1. Paradigms for Acquisition and Automatic Processing of Physiological Signals using Wearable Devices

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Abstract: *In recent years there has been a growing interest in the use of solutions for continuous monitoring of the health state and well-being of people using wireless devices, wearables in particular, which enable remote acquisition and analysis of physiological data. A massive amount of health-related data is acquired, processed and transmitted daily, leading to new problems such as the need to transmit large amounts of data with battery-powered devices and their automatic interpretation. The design of systems for remote monitoring and automatic interpretation of physiological data is a challenging task, which benefits from the use of new compression and signal analysis paradigms. In particular, the new data classification and analysis tools made available by the use of artificial intelligence and machine learning techniques constitute a very interesting possibility for the interpretation of the acquired physiological data. In this Chapter, we address the problems of compression and analysis of physiological data using Compressive Sensing (CS) and sparse signal processing, as well as their interpretation using automated systems based on Machine Learning (ML) techniques. As case studies, we consider the acquisition of the Electrocardiogram (ECG), and its processing in the compressed domain to compute heart rate variability. Moreover, we describe the results obtained from the automatic classification of arrhythmias, still after acquiring the signal in the compressed domain. Focusing on the general case of people's well-being assessment, we will present the results obtained by analyzing, in addition to the ECG, the Electrodermal Activity (EDA), which has been shown to be highly correlated with the reaction of the sympathetic nervous system to stress. A complete system, describing the acquisition and analysis using ML techniques, will be presented.*

1.1 Introduction

The use of telemonitoring systems, in particular the concept of Wireless body sensor networks (WBSNs), promises to allow continuous and remote monitoring of physiological signals [1, 2, 3, 4]. Wireless functionality allows the devices to continuously transmit a subject's data to a server, overcoming the limits of wired technology that restricts subject's movements and everyday life. One of the most important applications of such recently available technologies is telemedicine, which is particularly useful since it may reduce costs of hospitalization and provide remote analysis in sparsely populated or quarantined regions. As an example, Figure 1.1 shows a possible setup for continuous monitoring of a person's physiological and inertial signals (e.g., recorded via Inertial Measurement Units (IMU)), which can allow to track the mental and physical state of the subject in telemedicine and Human Activity Recognition (HAR) applications. Possible scenarios in which similar approaches can be adopted, among others, range from automatic stress

2. Design and Deployment of Data-driven Solutions for Medical Image Analysis

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Abstract: *It is increasingly evident that the design of image analysis systems in the medical field can no longer be conceived as focused exclusively on visual processing technologies and algorithms. To better express and envisage real uses of modern data-driven approaches, and in particular of deep learning architectures, it is necessary to involve a rethinking of how to approach problems that require a careful balancing of perspectives according to collaborative and transdisciplinary design paths. Following the traces left by a concrete experience made in the period of the COVID-19 pandemic, this chapter aims to touch and connect the salient points of a modern approach from the design to the deployment of image analysis solutions in the biomedical field.*

2.1 Introduction

Several types of sensors generate different forms of data representative of the most diverse physical realms. The developments in the field of Artificial Intelligence (AI) are expanding the horizon of applications critically relying on the interpretation of this abundance of acquired digital data. This is changing the way researchers approach their own disciplines and the relationships with others, opening new perspectives but also new issues and related research challenges. The world of signal processing and image analysis in the various biomedical domains is no exception [1].

Today, it is difficult to find a decision-making process that involves the analysis and interpretation of dense data – i.e. acquired with instrumentation that replaces or enhances the human senses, such as sight and hearing – which escapes the possibility of an interpretative approach exploiting AI, and in particular Deep Learning (DL) techniques. It is as if it became more natural to approach a perceptual problem with an interpretative approach similar to the one governing the interpretation of data which are perceived by human senses, although in a more or less mediated way with respect to measurement and reproduction devices. There is no doubt that DL techniques are raising the bar of the difficulty of treatable analysis tasks, but it is now clear that this cannot fail to involve far-reaching changes in the way to approach complex data analysis problems. This necessarily involves a broadening of thought around the implications of technological solutions aimed at entering into a dynamism, if not sharply substituting, at least highly adjuvant to human reasoning. In a simplified view, the possible design of technological solutions capable of offering performance equal or superior to that of the clinicians is certainly a source of enthusiasm but also a possible source of bewilderment and frustration for the ICT scientist. In fact, it can be much

