Integration of a functional calibration procedure and usability study towards the digitalization of upper limbs rehabilitation

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Background and objectives:
Neuromotor rehabilitation has a primary relevance among healthcare services. The combination of Virtual Reality and inertial measurement units (IMUs) promises to maximize functional recovery: serious games merge engagement and rehabilitation purposes providing task-oriented activities in contextualized scenarios [1]; IMUs gather kinematic parameters to monitor the therapy.
This work focuses on a digital rehabilitation device which enables patients affected by neuromotor disorders to perform rehabilitative sessions for upper limbs at home with a sensorized shirt interacting with serious games. The main purposes have been the integration of a functional Sensor-To-Segment calibration procedure to manage the misalignment between sensors and body segments and the evaluation of anatomical joint angles, the assessment of the validity and accuracy of the IMU-based system through the comparison with the optoelectronic system, and the implementation of a usability protocol to assess the intuitiveness and the adequateness of the user interface for both patients and therapists.

Methods:
- An upper limb mechanical model has been designed to implement and test the Sensor-To-Segment method proposed in [2]. Simulating the acquisition of five sensors arranged as in the shirt, the quaternions related to a static pose and a functional movement necessary for the calibration procedure have been obtained. Sensors' readings have been exploited to estimate reference directions necessary to define the matrix which relates the sensors' reference frame to the anatomical one and to compute anatomical joint angles. The application of the calibration procedure has compensated for the Sensor-To-Segment misalignment.

- A validation protocol has been designed to assess accuracy of the measurements: real data gathered from the device during movements have been calibrated and compared to the measurements simultaneously acquired by the optoelectronic system for 20 healthy subjects.

- A usability test protocol has been designed according to [3] to examine the use scenario and identify errors: questionnaires have been filled by 15 medical professionals and 15 patients.

Results:
- Results have shown coherent outcomes for orientation and Range-of-Motion values along the principal axis of functional movement. The comparison between calibrated

data concerning optoelectronic system outcomes has presented significant correlations along the principal axis of movement, while differences in measurements have occurred on the other axis. Thus, the combination of effective strategies for the optimization of initialization and calibration procedures could demonstrate the device's reliability.

- Usability test results have revealed a general willingness to use the technology, which has proven to be an easy-to-use and engaging tool for rehabilitation therapies.

Conclusions:
The digital rehabilitation device has resulted to be promising and effective. The Sensor-To-Segment calibration procedure has been essential to estimate anatomical joint angles. From the perspectives of patients and therapists, it has proven to be an easy and engaging tool. Hence, results will lead to further evolution of the device and contribute to the digital transformation already in place.

Bibliography:
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