WIRELESS BODY AREA NETWORKS: A NEW PARADIGM OF PERSONAL SMART HEALTH.

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Abstract—In recent years, the healthcare system is undergoing a profound change shifting from a reactive care, in which people are treated when necessary, to proactive care, based on people's involvement in their own health on a daily basis. This innovative model of healthcare provision aims to expand the capabilities of the healthcare systems outside hospitals, relying on recent technological advances in the development of smart systems. Of paramount importance for this model to be effective is the possibility to access the physiological state of patients in daily life settings, with the purpose of improving diagnosis and treatment of diseases in a personalized fashion and of empowering people towards a major awareness in the management of their own health. Favoured by the latest improvements in both sensors manufacturing and information and communication technologies, wireless Body Area Networks (BAN) represent a smart solution for the multiparametric collection of physiological data. These systems are constituted by networks of wearable sensors that wirelessly communicate to a central unit, satisfying requirements of portability, non-invasiveness and real-time continuous moni- toring. The aim of this white paper is to highlight the impact of wireless wearable multi-modal recording in healthcare, reviewing the most important applications in today's smart cities.

I. INTRODUCTION

One of the main challenges smart cities need to cope with is the increase in world population. According to the United Nations 2015 World Population Prospects [1], the number of people is projected to increase by more than one billion within the next 15 years, reaching 8.5 billions in 2030, and to increase further to 9.7 billions in 2050 with 66 percent of people living in cities [2]. This rapid growth requires the development of new efficient and sustainable solutions in smart cities, involving many different application scenarios, such as energy distribution, transportation, communications, healthcare, government, just to mention some examples.

Within the same context, the recent technological advances have fostered the widespread integration of ICTs in everyday activities. Smartphones, Cloud Computing and Internet of Things represent the fundamental constituents of nowadays' smart systems, that drive the change for a smarter world based on instrumentation, interconnection and intelligence [3]. In- strumentation enables the collection of real-time data through embedded sensors that communicate over wired or wireless networks. As an example, one may think at video-surveillance cameras in public spaces, electricity meters in households, humidity sensors in museums. The interconnections favour new ways to share information. Finally, intelligence is needed in terms of new computing models, algorithms and advanced analytics to treat massive amounts of data provided by smart sensors and to enable better decisions for cities and citizens.

Fostered by demographic issues and technological trends, the healthcare system is experiencing a shift, going from an episodic care provided by hospitals when needed, to a proactive care, in which citizen are actively involved in the management of their own health, thus reducing the demand on healthcare structures and guaranteeing better prevention.

In order to empower people towards a more efficient and sustainable healthcare system, several solutions have been proposed to collect and analyse data, as well as to infer the cognitive and physical state of a subject, without the need for medical doctors to assess the condition themselves. Data collection is favoured by the massive use of mobile devices and the widespread adoption of wearable sensors having the capabilities to gather information from a wide variety of physiological districts non-invasively and most naturally. Whereas most systems that are available nowadays allow the monitoring of a single physiological parameter at a time, clinical applications usually require a wider picture of the patient's physiological status, that may be provided by the combination of the information coming from different physiological systems. In this context, Body Area Networks (BANs) have been proposed as a smart paradigm for the simultaneous acquisition of multiple physiological parameters. In order to better understand the evolution of physiological monitoring leading to the introduction of BANs in today's society, a brief historical overview is presented in the next section.

II. BRIEF HISTORY OF PHYSIOLOGICAL MONITORING

The first scientific report of acquired physiological data dates back to the eighteenth century, in the work of Sir John Floyer. He was the first physician to measure the pulse in his routine clinical practice and invented what is known as the Physician's Pulse Watch, one of the first portable clocks implementing a seconds hand that could be stopped using a special lever [4]. This horological innovations allowed accurate pulse rate measurements, as well as respiration rate measurements, that were published in two volumes in 1707 and 1710. One and a half century later, the first record of a patient's temperature was published by Ludwig Taube, who employed a spirit thermometer to measure body temperature. The measurement of a fourth fundamental vital sign, blood pressure, was made possible by the introduction of the sphygmomanometer by Scipione Riva-Rocci in 1896 [5].

