Development and preliminary evaluation of the ArmTracker: a wearable system to monitor arm activity during daily life.

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Introduction

Upper limb assistive technology can play an important role in increasing the quality of life for people with neuromuscular disorders by improving their ability to perform activities of daily living and participate in social activities. Questionnaire and laboratory-based studies indicate that in general patients benefit from upper limb assistive technology. However, there is a lack of studies that provide rigorous quantitative and objective measurements during daily life to evaluate the effectiveness and usability of assistive technology. To overcome this issue, we have developed the ArmTracker system, a wearable system based on inertial measurement units (IMUs) that can measure arm movements during daily life. The orientation data from the IMUs is combined with a kinematic model of the upper body to calculate the elbow and wrist positions[1,2]. We have also developed algorithms to compute metrics that assess the quality of movement, including range of motion, functional workspace, and acceleration-based activity of the upper limb. After validating the performance of the system with a commercially available IMU-based movement capture system (Xsens MVN), we carried out a case study to compare the data extracted from a healthy subject and a subject with Becker muscular dystrophy. The work presented shows the development, validation and preliminary evaluation of the ArmTracker system.

Materials and Methods

Prototype: The ArmTracker system is composed of five IMU sensors (BNO055), a microcontroller with a high-speed SD card (Teensy 3.6) and a battery. All these components are integrated in a lycra shirt. The IMU sensors are located in the forearm, upper arm and torso (Figure 1). The system is capable of measuring and storing absolute orientation data (expressed in quaternions) from all sensors, and acceleration data from the forearm and torso at 50 Hz for approximately 8 hours.

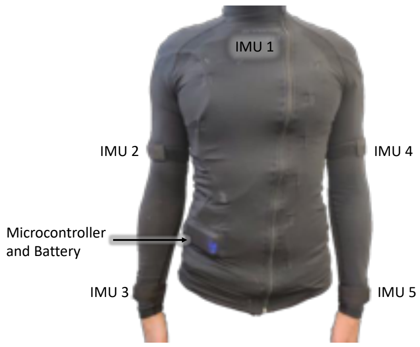

Figure 1. First prototype of the ArmTracker system with 5 IMU sensors, a microcontroller and a battery.

Kinematic Modeling: The orientation information obtained from the IMU sensors was used to calculate the three-dimensional (3D) positions of the elbow and wrist joints. To obtain these position estimates we first applied a *sensor to segment calibration*[3] using a static pose (known as N pose) to find the absolute and relative segment orientation estimates[4], and then with the length of the upper arm and forearm segments we applied forward kinematics to calculate the position estimate of the elbow and wrist joints.

System Validation: To validate the accuracy of the ArmTracker, we compared our prototype to the gold standard IMU-based motion capture system: XSens MVN. We carried out several measurements of single joint movements wearing both systems at the same time, and compared estimates of joint positions and joint angles (expressed in Euler angles). Moreover, we also tested the system stability when measuring and storing data. In the first test we measured static data for 12.5 hours. Afterwards, we conducted a dynamic motion capture during 6 hours, repeating periodically the static N pose, and compared the joint positions for each N-pose.

Movement Quality Metrics: Three types of metrics were computed to analyze the quality of the upper limb movements*: Range of Motion*, *Functional Workspace Distribution* and *Accelerometry*. Range of motion was calculated by computing shoulder elevation and elbow flexion using the cosine rule as in *I. Howard et al*[5]. The second metric, i.e., functional workspace distribution was used to assess the 3D position of the hand over time. With this metric it is possible to study the time percentage that the hand remains in different regions. Finally, from the wrist acceleration data we calculated the bilateral arm activity[6,7] to analyze the activity of each arm moving individually and the activity of both arms moving at the same time. This metric also takes into account the dominance of each arm.

Results & Discussion

System Validation: Comparisons of joint positions and angles between the ArmTracker and the Xsens MVN systems showed a maximum position error of 43.5 mm and 41.8 mm for the elbow and wrist joint respectively; and a maximum angle error of 10 degrees and 25 degrees in shoulder internal/external rotation and wrist pronation/supination respectively. Static stability tests showed a maximum mean error of 0.0091 of the quaternion values which range from -1 to 1. Dynamic stability tests showed a maximum joint position error of 80 mm between the N-poses.

