Evaluation of IMU ZigBee Sensors for Upper Limb Rehabilitation

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***Abstract*—This research presents a novel wireless sensor technology orientated to improve pos-stroke rehabilitation robotics. The new system consists in a ZigBee network, based on wearable Inertial Measurement Units (IMU) easily adaptable to patient clothing or orthotic frame permitting kinematic measurement in continuous therapy motion all over the body segments as a Body Sensor Network (BSN). The developed system was applied to upper limb movement during repetitions of a standard trial of reaching and grasping, due to its importance in post-stroke victims daily life. The introduced tool was evaluated through simultaneous capture of the movement by an optical tracking system, which allowed to contrast the elbow angle variation obtained from IMU measurement with 3D videography data, recognized as the golden standard method.**

I. Introduction

Many stroke victims regain their abilities in daily activities, however, they have quantitative limitations, such as reduced speed and accuracy despite neurorehabilitation. Clumsy and slow performance may be a considerable impediment to these patients, especially when fine manipulations are required. Research on the factors involved in chronic functional disability and dexterity of upper limb movements would help to enhance treatments and to elucidate the pathophysiology of motor recovery after stroke [1].

Sensors for rehabilitation robotics should have specific characteristics, such as, a small size, a long battery life, and the ability to extract a wide range of parameters from human motion. These characteristics made Microelectromechanical Systems inertial sensors (MEMS) attractive [2]. Accelerometers, gyroscopes and magnetometers sensors can be combined through Inertial Measurement Units (IMU), in order to obtain the typical kinematic data: acceleration, speed, position, and orientation. The development of a real-time IMU sensor, small enough to be integrated with easy adaptability would improve actual rehabilitation robotics systems and also applications such as on line monitoring of therapy evolution for both: medical staff and the patient benefit through biofeedback tools.

ZigBee technology defines the network, security and application framework for an IEEE 802.15.4-based system. These capabilities enable thousands of devices connected on a single wireless network. The growing expansion of ZigBee Alliance in the healthcare space has resulted in the development of the ZigBee Health Care public application profile (ZHC) [3].

This work aims to achieve the development and evaluation of a monitoring architecture for rehabilitation therapy robotics based on the ZHC network of wearable IMU sensor nodes. These sensor nodes will allow the kinematic and muscle electrical activity measurement of patients in continuous therapy motion over all the body segments as a Body Sensor Network (BSN), to be used in rehabilitation robotics applications.

II. Material and Methods

The present work shows a an evaluation of the ZigBee IMU sensor (ZIMUED) developed in the article referred as [4]. This evaluation of system effectiveness was performed through simultaneous recording from ZIMUED wearable sensors and an optical system for three-dimensional motion analysis recognized as the golden standard method. The comparison between the same variable simultaneously measured by both techniques will permit to verify the wearable sensor reliability.

The Biomechanics Laboratory (FI-UNER) owns a videography system for 3D motion analysis based on two cameras capturing markers position at a sample frequency of 60 Hz synchronized by a 18-binary led array counter. Video cameras are located at an angle of 90 degrees respect each other and at a distance of 1.4 meters long from the object point, in order to record the subject movement from right and left sides. Previous to the trial measurement, a calibration cube is registered to know the exact relation between pixels and real space distance in meters, beside, their coordinates will be used later to transform the LSC (Local System Coordinates) to the GSC (Global System Coordinates).

The chosen movement to be studied was to reach and grasp an object due to its importance in patient independence as mentioned in the introduction. The 10 retroreflective skin markers were carefully placed over key anatomic places that are easily identifiable and reproducible (figure 1).

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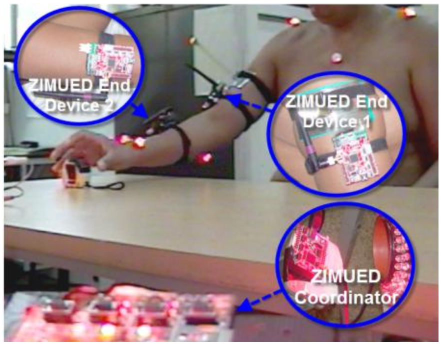

Fig. 1. Location markers and IMU sensor for simultaneous recording.

The joint center reconstruction from markers position requires an anthropometric model application to estimate the shoulder (centerS), elbow (centerE) and wrist (centerW) coordinates as proposed for Rab [5]. Once the spatial orientation of each segment involved in the movement, is obtained, joint angles, velocities and moments can be calculated.

In this report the elbow flexion-extension angle was elected as a first approach to verify the new system capability. A total of 9 healthy subjects, male and female between 20 and 30 years old, were registered during the performance of a standard movement of reaching and grasping. Each trial consisted on the subject sat down in a chair in front of a table with forearm resting above the surface, in an approximately initial angle of 90 degrees respect to the arm. Repetitions of reaching and grasping an object were recorded by the two systems of measurement.

III. Results

In Figure 2 standard movements achieved by the same subject are shown to illustrate the IMU-ZIMUED system quality against 3D videography record. Each color represents a single trial simultaneously registered by the novel method in dashed line, and the optical tracking system in solid line. Shape and amplitude similarity can be verified.

Total repetitions for 2 different subjects are exposed in Figure 3 a) y b) on independent images, also representing the elbow flexion-extension angle with their respective mean values in solid black lines and standard deviation in dashed black lines.

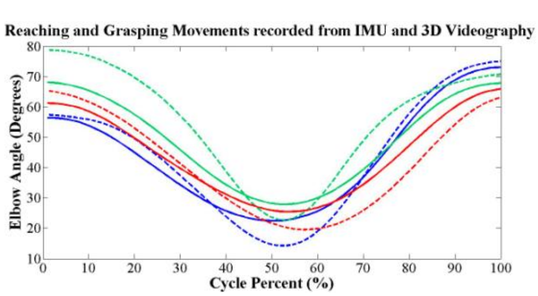

Fig.2. Each color represents the same movement recorded by the wearable system in solid lines and 3D videography in dashes.

a) b)

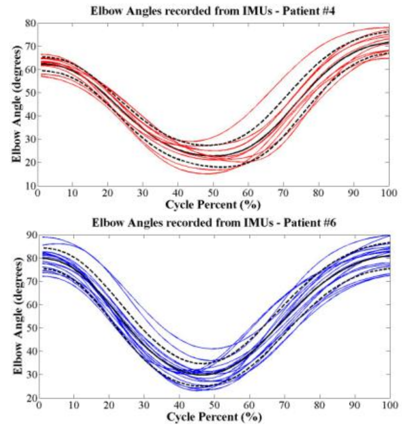

Fig. 3. Total repetitions of 2 different patients: a) patient #4 in red and b) patient #6 in blue lines, with their respective mean values in solid black lines and standard deviation in dashed black lines.

IV. Discussion

The novel developed system was evaluated with simultaneous 3D videography system obtaining similar results when the elbow flexion-extension angle is compared. In addition, the elbow flexion-extension angle assessment for 9 subjects in 10 repetitions shows high repeatability of the IMU-ZIMUED recording. In the advance of this research, further kinematic analysis will be achieved to compare net moment curves.

V. Conclusions

In a later stage of this research, deeper statistical analysis will be done aimed to perform a major validation of the wireless system proposed. This device also allows sEMG quantification which be further acquired to assess the relationship between muscle activity and the kinematic data, providing a new perspective in the process of diagnosis, treatment or rehabilitation, which are the ultimate goal of the system: on-line biofeedback with a reliable small and low cost device.

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