humidity	no	no	no	yes	no	yes
Criterion 2		+	+	+	+	+	+
Price (€)		300 €	235 €	125 €	170 €	100 €	80 €
Criterion 3		+	+	+	+	-	-
API/SDK		yes	yes	yes	yes	no	no
Criterion 4		-	+	+	+	-	-
Supported platform		iOS 8+ Android	Windows (including Windows Phone) iOS Android	Windows (including Windows Phone) iOS Android	Windows (including Windows Phone) iOS Android	iOS Android	iOS 8.3+

5.3.2. Home automation systems

In home automation systems many sensors (many sensing devices) send the data to a hub, which manages the devices installed in a given environment on the one hand, and stores the data in a cloud storage on the other. This kind of solution allows for individual selection of sensors, however increases the overall cost and increases the number of components to be installed in a given location. During installation synchronization of sensing devices with the hub requires multiple user actions, which may be seen as cumbersome and inconvenient by some users.

The assessment of home automation systems versus the defined device selection criteria is presented in Table 5.6.

Table 5.6. Home automation systems with environmental sensors and their assessment versus device selection criteria

						
Model		NOTION	Lapka	SmartThings	Cozify	ARCHOS Smart
Criterion 1		-	-	-	-	-
Sensors	Air temperature	yes	yes	yes	yes	yes
	Relative humidity	yes	yes	yes	yes	yes
	Noise level	yes	no	no	no	no
	Luminosity	yes	no	no	yes	yes
	Concentration of CO_2 in the air	no	no	yes	yes	no
	External air temperature	no	no	no	no	yes
	External relative humidity	no	no	no	no	yes
Criterion 2		+	+	+	+	+
Price (€)		130 €	250 €	195 €	285 €	250 €
Criterion 3		-	+	+	+	-
API/SDK		no	yes	yes	yes	no
Criterion 4		-	-	-	-	-
Supported platform		iOS 8+ Android 4.3+	iOS 7+	Windows iOS Android	Windows iOS Android	iOS Android

6. Selected user device package

In chapter 5 we summarized how various devices envisaged to be used within Fit4Work available for purchase off-the-shelf fulfill (or not) the requirements of the sensing scenarios defined in Chapter 3. In the current chapter we discuss the findings in the context of the probable set defined in section 4.2. This set has been foreseen to include a wearable device, a 3D sensor for body motion capture, a device/devices for ambiental sensing and a smartphone. This setup of the user device package has been used for the following decision making process.

6.1. Criteria 'critical'

6.1.1. Criterion 1. Measured parameters

- Wearable device: only two wearable devices out of those found and analyzed by the authors are capable of sensing all parameters required by the Fit4Work sensing scenarios. These are Microsoft Band2 and Empatica E4.
- Body motion capture device: all devices listed in chapter 5 enable capturing body motion.
- Environment sensors: no device or system (consisting of a number of separate sensors) enables to measure all essential parameters. The closest to the needs is Netatmo – it allows to measure all required parameters but luminosity. In addition, it also makes it possible to directly measure external air temperature and external relative humidity.

The look into the environment sensors means that we should aim to delegate the luminosity measurement to the smartphone included in the user device package. This phone should, due to the findings of the user requirements analysis done by WP2, work under the control of the Android operating system. These two requirements are fulfilled for example by Samsung Galaxy S6 phones. The authors, having their very good experiences with using the predecessor of this model – Galaxy S5, support this model as the working candidate at this moment of the analysis. It must be noted that this smartphone is also equipped with an accelerometer. This helps to use a better strategy for detecting the type of physical activity – the method foreseen to be used by the Fit4Work system is based on this particular sensor.