With subsequent improvements in measurement accuracy, pulse rate, respiratory rate, temperature and arterial blood pressure started to be considered as standard vital signs to be monitored in hospital care, and since the 1920s all patient charts report such measurements.

Fig. 1. Typical monitoring equipment that is found in ICUs. Attribution: [6]

Significant improvements in measurement of the cardiac activity happened at the beginning of the 20th century, with the invention of the string galvanometer for the measurement of the electrocardiogram (ECG), the first instrument providing continuous recording of the electrical activity of the heart [4]. Its creator, Willem Einthoven, was awarded the Nobel Prize in physiology in 1924. The possibility to measure the electrical activity of the heart opened new ways for the monitoring and treatment of acutely and chronically ill patients, so that by the late 1950s new organizational units, the intensive care units (ICUs), were introduced in hospitals. The first ICUs were simply rooms for prolonged stay after open-heart surgery, in which patient's vital signs were constantly monitored by specialized nurses. However, the fast development of transducers and electronic equipment during the World War II made it possible to obtain more and more automated instruments, until computers were introduced for physiological monitoring into the ICUs. The early bedside monitors were built around analog-computer technology and derived data from analog physiological signals, while subsequently digital instruments were introduced and the acquisition process became fully digital.

Recently, patient monitors have evolved in order to allow the measurement of many parameters including blood gases, chemistry and hematology. They are mostly employed in hospital's ICUs for the care of critically ill patients (Figure 1), however it is possible to find them also in medical- surgical units, as well as in labor and delivery suites, in emergency rooms, or even at patient's homes, for diagnostic or therapeutic purpose. This kind of medical devices include the most accurate and up-to-date medical instrumentation, that allows to acquire physiological parameters from non-invasive sensing equipment. However, they require patients to be in a hospital, in a care facility or at home in a bed, resulting in a reduced, if not suppressed, daily routine for the patients.

On the other hand, many solutions are being developed nowadays in order to enable patients to have the greatest possible level of autonomy and independence, while keeping safety and health monitoring at the first place. Among the most recent developments and as an evolution of pioneering studies [7], Body Area Networks represent a smart solution for the integration of sensing equipment in daily activities. BANs are special purpose sensor networks constituted by a system of devices and appliances placed in close proximity to a person's body, that guarantee the simultaneous acquisition of physiological parameters coming from different physiological systems. They are specifically designed for medical or health- care applications [8]–[10]. These devices include low-power, miniaturized, lightweight, wireless sensor nodes that monitor the human body functions and communicate to a central control unit, whose purpose is to provide the connection to a range of different services. Patients' data may be for example transmitted to a hospital or to a medical doctor, it can be stored in a patient record database or sent to a processing unit for further elaboration (Figure 2).

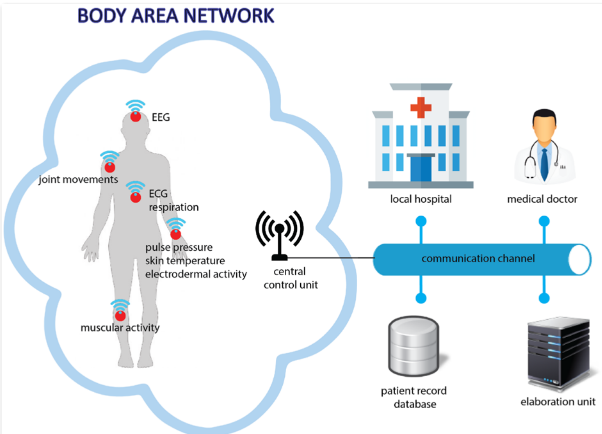

Fig. 2. Schematic architecture of a wireless BAN.

III. ENABLING TECHNOLOGIES

Body area BANs result from recent technological advances in at least three different fields:

- Sensors manufacturing
- Telecommunications
- Data analysis tools

A. Sensors manufacturing

The development of real portable systems was prevented in the past by the size of the sensors used for the acquisition of physiological signals and the electronics that was needed to acquire, process, store or transmit data from the acquisition site. However, these problems have been addressed thanks to recent advances in manufacturing of sensors that have drastically reduced the sensors' dimensions. Nowadays, a recent fabrication technique for the production of microelec- tomechanical systems (MEMS) allows to realize sensors with dimensions ranging from 20 micrometres to 1 millimetre.

