Smart Sensing and AI for Physical Therapy in IoT Era

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Smart Sensing and AI for Physical Therapy in IoT Era

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Abstract. It is well known that medical spending increase with disability status. Per capita spending for people with five or more limitations in activities of daily living (ADLs) is nearly five times the amount incurred by those with limitations in only one instrumental activities of daily living (IADLs). Physical therapy is the way to improve the motor capabilities however it takes a lot of time, it requires physiotherapists services, is often painful and the outcome are evaluated in subjective way. New technologies including smart sensors were adopted in healthcare including wearable solutions for cardiac and respiratory activity monitoring and successfully are contributing to reduce the costs of services. In the case of motor activity and particularly in physical rehabilitation the developments are still reduced the physical therapy services are using as hardware mechanical equipment without sensing, embedded processing and internet connectivity that significatively reduce the possibility to measure and evaluate the physical training outcomes in objective way. In this paper the disruptive solutions for physical therapy are presented that are based on hot technologies such as smart sensors, IoT, virtual reality (VR), mixed reality (MR), and artificial intelligence (AI). Applied AI may conduct to develop models, classifiers (gait classification) and short term or medium term prediction of physical therapy outcomes. Highly motivation of the patients under physical rehabilitation can be increased promoting serious game characterized by VR and MR scenarios.

1. Introduction

The Physiotherapy treatment modalities and techniques are effective at facilitating muscle activation and strength, assisting with joint mobility and soft-tissue problems, modulating pain and inflammation. Treatment can involve joint mobilization, strength and stability exercises and stretching, manual soft tissue therapies (including massage, myofascial, trigger point, positional releases), hydrotherapy, electrotherapy, etc. With progress in methods of therapy and increasing demand on reducing costs in national health care, evidence-based physiotherapy has become a demanding endeavour with pressures from both insurers and employers

Recent work reported in the literature on tele-rehabilitation have been underscore the need for unobtrusive, robust to noise, reliable, mobile smart sensors for motor activity assessment in rehabilitation. Several solutions on smart equipment for physical rehabilitation monitoring are reported in [1-2] as so as the remote physical rehabilitation based on remote sensing and serious game [3-4]. The extraction of complementary information such as heart rate, SpO2, respiratory rate, heart rate variability during the physical training sessions in real, virtual, or mixed scenario can be used to extract useful data to assure more safety and to adapt the physical training plan to the patient cardiac and respiratory condition [5].

Regarding the remote sensing in the last years several commercial solution were adopted to serve as part of physical rehabilitation frameworks. Since 2011 Microsoft Kinect technology appear one of the main remote sensing solution adopted as part of tele-rehabilitation. The latest version of this type of remote sensing device, Azure Kinect dk that works together Azure Kinect Sensor SDK that provides low-level sensor access for Azure Kinect DK hardware sensors and device configuration, the main and applied functionalities being the access of human body joints Cartesian coordinates. Other types of remote sensing device that were used are LeapMotion that was used in different serious game developed by the group and reported in different publications [6].

An objective evaluation of functional status based on accurate measurement systems that could extract the information in non-invasive and unobtrusive way represents contributes to validate the applied physiotherapy techniques for individual cases together the cardiac and respiratory status that can assure optimal conditions for physical rehabilitation effort. Appropriate choice of the applied techniques might conduct to reduced recovery period without risks related undesired cardiac or other type of events. To increase the motivation on performing the recommended exercises and the quality of execution according with the physiotherapy recommendation as so as automatic generation alerts based on cardiac and respiratory condition continuous monitoring represent an important issue. Different solutions including serious game and 3D virtual reality are designed to increase the patient adherence proven their effectiveness to increase the patient engagement on proposed recovery program [7]