6.1.2. Criterion 2. Budget

Table 6.1. Potential setups of user device package in the context of the package cost limit (€1250)

Wearable device	Microsoft Band2	Empatica E4
	€175	€1170
Body motion capture device	The most expensive – Structure Sensor	The most expensive – Structure Sensor
	€470	€470
Environment sensor(s)	Netatmo	Netatmo
	€160	€170
Smartphone	Samsung Galaxy S6 32GB	Samsung Galaxy S6 32GB
	€420	€420
TOTAL COST	**€1225**	**€2230**

At the proposal submission time the budget for one user device package has been estimated at €1250. The possible device packages (as limited by the analysis of criterion 1) in the context of this total package cost are presented in Table 6.1. Due to the high cost of the Empatica device, the package containing this wrist band is out of the assumed budgetary limit. In this place we want to stress that according to our knowledge Empatica is first of all created as a device for use by researchers. Therefore we realize that Microsoft Band2, despite providing all the necessary measurements, may provide them with lower accuracy and/or precision.

6.1.3. Criterion 3. Availability of measurements through an API

- Wearable device: Microsoft Band2, which was selected (after looking into criteria 1 and 2 above) as the foreseen wearable device included in the Fit4Work user package, allows to read all necessary measurement through a provided API. Criterion 3 is therefore met by this device which is a strong candidate for final selection.
- Body motion capture device: all devices listed in chapter 5 enable to read their tracking data via an API. However, the Creative sensor allows it only via a proprietary API – it does not support OpenNI framework. Therefore we cut this device from further analysis.
- Environment sensors: Netatmo, which was selected by Criterion 1 as the candidate, and confirmed as such by Criterion 2, allows to read the measurement through an API. These measurements are not read directly from the device. Instead they are read from the cloud operated by the manufacturer of the device. Reading measurements of luminosity sensors from the Samsung Galaxy S6 smartphone is possible for any application wishing to do so.

6.2. Criteria ‘supporting’

Due to the fact that criteria ‘critical’ have not helped to select one particular 3D sensor, we must continue with the analysis through further criteria, defined as ‘supporting’.

6.2.1. Criterion 4. Platform independence

According to the findings, none of the body motion capture devices is supported by all three leading smartphone (mobile) operating systems. However, the Structure Sensor is supported on iOS and Android systems. Asus Xtion PRO and Fotonic Astra Pro are supported by one selected mobile operating system (Android and iOS respectively). It is not possible to connect any of the other devices to a mobile device such as smartphone. The Structure Sensor becomes the leading candidate for the body motion capture device.

6.2.2. Criterion 5. Minimization of the number of devices in the user set

This criterion is not applicable to the further analysis as we aim to select a single device for body motion capturing.

6.2.3. Criterion 6. Ergonomics, usability and design

Looking into this criterion in the context of the three remaining (i.e. enabled for mobile devices) body motion capture devices should, according to us, first and foremost take account of the easiest portability of the devices (i.e. capacity to be carried around easily). The easiest portability therefore could be defined by the small physical size of a device, thus enabling the user to easily take it with themselves anywhere they desire (e.g. for a trip). In this regards the leading candidate – Structure Sensor – seems the best. This device is designed to be mounted on a mobile device such as a tablet of a smartphone. This is enabled through a mounting system using a bracket.

Due to the fact that Structure Sensor creates bigger potential for the development of the Fit4Work product after the termination of the project (richer list of supported mobile operating systems, design for mobile devices), we may decide that this device is the one to be selected as an element of the user device package.

6.3. Final selection

The discussion presented in the previous sections of the current chapter allow to define the foreseen setup of the user device package as presented in Figure 6.1. The key fact about this setup is that it fulfills of the needs imposed by criteria defining 'critical' requirements for devices. At this stage of the project execution it must be however noted that this selection should be treated as the working selection. The selected devices must be confirmed as suitable within specific research connected to the development of sensing scenarios as described in chapter 3. Moreover, they must be also confirmed as acceptable by the representatives of the target users – during the working session of the design and development process, and through pilot use.

The selected (working) user device package contains:

- Microsoft Band2;
- Structure Sensor;
- Netatmo;
- Samsung Galaxy S6.

Figure 6.1 . Selected (working) Fit4Work user device package containg all necessary sensors

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