3. E-Health at the Edge: A Layered Approach based on Wearable Computing Systems

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Abstract: *The Edge computing paradigm has been recognized as an essential alternative to standard cloud-based approaches to support pervasive and time-dependent applications. An Edge-based approach is then essential to support human-centric applications in the context of the healthcare industry. Innovative e-Health and Ambient Assisted Living (AAL) solutions can be obtained through the integration of existing platforms and services. Moreover, in such contexts, wearable computing systems (WCS) are becoming a "de facto" standard to continuously monitor individuals. To this aim, it becomes crucial to exploit WCS platforms and follow an interoperability specific strategy of seamless integration, interconnection and merging of heterogeneous systems. This approach allows to build up new ecosystems WCS-based, on top of which value-added applications can be implemented, designed, managed and executed. A WCS-based architecture along with a simulation-driven design strategy and some realistic healthcare and AAL use cases will be shown to demonstrate the effectiveness of the proposed approach.*

3.1 Introduction

In recent years, the Internet of Things (IoT) paradigm has emerged as one of the most interesting technology topics since it enables many services and trends related to different and challenging communication scenarios. For this reason, thanks to its multidisciplinary approach, IoT is actually revolutionizing many aspects of traditional healthcare paradigms since traditional healthcare systems can no longer satisfy the needs of a continuously growing society such as the inherent need of assisted-living environments for elderly people [1].

In this evolutionary context, interconnected sensing technology, such as that provided by IoT wearable devices, presents a promising solution for objective, reliable, and remote monitoring, assessment, and support through ambient assisted living (AAL) [2]. In fact, both the market and the research community have experienced an exponential growth in the use of wearable technologies, and these are now considered to be of critical importance in certain consumer goods and services sectors, including healthcare [3]. Furthermore, the integration of wearable computing devices in modern Edge computing IoT systems [4] can accelerate, not only in the healthcare area, the development of mobile solutions based on the people-centric paradigm with evident repercussions on improving the quality of life.

Following this modern vision, healthcare Edge computing is becoming a way to collect and elaborate near real-time results by processing data as close as possible to the source, clearly stating

4. From Brain-Machine Interfaces to Neurorobotics

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Abstract: *Brain-machine interfaces (BMIs) allow humans to interact with external devices through their electroencephalographic (EEG) activity, and represent an alternative communication and/or control channel for people suffering from severe disabilities. The technology has paved the way to a new interdisciplinary research field: the neurorobotics. The main objective of neurorobotics is the development of techniques endowing assistive devices, such as telepresence robots, powered wheelchairs or exoskeletons, with the capacity of understanding and translating human intention into real-time driving signals for the robotic system. In this chapter we will present the latest advances in the field to increase the reliability and robustness of brain-actuated devices. In particular, we will focus on techniques to fuse multimodal neurophysiological signals with the robot's intelligence and to contextualize high-level BMI user's commands according to the surroundings. Furthermore, we will highlight the necessity to promote the active role of the robotic intelligence in order to improve the recognition of the human motion intention, to enhance the human-robot interaction and to maximize the provided assistance in out-of-the-lab neurorobotic applications.*