Moreover, the integration of different components in small units is favoured by advances in System-on-Chip strategies, that result in integrated circuits combining sensing equipment, amplification stages, data processing hardware and also trans- mission modules.

In addition, recent developments in textile fabrication tech- niques have favoured the introduction of sensors that are integrated into garments, thus guaranteeing maximum comfort and ease of use for body-worn sensors. As an example, the WEALTHY system developed by Smartex s.r.l. is a sensorized t-shirt that is equipped with strain sensors, pressure sensors and electrodes that are fully integrated into the garment, employing smart materials such as piezoresistive yearns or sewing fibers containing metals into the textiles [11].

B. Telecommunications

As for the communication between different sensing units, efforts have been directed towards the development of low- power and low-cost wireless communication standards, em- ploying very small transmitters and receivers. In these regards, it is worth mentioning the work of the IEEE 802.15 working groups, that specifies wireless personal area network standards. Protocols such as the well-known Bluetooth or ZigBee are part of the 802.15 specifications [12], as well as the regulations on primary issues in wireless communications between wearable devices, such as data-rate, battery life, security.

C. Data analysis tools

Advances of data analysis techniques in the fields of sig- nals processing, pattern recognition and artificial intelligence represent the basis underlying all the stages of the acquisition chain consisting in recording, digitalizing, processing, storing and transmitting physiological signals. Because of the huge amount of information that could be potentially collected every day, interest in how to treat Big Data [13] has started to enter the healthcare context. Particular emphasis is placed on the analytic tools for the extraction of physiological or clinical parameters from the recorded data. As an example, the online recognition of cardiac disturbances such as atrial fibrillation is made possible by the adaptation of optimized algorithms for the implementation on on wearable devices [14]. Moreover, analytical frameworks are being developed for the integration of the data coming from different physiological systems. A recently-proposed paradigm called Network Physiology aims to study the human body from an integrated perspective, in which physiological systems do not evolve in isolation, but continuously interact to preserve the body functions [15]. The interactions between physiological systems are reflected into the properties of the recorded multiparametric physiological signals, that are analyzed using well-defined frameworks, such as that of information dynamics [?], [16].

IV. APPLICATIONS

A. Remote monitoring

One of the main potentialities of BANs is the possibility to provide a continuous monitoring of patients affected by long-term or chronic diseases, in the attempt to help the treatment of the disease and/or the response to acute episodes. Currently, healthcare costs and management usually prevent the possibility for patients to be monitored for long periods, either in hospitals or using expensive medical devices for home-monitoring that are borrowed for limited amounts of time. BANs may provide a relatively low-cost alternative that benefits both the patient and the healthcare facilities, relieving the burden of periodic medical examinations on hospitals and allowing the patients to conduct their usual daily life. Several solutions are being developed in this direction, where the simultaneous recording of different physiological parameters serves the purpose of offering a wider clinical picture of the patients' status. As an example, the detection of epileptic seizures is receiving much attention, because of the impairing consequences related to the acute episodes. Indeed, acute episodes result in a complete impossibility for the subject to interact with the surrounding environment. Thus, being able to detect such episodes may be crucial for an immediate intervention of clinical personnel. Since epileptic seizures are characterized by stereotypical movements accompanied by changes in the electroencephalographic activity, current seizure detection system combine accelerometers, EMG and EEG signals [17], [18]. Parkinson's disease is another critical application of BANs. Detecting slowness of movements or muscle rigidity may help in preventing falls, reacting to them and better characterize the current state of progression of the disease [19]. Cardiovascular system functions are also worth monitoring because of the high mortality rate related to cardiovascular diseases. Whereas pioneering studies applied the BAN concept to ECG monitoring [7] (Figure 3), current systems are developed for the simultaneous recording of multiple physiological variables of interest, including heart rate, blood pressure, skin temperature, respiratory pattern [20].

