Arm Kinematics Estimation with the Harmony Exoskeleton

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***Abstract*—Wearable robots can monitor various aspects of treatment progress that cannot be obtained from observation or typical motion capture devices, and they can provide precise and reliable measurements of parameters related to motion and forces. Here, we present a comparison of human arm kinematics estimated from the Harmony exoskeleton's sensors with a motion capture system. Kinematics estimated using the robot data closely matched the kinematics measured by the motion capture system, and we anticipate that, with a few improvements, Harmony will be able to estimate arm kinematics with accuracy approaching motion capture technology.**

I. Introduction

POWERED exoskeletons have the ability to control human joints for coordinated movements in a subject-specific therapy, while providing precise and reliable measurements of motions and forces. They can provide augmented feedback (e.g., visual, haptic) to users, and monitor various aspects of treatment progress that cannot be obtained from observation or pure motion capture (mocap) devices (e.g., arm stiffness by enforcing the arm trajectory). Studies have shown their outcomes are better or equivalent compared to conventional therapy [1], [2]. One important aspect of upper-body rehabilitation is to maintain the correct shoulder coordination to avoid impingement of the rotator cuff that can cause pain and injuries. This is especially important for stroke patients, since shoulder subluxation and abnormal coordination are recurrent symptoms. Harmony [3] (Fig. 1) is a bilateral powered exoskeleton designed to closely match the natural coordination of the shoulder girdle. It allows for wide range of motion and assessment of shoulder coordination, features not available in any comparable exoskeletons found in literature. Kinematic alignment with respect to the human joints is achieved through the mechanical design and mathematical model. Human joint angles can be estimated using the robot model and measured angles of the actuators.

In this study, we present a comparison of human arm movements measured from the Harmony's sensors to movements measured directly with a mocap system.

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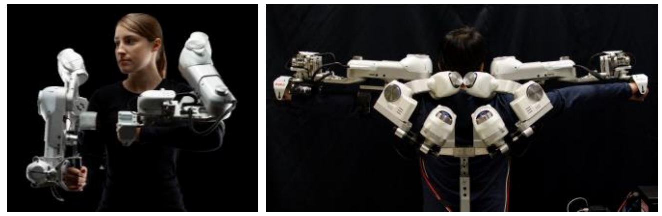


Fig. 1. The Harmony exoskeleton.

II. Materials and Methods

One healthy subject wore the exoskeleton and performed volitional movements with the right arm while the robot compensated the weight of its own segments. The subject conducted a sequence of three sets of three repetitions of different exercises (reaching forward, diagonal motion from outside and above toward center and below, and arm elevation in the scapular plane).

The kinematics measured from Harmony's sensors is compared with the obtained from a marker-based mocap system (PhaseSpace Inc., San Leandro, CA, USA). The marker placement for the mocap system is shown in Fig. 2. Mocap data was captured at 480Hz, whereas robot data obtained from 14 magnetic position encoders (Contelec AG Inc., Biel, Switzerland) was captured at 100Hz. Mocap data was interpolated using piecewise cubic splines when markers were not visible.

The measured kinematics includes shoulder girdle elevation/depression (SGED) and protraction/retraction (SGPR), shoulder abduction/adduction (SAA) and flexion/extension (SFE), elbow flexion/extension (EFE) and pronation/supination (EPS), which were obtained by taking the angle between the two respective segments, and the hand orientation and position with respect to the chest (HPO and HPP).

III. Results

The normalized RSME (NRMSE) was calculated by normalizing the RMSE over the entire period of one trial (approximately three minutes) with respect to the range of motion of the robot data. The NRMSE for the measured kinematics is shown in Table 1.

Kinematics over time obtained with mocap and robot data are depicted in Fig. 3. The angle difference representing hand orientation error was obtained by extracting the angle of the rotation quaternion between the hand frames measured from robot and mocap data, respectively. FPS was obtained by comparing the arm configuration and hand orientation. Jumps in the angle difference and FPS occurred in instants when hand markers were not visible.