4.1 Introduction

In the last few decades, scientific, medical and industrial research communities have shown a greater interest to the field of rehabilitation and health care. The interest resulted in the spread of technological solutions for assistance with the aim of improving the independence and the quality of life of people with motor, sensory or cognitive impairments, due to degenerative diseases (e.g., Parkinson, multiple sclerosis) or traumatic lesions (e.g., stroke, amputations, spinal cord injury). In this sense, the use of robotic devices has shown to be particularly promising in rehabilitation or assistance of people with motor deficits in order to perform tasks related to daily living activities [1]. The first practical applications brought out the necessity of focusing the research activities in the design of advanced interfaces between the human and the robot to allow a natural and efficient interaction, that should be also safe and fast. In this context, brain-machine interfaces (BMIs) represent a now well-known technology to record and translate brain electrical signals into outputs for several external devices, such as powered wheelchairs, telepresence robots, robotic arms and lower-limb exoskeletons [2]. This tendency of using neurophysiological signals to control robotic actuators set the birth of a new inter-disciplinary field, the *neurorobotics*, that highlights the complexity of the challenge linked to the capacity of measuring and understanding human intention from neurophysiological signals and covert them into control signals for the robot [3]. Indeed, even if neurophysiological interfaces have shown to be well-suited for people with a high level of disability, they are intrinsically noisy and due to the non-stationary of neural signals. As a consequence, the use of these communication channels to control a robotic device requires high workload for the user making their use alone unfeasible in applications outside a laboratory environment. Thus, it is of fundamental importance to equip assistive robots with both an

5. Cyber-physical Platform for Parkinson's Disease Stage Assessment based on the Neuro-Muscular Involvement during Gait

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Abstract: *One of the most common neuromuscular disorder recorded in people affected by Parkinson's disease (PD) is the presence of abnormal patterns in the gait cycle. For this reason, gait disorders assessment constitutes one of several parameters commonly used in the clinical practice to assess the disease progression. This chapter proposes an architecture that combine a Wireless Body Area Network (WBAN) and an FPGA-based computation core for the identification, and the real-time extraction, of gait-related diagnostic indexes oriented to the assessment of neuromuscular syndromes progression in the PD. Specifically, the proposed wearable and wireless architecture analyzes signals from 7 electrodes for electroencephalography (EEG) and 8 electrodes for electromyography (EMG) during walking. The EEG setup allows to study the motor-cortex area involvement, while the EMG one monitors the lower limb muscular patterns. The signals, transmitted to an Altera Cyclone V SE 5CSEMA5F31C6N device are digitized and pre-processed on-board. Next, data undergo to a time-frequency features extraction (FE) to define the diagnostic indexes. They will be used as input for a classification stage based on a Serial Support Vector Machine (SSVM). The system has been in-vivo tested on 5 subjects (n=3 affected by mild PD and n=2 by severe PD), showing an accuracy of 94% in the pathology stage recognition. In a future perspective of an application-specific integrated circuit implementation, the real-time data processing has been fully realized on the Altera Cyclone V FPGA. It returned an overall resources consumption of 31.04% adaptive logic modules, 15.87% registers, $< 6\%$ memory blocks and the 82.75% DSP blocks with respect to the available hardware provided by the target device.*

5.1 Introduction

PD is the second most common neurodegenerative disease after Alzheimer's one. The pathology incidence is globally critical, indeed, PD affects up to 18 people out of 100k every year [1]. It is characterized by a set of motor and non-motor symptoms that occur during the pathology stratification. Some of these symptoms are more common and constitute the guidelines for PD diagnosis. They include bradykinesia, rigidity, rest tremor, joints pain, *postural instability*, and *gait difficulties*. The present chapter focuses on those motor features that are affected by a progressive loss of dopaminergic neurons in the substantia nigra(i.e., mainly the last two). Although these symptoms are currently fought through a dopamine replacement therapy (i.e., L-dopa), it returns benefits only in the early stages of PD while, in later stages, it leads to disabling motor complications, such as the wearing-off phenomenon (end-of-dose deterioration) and *abnormal involuntary movements* (dyskinesia) [2], [3] .