B. Rehabilitation

Another application where BANs may provide great im- provements is home-rehabilitation. Rehabilitation is a process in which the patient needs to restore through training and therapy their functional capabilities after an injury, illness or disease [21]. Functional capabilities may involve physical, mental or sensory functions. A proper rehabilitation is funda- mental after disabling conditions, because it can completely or at least partially reverse the impaired patient's capabilities. On the other hand, the rehabilitation process must be followed by qualified therapists, as a wrong rehabilitation may even lead to a worsening of the disabling conditions, that may not be easily recoverable at a later time. However, therapists have limited availability and rehabilitation may be a long process.

BANs represent a turning point in this scenario, allowing rehabilitation to be performed by patients at home and without the need for a therapist to be physically present. Indeed, such devices may not only record, but also analyse the data coming from sensors in real time and provide guidance or feedback to the patient. Alternatively, a structured rehabilitation program may be implemented via scheduled exercise sessions that are remotely monitored [22]. As a further benefit, the recorded parameters may provide additional information with respect to the usual clinical monitoring. This is for example the case of physical rehabilitation performed through the use of accelerometers data, that may offer considerable improvements in tracking patients' movement especially around complex joints, where visual evaluation is often difficult [23], [24].

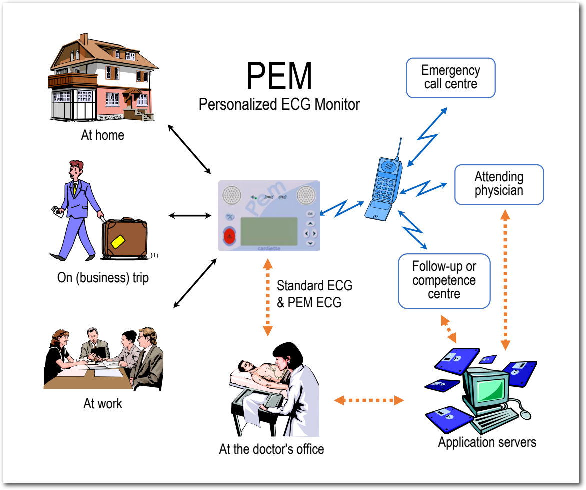

Fig. 3. Application of the BAN concept to cardiac monitoring: use case scenario of the EPI-MEDICS Personalized ECG Monitor [7].

BANs are also combined in today's systems with the potentialities offered by virtual reality, making it possible to create an interactive experience that fosters motivation and engagement in pursuing rehabilitation exercises, while maintaining a high reliability in tracking movements or ac- tions, for an effective rehabilitation output. This is particularly effective in neuro-motor rehabilitation, required for example for patients that suffer from motor disabilities or neurological injuries following a stroke. The rehabilitation therapy usually consists of repeated exercises, that can be facilitated through virtual reality, where even complex movement patterns may be presented to the user, while the movement is tracked using wearable sensors and feedback is provided about the accuracy of the performed exercise. Moreover, systems may also integrate EEG sensors to test the effectiveness of the rehabilitation in terms of functional recovery of the affected brain areas [25].

C. Biofeedback

Biofeedback systems represent another promising applica- tion for BANs. The term biofeedback (extrinsic feedback, aug- mented feedback) refers to the techniques aimed at providing biological information to patients, in addition to that generated by intrinsic body sensory receptors. This information has the purpose of improving patients' performance in daily activities by teaching them how to control their own physiological regulation processes, that are usually considered as automatic, and may be conveniently collected through a BAN [26].

Biofeedback techniques can be categorized in two groups based on the measured parameters, being physiological or biomechanical [27]. Physiological biofeedback monitors car- diovascular, respiratory or neuromuscolar systems, whereas biomechanical biofeedback measures movements, postures and forces. The information about the monitored biological pro- cesses may be fed to the user directly, as a visual information displayed on a screen, or indirectly, transforming the measured quantity into an auditory, visual or tactile feedback. Although many biofeedback systems are used for rehabilitation purpose, the potential applications are much wider. Indeed, biofeedback has proven its efficiency in controlling involuntary body functions or emotional states, such as chronic neck pain, stress-related hypertension, migraine headaches.