Exploratory Graphical Analysis: To test the system on a real scenario, a case study has been carried out, by measuring data of a healthy subject and an individual with Becker Muscular Dystrophy (BMD).

- <u>Range of Motion</u>: We found that the arm elevation angle of the individual with BMD was concentrated at 50 degrees while the healthy subject showed three peaks at 15, 30 and 90 degrees (Figure 2). It is likely that the reason why the individual with BMD did not show high elevation angles was because of the effort required to overcome gravity forces. Similar results were found for the elbow flexion/extension angle.

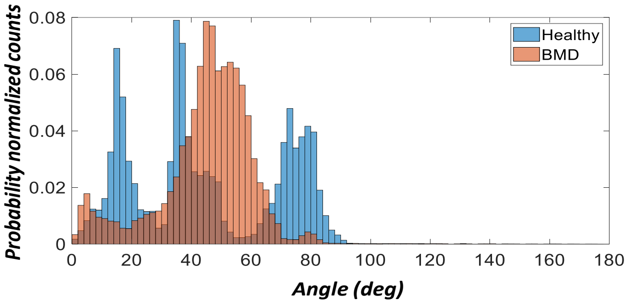

Figure 2. Histogram plot of the arm elevation angle of the participant with BMD and the healthy subject.

- <u>Functional workspace distribution:</u> In accordance with the results of the range of motion we found that the individual with BMD showed a low density in the regions above the shoulder height (below 3%) and spent 70% of the time in the distal lateral quadrant (Figure 3). Conversely, the healthy subject presented more density at the medial quadrants. Both subjects showed low density (i.e. 1.5%) at the lateral quadrant above the shoulder height. It is also noticeable the larger workspace volume of the healthy subject compared to the individual with BMD.

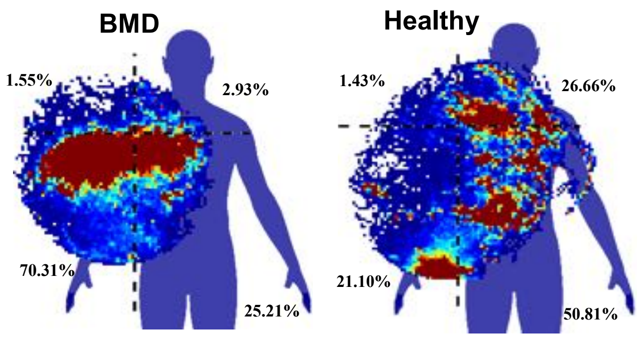

Figure 3. Density plots of the right hand position of the participant with BMD (left) and a healthy subject (right).

- <u>Accelerometry</u>: We found that the healthy subject showed a higher bilateral magnitude, which indicates movements with higher acceleration, than the individual with BMD (Figure 4). The healthy subject also showed higher activity of his dominant arm (more negative values of the magnitude ratio), whereas the subject with BMD showed a more symmetrical distribution.

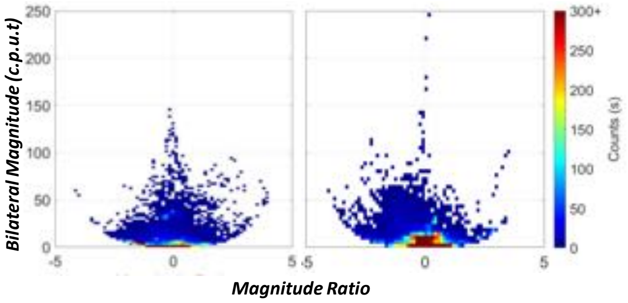

Figure 4. Bilateral Arm Activity[6,7] of the individual with BMD (left) and the healthy subject (right).

Conclusions

We have successfully developed a wearable system based on IMU sensors that can measure upper body motion outside of the laboratory environment for long periods of time (approx. 8h) and with low drift and long-term stability. We have successfully calculated movement metrics that are based on shoulder and elbow range of motion, functional workspace distribution and wrist accelerometry. These metrics have been calculated for 6 hours of data collection from a healthy subject and an individual with BMD. Future work will involve exploring the possibility of integrating a system that can measure muscular activity (EMG) to be able to comprehensively monitor the arm activity of the users. We also plan to use the ArmTracker system in combination with assistive technology, such as mobile arm supports, to analyze their effectiveness and usability.

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