Customization of Assistive Solutions in a Smart City Context

Matteo Zanetti, Giandomenico Nollo, Mariolino De Cecco
University of Trento, via Sommarive, 9 - 38123 Trento, Italy
matteo.zanetti@unitn.it

Abstract—Health is one of the main topics in the context of smart cities. Technologies are in continuous improvement and are playing an increasingly important role in the field of healthcare and rehabilitation. The aim of this white paper is to present innovative solutions, able to improve the self-sufficiency of patients with cognitive and/or motor impairments and help the clinicians during the rehabilitation and assistance period, giving them a suitable indicator of the patient point of view (mental stress and effort) and the performances achievable.

Keywords—Assistive technology; rehabilitation; wearable sensors; ambient assisted living, stress measurement; motion capture.

I. INTRODUCTION

The demographic studies underline how life expectancy has increased significantly, thanks to a higher life quality and the progress in the medical field. As stated by the World Health Organization (WHO), the proportion of the world’s population over 60 years will nearly double from 12% to 22% between 2015 and 2050 [1]. This phenomenon, coupled with the falling birth rate, brings to a rapid ageing of population in the most developed countries and an increase of chronic diseases and conditions. This trend could lead to a trade-off between the depletion of resources and the assurance to a fair access to healthcare services.

Elderly people that are fragile and characterized by a reduced independence need assistance by families and, in the worst cases, hospitalization in specialized structures. The result is an overload of the social assistance system. This is partly due to the fact that the patient’s house is not sufficiently safe and is not able to send to the caregiver emergency signals in case of need. It also does not facilitate the social inclusion of the person and his/her family, causing a progressive isolation. These conditions imply depression and spirit of renunciation, leading to a higher burden on the social assistance system. For these reasons, the problem is to give back to the patient the most possible self-sufficiency. In this scenario, technology plays an important role, making available solutions and aids. It can compensate the limited abilities of the user, enhancing the residual capabilities.

The development of assistive technologies is an issue that in recent years has received wide interest [2]. At European level, is active the UNCAP (Ubiquitous Interoperable Care for Ageing People) project1. Its goal is the creation of innovative products for supporting domiciliary care treatments and prevention, to delay the cognitive impairment of old people and facilitate their recovery. The project relies on an ecosystem of biosensors and localization solutions, indoor and outdoor, aimed at providing an infrastructure to continuously monitor and assist users noninvasively. Beside problems and risks intrinsic in application of devices and new procedures in hospital settings, the proposed technologies should be assessed with respect to their impact and acceptability by users and relatives-caregivers. Indeed, testing of the interaction of these technologies with the patient and his/her living environment is a poorly developed area. Furthermore, the identification of solutions capable to solve the specific needs of a patient is still an unresolved issue. An accurate assessment of patient status and needs is also required, both from a physical and cognitive point of view. Also, assistive technology should be customized on personal needs and wishes and a range of new services designed to encourage healthy lifestyles and active ageing process should be created [3].

The paper is organized as follows. In section II, the concept of Ambient Assisted Living (AAL) is presented. In section III, a brief introduction is provided about measures of emotions and effort that are used to assess the physical and mental status of the patient. In section IV, possible applications of motion capture measures in the rehabilitation field are shown, while section V concludes the paper.

II. AMBIENT ASSISTED LIVING

AAL is a term that encapsulates a set of technological solutions to make the environment in which a person lives smarter and cooperative. The main objectives are:

- to increase the period during which people can live in their favorite places, enhancing their self-sufficiency and mobility;
- to maintain the health and the functional capabilities of elderly people;
- to encourage healthy lifestyles for people at risk;
- to increase safety, prevent social exclusion and maintain the relational network of people;
- to support family members and care organizations;
- to improve the efficiency and productivity of resources in the ageing societies.

AAL solutions can help to recognize dangerous situations, monitor health and environment conditions and support the rehabilitation processes. In order to design effective solutions,
The project is aimed at implementing a laboratory for analysis and design and a domotic apartment. In the laboratory, the patient, assisted by the therapist, will try different ergonomic housing configurations to verify which tools will bring an effective benefit with respect to his/her specific functional deficiencies. The identified solutions will be then introduced in the apartment, in which the patient will experience them in a realistic scenario. The rooms of the apartment are equipped with advanced sensors to measure the performance of the user and his/her interaction with the assistive devices. The result will be a set of extensive parameters useful for diagnosis and evaluation of the patient’s status. At the end, the patient will receive a report in which the infrastructure changes that he/she should perform to his/her house and the recommended aids to improve his/her self-sufficiency are reported.