D. Ambient Assisted Living

Last but not least, BANs find great applicability in ambient assisted living. Ambient assisted living technologies include systems that are aimed at guaranteeing an improved indepen- dence and a better quality of life to people that need continuous healthcare assistance, due to motor and/or cognitive disabilities.

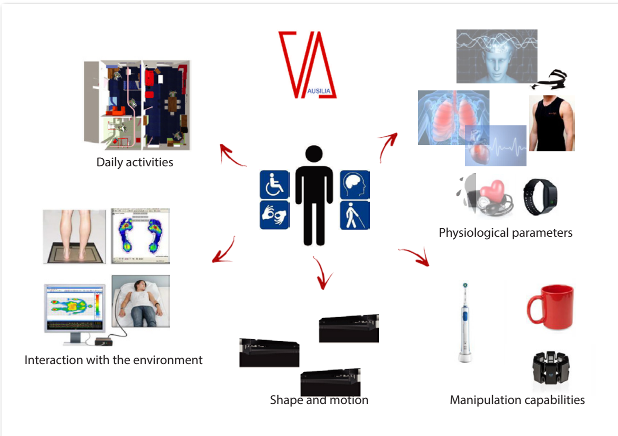

Fig. 4. Application to the BAN concept to the AUSILIA paradigm: framework of the sensing infrastructure of the apartment [28].

This systems usually include domotic appliances or hous- ing facilities, aimed at addressing the specific patients' needs, as well as ambient sensors installed in the living areas to monitoring patients' activities and provide a feedback to healthcare professionals or family members. In addition, a fundamental role is played by physiological monitoring systems, that are aimed at evaluating the patients' emotional or cognitive effort coming from the interaction with the assistive technologies and inferring their health status [29]. Being quality of life one of the main points of ambient assisted living solutions, physiological monitors must be as less invasive as possible, guaranteeing maximum portability while providing clinically relevant information. Given these requirements, BANs seem to represent a very effective solution.

An example of applied ambient assistive living concept is the AUSILIA (Assisted Unit for Simulating Independent LIving Activities) project, an initiative coming from the collab- oration between the University of Trento and the Local Health Trust [30]. The purpose of the project is to foster indepen- dent living of patients suffering from impairing conditions or recovering from traumas. To this aim, the AUSILIA project relies on a sensorized apartment and an evaluation gym, aimed at providing a transit infrastructure between hospital care and dehospitalization. The apartment is equipped with the newest assistive facilities such as special furnitures or ad- hoc tools. Moreover, state-of-the-art sensors and cameras are installed with the aim of tracking, recording and providing feedback about the patients' activities while interacting with the environment (Figure 4). The gym on the other hand is useful to give the possibility to patients to try different furnitures or instrumentations suitable to their specific needs. The effective apparatus will be then transferred to the patients' house after dehospitalization. The whole process is facilitated by monitoring the vital parameters of the patients, via a BAN employing a sensorized t-shirt, a wrist-worn sensor and an EEG headset. All devices are wireless and wearable, and communicate in real-time to a central unit that process- es patients data. The recorded signals are electrocardiogram, respiratory pattern, skin temperature, skin conductance, blood volume pulse and electroencephalographic activity. Physiological monitoring is fundamental in this context, in order to create a better picture of the patients' cognitive and emotional status in the interaction with the assistive technologies. The extracted information can be fruitfully used to favour a more accurate selection of the right apparatus meeting the patient's needs, based on quantitative physiological evaluations.

V. CONCLUSION

This white papers aims at highlighting the importance of smart solutions for the pervasive provision of healthcare to citizens living in smart cities. In particular, wireless BANs represent a turning point for the multiparametric physiolog- ical monitoring outside hospitals. Recent applications have demonstrated the potential of such systems in the treatment of diseases, monitoring of health status, physical and cognitive rehabilitation, ambient assisted living, the benefits involving healthcare facilities, caregivers, patients and their relatives. The ever-increasing use of BANs in many healthcare scenarios represents an important step forward towards the application of proactive models of healthcare in smart cities.

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