6. Patient Monitoring through eHealth Solutions: A Signal Processing Perspective

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Abstract: *Thanks to the widespread dissemination of Information and Communication Technologies (ICT), patients are very often treated at home. In this environment eHealth systems, through the employment of Internet of Things (IoT) and technologies, allow enabling remote patients monitoring. Such systems require a seamless integration of heterogeneous sensing units and medical devices, in order to acquire, process and infer high-level information on the patient's status. At the same time, an ubiquitous, secure, reliable and real-time access to such information must also be granted. Following these guidelines, this chapter describes two eHealth systems which aim at remotely monitoring patients by employing beyond State-Of-The-Art signal processing solutions. The first one is SmartPants an IoT-based wireless system specifically designed for the remote rehabilitation of lower limbs in post-stroke patients. It consists of multiple IoT nodes and a software application that provides real-time feedback on the rehabilitative exercise currently being performed by the patient. The second eHealth system is SmartGlass. It is a prototype of wearable IoT-based glasses able to detect external symptoms in the very early stages of neurological diseases. Namely, SmartGlass is able to detect the presence of Essential Tremor (ET) of the head and to count the number of EyeBlinks (EBs) at the same time. Every system tackles a different eHealth problem from several viewpoints: i) data sensing and processing, ii) information extraction and analysis and iii) employed network architecture for information handling. For each of the aforementioned eHealth system, the employed approach will be deeply described along with the numerical results related to its performances.*

6.1 The future of healthcare: IoT for eHealth

In the latest years, the Internet of Things framework has gained increasing success, encouraging new trends and enabling innovative smart services. New concepts have been introduced, such as smart home, smart city, intelligent and connected vehicles, eHealth, smart factory, and many more [1]. Indeed, a variety of frameworks are benefiting from the great technological innovation derived from the IoT environment, thus enabling interactive smart spaces, advanced worldwide logistics, connected vehicles and an ICT-based healthcare system [1, 2].

The basic innovation introduced by IoT consists in relying on a massive presence of nodes, characterized by different capabilities, energy, and size, always connected to each other and to the Internet. The hugest impact provided by IoT lies in the diffusion of a large number of nodes differing in size, energy and storage characteristics, featuring direct interconnection among themselves and to the Internet. This framework provides concrete opportunities to exploit the capabilities derived from a huge and smart connected network of *things*. In this context, there are peculiar applications that are gaining special benefit from the current IoT revolution, due to their inherent

7. DOMHO: A Smart Assisted-living Solution for Fragile People

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Abstract: *The chapter discusses the potential of the Internet of Things (IoT) paradigm in the context of assisted living for elderly and fragile people, in the light of the peculiar requirements of such users, both from a functional and a technological perspective. We stress some aspects that are often disregarded by the technical community, such as technology acceptability and usability, and we describe the framework and the phases of the current co-design approaches that imply the active involvement of the final users in the system design process. Thereby, we identify a series of design practices to merge technical and fragile people's requirements. Our analysis is backed up by the description of DOMHO ,[1] a prototypal IoT-based ambient assisted living (AAL) system that embodies most of the concepts described in the chapter, and that has been deployed in an apartment for the co-housing of individuals with disabilities, but was also designed for other environments, like shelter houses for elders. The first DOMHO realization in Treviso (Italy) received large media attention at the regional and national level, confirming its relevance for improving the quality of life of our society.*

7.1 Introduction

The European Commission recently reported that about one fifth of the European population suffers from some form of cognitive, perceptual or motor disability, making them *fragile* people [1]. To address this scenario, the Information and Communication Technologies (ICT) community is targeting new effective solutions for Ambient Assisted Living (AAL), in order to preserve daily living independence of impaired individuals at their future *smart houses*. This has been showed to highly increase the overall Quality of Life (QoL) of elderly and fragile people [2].

Modern AAL implementations consist of domestic environments that are equipped with a number of smart, interconnected devices that can continuously collect both health-related data from the users and environmental data from the surrounding space. Such data can then be used locally or sent to remote sites for further processing and storage, to finally become useful information for the persons in need, caregivers and medical doctors [3, 4]. In particular, in the last years there has been a growing standardization effort that promoted interoperability at all levels among devices from different manufacturers, thus expanding the concept of *ambient* to potentially all