In this context, accurate measurements of stress and effort (performed at any level, i.e., muscular, cardiovascular, or cerebral), combined with the subject behavior (motion of the subject while interacting with the assistive device) and the environment status, are the main determinants for assessing the cost/benefit ratio of each specific assistive technology.

The acquired data allow to evaluate the level of confidence reached by the user while training with the provided aids. The major benefit of this user centered approach is the reduction of costs of the healthcare system: the clinicians are sure to give the most suitable solution to the patient, minimizing future hospitalizations and changes in the assistive devices.

III. MEASURES OF EMOTIONS AND EFFORT

As stated above, the assessment of the impact and acceptability of the various technological aids mainly relies on the measurement of the status of the patient and on his/her subjective feeling. Therefore, in this section, a brief introduction is given about measures of stress and effort through physiological parameters.

A. Emotional States

Emotions in human being are a complex phenomenon that has received wide interest in the last century. There is not a universal definition of emotion, but in general physiologists agree that emotions can be subdivided in a subjective feeling, a physiological response of the body and external expressions (facial expressions and body language). The various emotional states could be identified through the measurement of physiological parameters, such as the cardiovascular activity, the electro-dermal activity, the muscular activity, the respiratory activity and the mental activity.

Emotions are in some manner linked to the activity of the autonomic nervous system (Fig. 1). The autonomic nervous system is fundamental for the balance of several body functions when a person interacts with different external stimuli coming from the environment. This system acts independently, without any voluntary control and awareness. The autonomic nervous system can be subdivided in two main parts: the sympathetic and the parasympathetic systems. Both are linked at several organs, such as heart, bronchi and lungs, skin, blood
The autonomic nervous system consists of the sympathetic and parasympathetic systems. The sympathetic system is linked to the fight or flight functions, preparing the body to face dangerous situations: heart rate and blood pressure increase, pupils and bronchi dilate, digestive processes slow down, peripheral blood vessels constrict, while the blood vessels of the appendicular muscles and the coronary system dilate. The parasympathetic system acts in the opposite way, being active in situations such as digestion, rest, and energy storage. In this case, the heart rate slows down, blood pressure decreases, bronchial muscle tone increases, blood vessels dilate, the respiratory activity slows down, and the muscles relax.

Measuring the balance between the sympathetic and the parasympathetic systems gives important information regarding what is happening in the human body. A higher activity of the sympathetic system with respect to the parasympathetic system indicates that the body is under acute stress.

One of the most famous models for emotion classification is the circumplex model developed by J. Russel [5]. In this model, the affective dimensions, such as displeasure, distress, depression, excitement, and other emotional states, are assumed to be related in a highly systematic way. The model assumes that all the affective states are a combination of two main neurophysiological systems, which are related to pleasure-displeasure (valence) and to activation-sleep (arousal). Fig. 2 shows graphically this concept. The various emotions are a combination of these two main dimensions. For example, excitement is a combination of high pleasure and high arousal, while depression shows low pleasure and low arousal.

**B. Human Fatigue**

Human fatigue can be distinguished in three main categories:

- **whole body physical fatigue**;
- **localized muscular fatigue**;
- **mental fatigue**.

Whole body physical fatigue is a condition that affects the whole organism as a deterioration in physical and mental performance. It can arise due to environmental factors, such as noise, illumination and climate, psychological factors, such as responsibility, worries, conflicts and condition of health, fitness and nutrition.

Muscular fatigue affects localized areas of the body. It is the result of sustained or repeated exertions of the body. Symptoms of this kind of fatigue include the increase of the heart and breathing rate, tremor, reduced sensitivity of the muscle to voluntary requests coming from the nerve centers and profuse sweating. The efficiency of the muscle work is progressively reduced, also due to psychological factors, such as anxiety, nervousness, and apprehension.

