Smart Walker Solutions for Physical Rehabilitation

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In the last decade, the clinical reasoning in physical therapy has been to develop systems for physiotherapists to make clinical decisions rapidly, effectively and efficiently, in response to the increasingly complex needs of health and rehabilitation units [1]–[3]. Some studies show the importance of walking aids during rehabilitation from some diseases, and after surgery for arthroplasty in the elderly population [4], and in elderly patients with balance disorders, muscle weakness [5] or in people with diabetes mellitus [6]. Walkers are important devices that aid the rehabilitation process. The use of a walker is recommended for gait changes and imbalance due to various factors, such as surgery of the lower limbs or neurodegenerative changes, especially in the early recovery period [7].

Aging, Walkers, and Physiotherapy

To improve the quality of life of people affected by motor limitations as they age, a challenging task is to develop new architectures like instrumented smart walkers using software that assist users increase their balance, and diminish falling [8]–[10], which are major causes of morbidity for the elderly [11]. At the same time, the use of smart equipment with communication capabilities and software associated with electronic health records [12] will allow objective evaluation of physical rehabilitation programs. Various research groups and industries are developing new devices that help users stay balanced by giving a wide base of support.

Types of walkers include the standard walker with no wheels, the two wheeled walker, and the four wheeled walker. The choice of one of these types of walkers is related to the user's gait limitations and stability requirements. Standard and two wheeled walkers are generally used as primary walking aids. General use during rehabilitation proves to improve confidence and restore or maintain motor ability at the highest possible level. A study in [13] showed that walker assistance does not interfere with rehabilitation outcome and in some cases may decrease the rehabilitation period. The study was based on subjective observations of walker users.

Physical Rehabilitation Assessment Network

To permit continuous monitoring for the physical rehabilitation field, walking aids need to have sensors to measure the parameters related to walking, data acquision and processing, communication units, and network capabilities for remote assessment of the users. A physical rehabilitation network architecture, presented in Fig 1., would include a set of smart walker nodes with wireless communication protocols. We considered Wi-Fi, Bluetooth, Bluetooth LE and IEEE802.15.4 for use because of the required communication ranges, data flow, communication security concerns and the need for autonomy.

The Physical Rehabilitation Network we developed uses Wi-Fi mobile nodes and transmits data from home or clinic-based clients to physiotherapists using an Internet connection. As part of client-server architecture, the data coming from clients is stored in a remote database installed in a Physiotherapy Server where it can be accessed by different web or mobile applications associated with remote physiotherapy to evaluate the rehabilitation sessions in an objective manner. To monitor the walker's activity during gait rehabilitation training, the walker's sensors could measure forces, acceleration, and lower limb motion patterns. Considering the health condition of the users the measurement of cardio-respiratory parameters such as heart rate, and saturation of peripheral oxygen (SPO2) may also help the physiotherapist to optimize the rehabilitation sessions. Research work related to cardio-respiratory assessment through smart walker is reported in [14].

Instrumented Walkers - Smart Walkers

The measurement of quantities such as forces, accelerations, velocities, heart rate, and oxygen saturation during

This work was supported by the Instituto de Telecomunicações and Fundação para a Ciência e Tecnologia and the project "EHR-Physio: Electronic Health Records-Needs, Requirements and Barriers in Physiotherapy", PTD/DTP-DFS/1661/2012.

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a training session is performed through the use of sensors and signal conditioning circuits embedded on the walker level. Analog processing and signaling circuits may provide visual information to physiotherapists regarding the user's balance and risk of falling. However, advanced features such as gait rehabilitation metrics calculations, gait pattern recognition, power management, and selective communication with the physiotherapy clients requires added acquisition, digital processing and communication modules that transform the instrumented walkers into smart walkers. Smart walker prototypes associated with the Physical Rehabilitation Assessment Network are presented in Fig. 2. The prototypes are characterized by one or two motion sensors (rad, rad1, rad2) that measure the force and acceleration during the gait rehabilitation session (standard smart walker, 2W smart walker) or during common daily activity (4W smart walker).