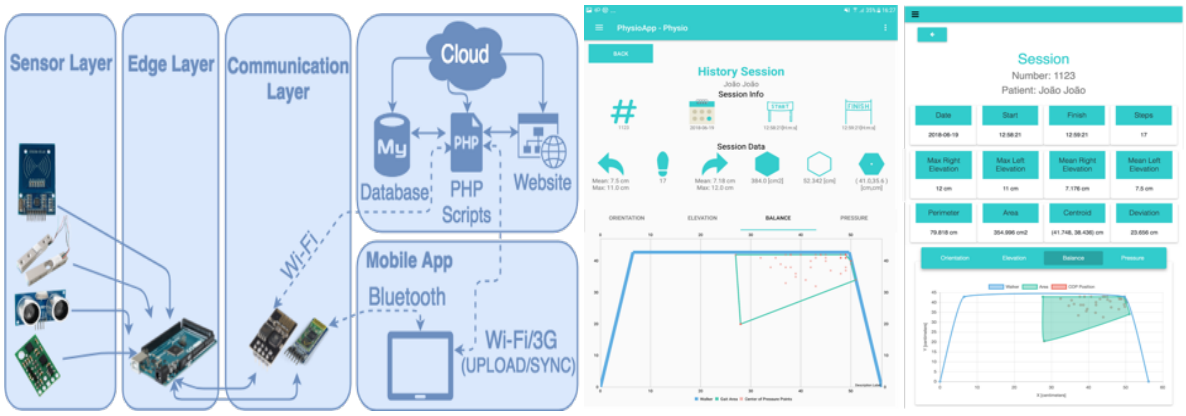
A way to increase the motivation for physiotherapy training is the usage of serious game adapted to the user rehabilitation needs that provide at the same time feedback to the users about health status condition (e.g. SpO2, HR, HRV). Ma and Bechkoum developed a serious-game based therapy to stimulate physical exercises practice by stroke patients with upper limb motor disorders [6] and in our group several serious game frameworks were developed, many of them being designed for upper limb rehabilitation [9]. In virtual scenarios the system allows patients to interact in real-time with virtual objects to practice specific motor skills through diverse modalities. On another hand, an interesting Android-based application is DroidGlove, a serious game for wrist rehabilitation that runs on small portable devices [8] . Motivational interaction with virtual reality scenario are provided also by extended systems reported by Postolache et al [9] where smart gloves are used to navigate and interact with virtual objects in a virtual scene considering semi-immersivity conditions.

A serious game for balance rehabilitation is presented by Betker et al [10] in which a video game-based tool is controlled by a center–of-pressure (CoP) for the maintenance of balance in a short-sitting position for people with chronic spinal cord and traumatic brain injuries. Similar work was reported in [11] where the data from a force platform is used to adapt the game scenarios and virtual object distribution that will be checked to avoid unbalance of the user and accidents. The gait recognition and classification is an important task as part of diagnosis and evaluation. Different classifiers for gait were developed to be applied to sensor data (shimmer IMU) disposed on the level lower limb. Several results are reported by Leite et al [12]. Latest development in the deep learning algorithms were created good opportunity to be used also in the physical rehabilitation for objective evaluation. Thus, smart sensor-based rehabilitation exercise recognition system was reported by Zhang et [13] al that are developed a deep learning framework for the mentioned task. Other technologies such as IoT are also part of the newest developments that assure the physical therapy services digitalization as part of general services digitalization direction.

2. Smart Sensors and IoT for healthcare services

The convergence of healthcare, instrumentation and measurement technologies will transform healthcare as we know it, improving quality of healthcare services, reducing inefficiencies, curbing costs and improving quality of life. Two technologies are frequently considered as part of tele-medicine solutions particularly for remote physical therapy implementations. Thus, can be mentioned the smart sensors as part of IoT ecosystem. The smart sensors and also smart actuators are characterized by sensing or actuating, embedded processing and communication capabilities and are

the main component of smart equipment that are reported in the field of smart physical therapy. An example of smart walker prototype designed for gait rehabilitation after stroke events is reported in [14]. The general architecture and the hardware components are presented in Figure1.a.



a) b)

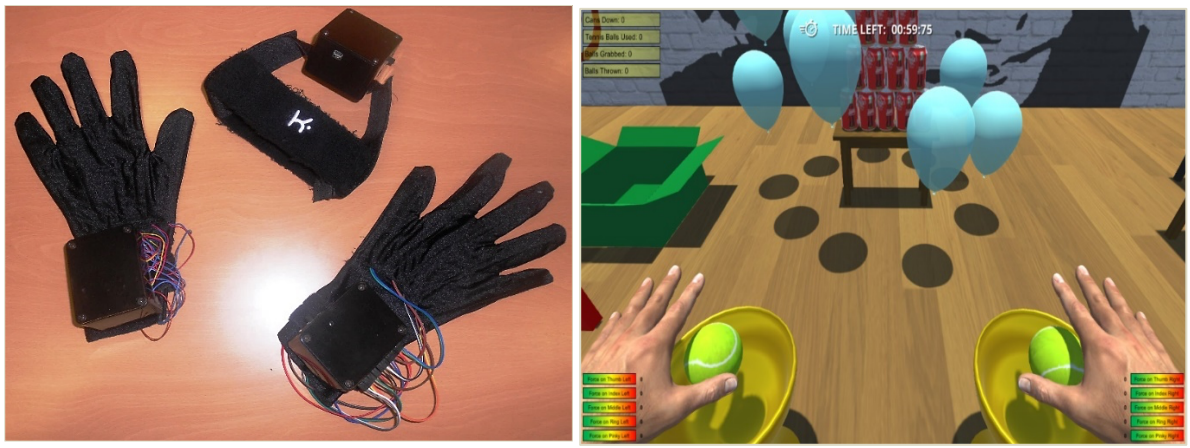
Figure 1. Smart walker implementation a) IoT layers b) mobile and web APP for gait training based onsmart walker.