Mental (or cognitive) fatigue is related to the cognitive activity. It can be defined as a change in psycho-physiological state, due to an intense and/or long mental effort. The main symptom is the difficulty in maintaining task performance at an adequate level.

**C. Physiological Measurement**

There are descriptions of several technologies with the aim of health monitoring in literature. One of them is the new phenomenon of Wearable Sensors [6]. These devices (Fig. 3) can be accessories or clothes and may comprise various sensors for measuring physiological parameters, such as the heart rate and the respiratory rate, the blood pressure, the brain activity, the body temperature, and the skin conductance. The general trend goes towards the development of less invasive,
low consumption and low cost devices. One of the biggest advantages of these systems is the ability to get information without having to reside in a specific place and ensure a certain freedom of movement. They also can guarantee a non-invasive 24-hour monitoring: they may allow easy monitoring of the patient’s physiological parameters during daily activities and identify potential situations of stress or overexertion. However, there are some critical challenges in the use of these devices, such as the limited battery life, privacy concerns, improvement of efficiency and non-invasiveness, clinical validation and standardization [7]. The big advantage of this kind of systems is the ability to monitor an increasing number of individuals with problematic conditions even in places difficult to reach, while still providing a prompt intervention in case of emergency. Indeed, they can establish a continuous connection between the patient and caregivers.

In [8], a brief explanation is given about the physiological parameters and sensors used to perform stress detection. The main ones are:

- the electro-dermal activity (EDA) sensors that measure changes in the electrical conductivity of the skin surface;
- the cardiovascular system activity that is frequently measured through blood volume pulse (BVP) and electrocardiography (ECG) signals;
- the facial muscle activity that is measured through electromyography (EMG). The EMG detects the electric potentials caused by the voluntary contraction of the muscle;
- the respiratory system activity that is strongly related to the cardiovascular system activity. The performed measures are usually the respiratory rate (RR) and the respiratory amplitude (RA);
- the electroencephalography (EEG) signals. In particular, research focuses on dry EEG sensors that do not require skin preparation.

One of the most frequently used physiological phenomenon to perform stress detection is the heart rate variability (HRV) that refers to the variation in the time interval between heartbeats (the R-R tachogram). The HRV is correlated with the interaction between the sympathetic and the parasympathetic nervous system. The computation of the power spectral density of the HRV makes possible to distinguish stress situations: taking into consideration the low-frequency band (0.01-0.08) Hz and the high-frequency band (0.15-0.5) Hz, the increase in the LF and in the LF/HF ratio is related to anxiety [9].

In [10], the impact of a prolonged mental activity is studied, analyzing the strong correlation between the EEG signal and the HRV power spectral density. After the feature extraction, the authors applied a support vector machine (SVM) algorithm to differentiate two mental fatigue states.

In [11], a combined cardiorespiratory analysis during mental stress is presented. The authors used the information theory to assess the interaction between respiration and HRV.

Generally, it is necessary to acquire more than one physiological signal for distinguish if a user is affected by stress or effort. For example, using only the heart rate could lead to a misclassification. Indeed, it does consider that an increasing of the heartbeats could be linked also to a physical activity and not only to a stress situation. For this reason, the development of techniques of clustering and pattern recognition is necessary for a reliable estimation of the stress level.

A comparative analysis of feature reduction and machine learning methods for physiology-based emotion estimation is presented in [12]. In this case, the physiological signals measured by the authors were ECG, respiration, skin conductance and skin temperature. The aim of the paper was to find the best compromise between the accuracy in the classification and the real-time implementation.

D. Visual Measurement

This kind of measures refers to the observation of changes in facial expressions, eye movements and head movements [13]. For example, the analysis of the eyelid activity allows extracting information about the level of vigilance. In particular, PERCLOS [14] is one of the most reliable measure of alertness level: it determines the proportion of time the eyes are closed.

The development of the computer vision technology enabled the implementation of non-intrusive devices, such as a camera, to detect the visual facial features related to fatigue.

E. Subjective Measurement

Subjective (or self-report) measures relate to how people say they feel. In general, they are questionnaires or self-assessment scales. Among them, we can enumerate the Stanford Sleepiness Scale (SSS), the Visual Analog Scale (VAS), the mood descriptors and the diary method.