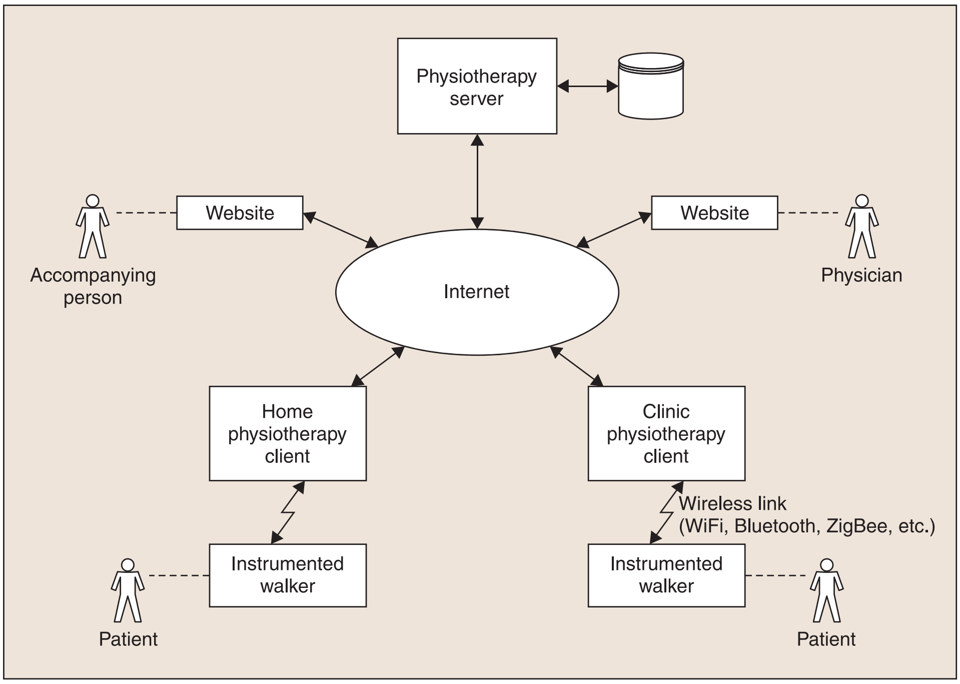

Fig. 1. Physical Rehabilitation Assessment Network based on Wi-Fi smart walkers.

Smart Walker Sensors

The sensors embedded in the walker were chosen to extract the relevant information related to the walker's use during the physiotherapy sessions such as applied forces, accelerations and motion patterns.

Force versus Pressure Sensors

The relationship between force and pressure is given by:

$$p = \frac{F}{S} \tag{1}$$

where F represents the applied force, S the surface area and p represents the pressure. The force distribution over a surface is not uniform and the pressure is not constant. There are some common applications where the measurement of pressure distribution over a support surface of a mechanical structure is essential to avoid excessive loading that cause their collapse. In the case of biomedical applications, for example, gait parameters from patients undergoing physiotherapy treatments can be extracted by having the patient use smart insoles equipped with force or pressure sensors to measure ground reaction forces distribution during locomotion with or without aiding walking devices [15]. For walker solutions that can be used for rehabilitation purposes, interface pressure sensing technologies based on load cells, pressure-mapping systems, and force sensing resistors (FSR) will be the most promising sensing technologies in this field.

Force and Pressure Sensing Technologies

Load cells sensing is based in the deformation of a material when it is submitted to a mechanical effort. For small deformations, the relationship between stress and applied load is given by:

$$\sigma = \frac{F}{A} \tag{2}$$

where σ represents the normal stress, F represents the load and A represents the cross sectional area. Assuming an elastic behavior of the material, the normal stress and the axial or transversal strain are given by:

$$\begin{aligned} \varepsilon_L &= \frac{\sigma}{Y} \\ \varepsilon_T &= -v \cdot \frac{\sigma}{Y} \end{aligned} \tag{3}$$

where ε_L and ε_T represent the longitudinal and transversal strains, respectively, v represents the Poisson ratio of the material, and Y represents its Young modulus.

Usually, resistive strain gauges are used to sense the deformation and the signal conditioning circuit that is associated with these kinds of sensors is based on Wheatstone bridges. Since the resistance variations are very low, sometimes on the order of a few tens of mΩ, full configuration of the bridge circuit with four sensors is used to compensate errors caused by temperature variation and to increase measurement sensitivity. The load cells work as force sensors since, by themselves, they can only give information about the total force applied to its bearing structure and cannot give information about the

Based on the information provided by the sensors, individual training sessions can be selected by the physiotherapist to extract information about the evolution of physical capabilities of the trained walker's user.

Conclusions

Smart walkers represent an important research field as healthcare needs increase with aging. Implementing physical rehabilitation assessment networks based on smart walker nodes that measure force, acceleration and motion allows remote monitoring of physical rehabilitation sessions using Internet connectivity and mobile applications. The applications may also allow sensor data storage and analysis based on client–server architecture. The results that were obtained showed clearly that the proposed technologies can give important contributions to improve the quality of life of walker users by monitoring unbalance and instability conditions that can result in falls and harmful injuries.

Acknowledgment

The authors give special acknowledgment to MSc. Ruben Costa who collaborated with the project team on mobile applications development.

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