As it can be observed in Figure.1 the implemented smart walker prototype is characterized by several layers from sensor layer to cloud and mobile computing layer all of this layers materializing and IoT implementation for gait rehabilitation equipment. Can be underlined load cells as the main components of sensor layer associated with the measurement of floor reaction force during the walker usage but also the IMU usage for walker acceleration and direction of walker motion. The signals coming from the sensors is acquired by Arduino mega based platform pre-processed and transmitted using short range communication protocols expressed by Wi-Fi and Bluetooth. The Wi-Fi communication capabilities provides direct Internet connectivity while the Bluetooth is used for real time display of the data using a mobile APP (Figure 1.b). Additionally a web APP was also developed to make easily the data visualization through a common browser. The presented APPs are able to display the CoP (Center of Pressure) during the aided gait training highlighting the right user balance. The data can be also stored from different walkers and analysed using data science techniques to extract objective information about the evolution of user walking capabilities. IoT ecosystem will be discussed underlining a set of new sensing technologies and the integration of this on the smart sensors. History and future of IoT ecosystem are discussed starting from RFID and providing interesting approach about 5G for new implementation for physical therapy. Related IoT protocols such MQTT and IoT platforms such The Thing Network for healthcare will be presented including strength and drawbacks.

This brief example of the group of smart equipment for physical therapy as IoT implementation offer new and vision of exciting possibilities for more robust, reliable, flexible and low-cost healthcare systems and patient care strategies based on data. These may provide value-added information and functionalities for patients, particularly for those with neuro-motor impairments. It has great importance in developed countries in the context of population ageing.

3. Wearable and Remote Sensing for VR theragames

Theragames represents the serios games associated with physical rehabilitation that are characterized by virtual reality and mixed reality scenarios to be used for upper limb and lower limb rehabilitation for a higher user motivation. The interaction between user and VR scenario can be materialized using wearable smart sensors [15] or remote sensing materialized by commercial natural user interfaces such as Kinect or Leap Motion. Example of upper limb theragame is reported in [4] the implementation combines VR but also wearable devices (Figure 2) for upper limb rehabilitation.



a) b)

Figure 2. Theragame and Wearable Interface a) smart gloves and head band game interfaces; b) cans down virtual reality serious game for upper limb rehabilitation.

As part of these interactive environments, 3D image sensors for natural user interaction with rehabilitation scenarios and remote sensing of user movement, as well as thermographic camera for remote evaluation of muscle activity will be presented.

4. AI for physical therapy

Artificial intelligence (AI) solutions applied for physical therapy data provided by the smart sensors associated with interactive environments as so as training support equipment (e.g. smart walkers, crutches, force platforms) are considered. Example of applied AI algorithms for gait classification, balance control subsystems, physical rehabilitation outcome prediction using classical AI algorithms but also the latest deep-learning algorithms will be presented. Will be discussed the importance of AI on diagnosis and evaluation but also on training plan evaluation for higher motivation and reduced rehabilitation periods.

5. Conclusion

Smart Physiotherapy based on smart sensors IoT and theragames supported by virtual reality or mixed reality assures an increased quality of services, reduced rehabilitation period. The smart sensors are producing big data that can be used for physical rehabilitation models and for predictionof the physicalrehabilitation outcome. Personalized serious games with natural user interfaces data storage and analysis associated with smart physiotherapy IoT compatible increase the patient motivation and physical therapyeffectiveness. AI andbig data Analysis can be used to improve the QoS for physical therapy services.

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