F. Performance Measurement

These methods rely on a set of performance tasks to determine the level of stress. The advantage of this kind of measurement is that they are indirect, but the main drawbacks
are that usually they cannot be self-administered. Indeed, they need expert data analysis and are limited to laboratory studies. An example is the Walter Reed performance assessment battery [15].

IV. MOTION CAPTURE MEASUREMENT

A motion capture system allows recording the movements of people or objects to render a 3D computer model that is useful for recreating the motion and for obtaining a very detailed analysis of even complex movements. These systems can objectively extract movement parameters otherwise invisible to the human eye.

In clinical settings, a motion capture system could be useful for what concerns the rehabilitation and ergonomics studies. For example, also in absence of the caregiver, the system could determine if a complex activity is made in a proper way and the extracted parameters can be related to posture, balance and motor control. It helps to identify the problems that the patient encountered during the execution of the various tasks.

There are different types of motion capture systems. At first sight, these systems can be subdivided in two main categories: marker-based and marker-less. Generally, the systems that use markers are more accurate, but more expensive. Moreover, this kind of systems requires a certain amount of time in the preparation of the subject, because the markers must be placed in a very precise manner and they can also affect the naturalness of movements.

For the above reasons, in the last years there is a growing interest in marker-less technologies, that have the benefits to be cheaper and portable. One of them is the Microsoft Kinect sensor (Figure 4). A study of the possible use of these sensors in the rehabilitation field was conducted in [16] and [17].

V. CONCLUSION

This paper presented some examples on how technology can improve the quality of social assistance services. In particular, it was shown how motion capture systems and wearable devices can be used to monitor and evaluate the status of the patient in a non-invasive manner. Given the variety of syndromes and correlated deficiencies, the different response of the single user and/or his/her environment, it is of paramount importance to identify personalized solutions that optimize the cost-effectiveness. It is therefore important that the process of identification and allocation of the various assistive devices should be based on specific and personalized studies for every single patient. A good solution could be training the user with facilities such as the ones explained in section II. In this case, the patient could try the possible assistive/domotic solutions and the therapists could have an objective indicator of the performance and the benefits that these technological aids could lead in the daily life of the patient.

REFERENCES

Matteo Zanetti received the MEng in mechatronic engineering from the University of Trento (Italy), where he is currently a student of the Doctoral School in Materials, Mechatronics and Systems Engineering. His research regards measurement systems for assistive technology, focusing in particular on integrated measures of physiological stress and motion capture.

Giandomenico Nollo, Italian degree in Physics, and PhD in Physiologic. Chair of the Healthcare Research and Innovation Program of the Provincia Autonomous of Trento at FBK, chair of the Health and well-being working group of IEEE Trento Smart City initiative, Fellow researcher at Department of Industrial Engineering University of Trento. He has been responsible of several research projects and grants in health Sciences and technologies. He is co-author of more than 150 papers on human biosignals monitoring and modelling of cardiovascular and brain systems, health technologies development and assessment. He taught courses at University of Trento and University of Verona in the field of Bioengineering and Health Physics. He was advisor of several thesis of laurea in Physics and Engineering, and promoter of PhD thesis. He was organizer and chair of international conferences, founder of the Italian Society for Health Technology Assessment (SIHTA) and actually member of its steering committee. Member of the IEEE society.

Mariolino De Cecco, PhD, associate Professor of Mechanical Measurements and Robotics at the University of Trento. Head of the MIRO (Measurement, Instrumentation and Robotics) laboratory. http://www.miro.ing.unitn.it/ Main fields of research are measurements, robotics and space. Participated as local responsible in the framework of international projects such as UNCAP H2020, VERITAS FP7 IP, AGILE Eurostars. Co. Investigator of OSIRIS payload of ROSETTA, ESA Cornerstone Mission. Participated to the LISA TEAM (LISA - ESA Cornerstone Mission). Co-proposer and member of the steering committee of the AUSILIA project. Co-founder of Robosense, University startup company. Referee of different international papers and congress, and of different national and international research projects. Author of more than 70 papers on international journal with referee, 1 book chapter, 39 papers on national or international congress with referee, H-index 20.