Fig. 2. Marker placement for the mocap system. Three markers were placed on the chest, used as reference frame, one marker on the right acromion process, one marker on the right olecranon, one marker on the right wrist strap, and two markers on the right hand palm. Since the hand attachment cuff restrains the wrist movement in all degrees-of-freedom, the set of markers consisting of the one in the wrist and the two in the palm have a constant geometric relationship, thus, they were used to obtain the hand frame.

IV. Discussion

Kinematics estimated using robot data closely matched the kinematics measured by mocap data. The observed errors were likely due to cuff interface dynamics and inaccurate parametrization of the human arm dimensions.

A constant offset of approximately 30 degrees was observed in the hand orientation error, probably caused by misalignments in the attachment between the robot and the hand. This issue combined with jumps in the data due to missing hand markers caused a large RMSE for HPO.

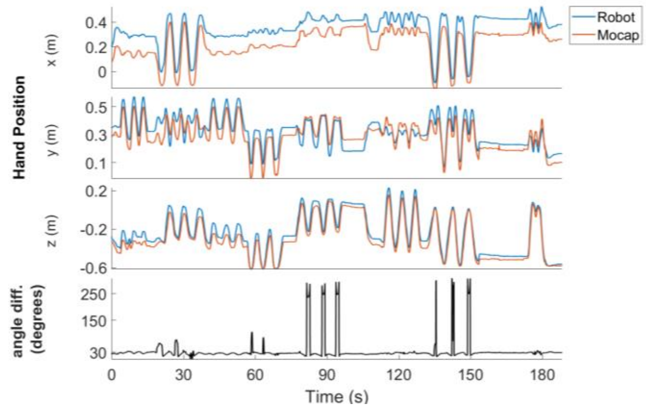
TABLE I
NORMALIZED RMSE (NRMSE) OVER THE ENTIRE PERIOD EXCLUDING HAND ORIENTATION (MOCAP VS ROBOT DIFFERENCE)

Measure	Normalized RMSE
SGED	0.2383
SGPR	0.2312
SAA	0.1245
SFE	0.1345
EFE	0.0342
FPS	0.5704
HPP (x axis)	0.1997
HPP (y axis)	0.1323
HPP (z axis)	0.0713

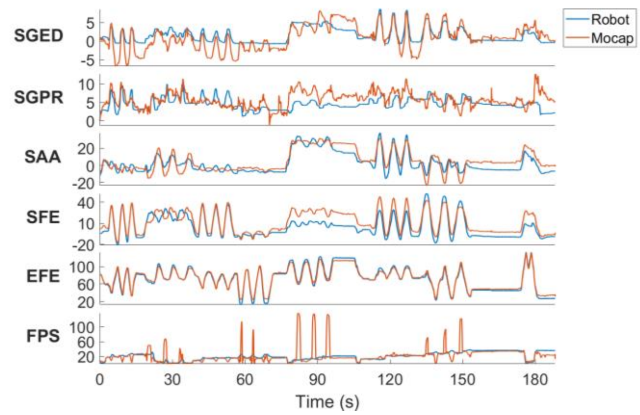
V. Conclusion

The method to estimate human arm joint angles from the Harmony's sensor data is promising. We are currently working to improve the accuracy of the estimation, by quantifying the cuff interface dynamics and also by including a calibration method to correct for inaccurate parametrization of human arm dimensions. Furthermore, in order to minimize marker drop-outs in the mocap system, we are testing different marker and camera placement.

We anticipate that Harmony will be able to estimate arm kinematics with an accuracy approaching motion capture technology. Such an advance would enable health care providers to deliver precise and quantifiable therapy in a biomechanically sound manner.



(a) Hand position in x, y, and z axes, and hand orientation error represented by the angle difference between the robot and mocap hand frames (black line).



(b) Joint angles in degrees.

Fig. 3. Comparison of the kinematics obtained with the robot data (blue lines) and the mocap data (orange lines) over time.

References

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