[1] See project website: `https://domho.it/il-progetto/`

8. Respiration Monitoring by Video Signal Processing

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Abstract: *Respiration is a fundamental human body function that may provide useful information about the clinical status of a patient. Suitable and continuous monitoring of the Respiratory Rate (RR) is thus essential to promptly detect anomalies that may be signs of potentially harmful or life-threatening disorders. However, traditional RR monitoring systems consist of sensors and devices which are often expensive, invasive, and can be deployed only in hospital settings, requiring trained medical staff. In this chapter, an overview of alternative low-cost and non-invasive video-based methods for respiration monitoring is presented along with a brief review of earlier work. Principles underlying the extraction of relevant information content from video signals are described and specific video-based solutions for newborn and adult monitoring are presented. Modelling and simulation of breathing patterns is also addressed. The performance of the proposed solutions is finally discussed also on the basis of experimental results.*

8.1 Introduction

Respiration is governed by the respiratory system, whose main function is gas exchange occurring in two phases: inhalation and exhalation. The sequence of these two movements is known as breathing or respiratory cycle. During inhalation, oxygen (O_2) is inspired through the nose or mouth and absorbed into the blood that diffuses it to the body cells for their nourishment [1]. On the other hand, during exhalation, carbon dioxide (CO_2), a waste product of cellular respiration, is released outside [2]. The exchange of these gases occurs in a specific region of the lungs: the alveolar-capillary membrane. During inspiration, the muscle of the diaphragm, positioned in the lower part of the thorax, flattens and contracts while the external intercostal muscles elevate the ribs, thus expanding the thoracic cavity and increasing its volume [1]. As a consequence of this volumetric expansion, the pressure into the thorax decreases compared to the atmospheric pressure and this difference helps to move air into the lungs, as it flows from higher pressure regions to lower ones, inducing inhalation. On the other hand, during expiration, the diaphragm and external intercostal muscles relax and return to the equilibrium position causing a reduction of the volume of the thorax cavity – a new pressure difference creates and is then equalized with the exhalation of air [1]. The respiration mechanism is shown in Figure 8.1, where inhalation and exhalation phases are depicted.

The Respiratory Rate (RR) is one of the main physiological parameter able to provide important information about the clinical status of a patient. It is clinically defined as the number

9. Monitoring Health and Behavior in an Ecological Environment with Digital Technologies

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Abstract: *The healthcare system is facing a moment in which a redefinition of paradigm is of paramount importance to sustain the new challenges imposed by the current socio-economic changes, such as the population aging and the increased incidence of chronic diseases. Digital technologies can contribute to moving health research and health care out of the laboratory and out of the hospital to monitor people in their living environments. We present several digital systems from our research portfolio, which we designed and validated in real-world conditions. Solutions range from wearable sensors and IoT objects for everyday use to integrated smart living environments. We illustrate their hardware design and data analysis pipelines from the perspective of their applicative domains. We describe applications that involve assistance to the older subjects and persons with motor impairment in everyday life, preventive interventions, and rehabilitation treatments.*

9.1 Introduction

We live in a historical period in which the global society faces profound socio-demographic changes that have considerably impacted the healthcare systems. On one hand, global birth rate is constantly decreasing by about 1.1%/year [1]. On the other hand, life expectancy is constantly increasing, expecting 2.1 billion people aged 60 and over by 2050 [2]. Concurrently, and partly as a consequence, a growing number of people are being affected by chronic diseases, causing 71% of global deaths [3]. These two major challenges require a model shift in healthcare delivery [4] by ensuring equal and sustainable treatments to the fragile people who need frequent checks and continuous assistance. On top of that, the recent COVID-19 pandemic exacerbated the burden the healthcare systems must deal with.

Digital technologies (DTs) offer a way to ameliorate the quality of healthcare systems [5], providing new means to meet these new needs efficiently. The term DTs in healthcare comprises solutions based on sensors, connectivity, and software applied in medical management [6]. The major breakthorugh advance in using DTs in the healthcare domain relies on the ongoing shift towards A2A (*anything to anything*) and A4A (*anywhere for anytime*) information processing [7], which comes with several advantages:

- Ubiquity - Patients do not need to be hospitalized or reach a healthcare facility to receive adequate assistance; even people who live in remote or rural areas or have limited access to healthcare can be assisted directly at home or in their residential facility.