ACCURATE ESTIMATION OF THE KINEMATICS USING AN IMU-BASED MOTION CAPTURE SYSTEM

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INTRODUCTION

Optical motion capture systems (MCSs) are widely used to capture the kinematics of different motor-tasks. However, optical MCSs are often expensive and require long and complicated preparation/collection procedures. An alternative method, however, is to use inertia measurement units (IMUs). IMUs are significantly cost-effective and convenient compared to the optical MCSs. Moreover, unlike optical MCSs, an IMU-based MCSs will not be limited to the vision field of the surrounding cameras or be disrupted by its markers being hidden. Lastly, IMUs do not require labeling/cleaning, making them even more convenient.

The objective of this study is to develop an IMU-based MCSs with graphical user interface (GUI) that can facilitate the accurate biomechanical kinematic analyses of the human and/or animal movement. Successful accomplishment of this application will enable a more affordable, accessible, and portable biomechanics lab of human movement analysis for researchers and provide simple ways for clinicians to diagnose pathological movements of their patients.

METHODS

The motion capture system developed in this study comprises 16 wireless IM sensors (Delsys Trigno, Natick, MA) bilaterally attached to major upper and lower extremity links as follows: Back of the shoulders (scapula), upper arms, forearms, back of the hands, thighs, shanks, feet, and unilateral at lumbar (L3), and sternum. IMUs captured three-dimensional angular velocity (gyroscope), acceleration (accelerometer), and magnetic field (magnetometer) at 60 Hz. The incoming data was low-pass filtered using a third-order zero-lag Butterworth with a cutoff frequency of 5 Hz [1]. The algorithm built quaternions from the gyroscope data and mathematically rotated the vector representing the corresponding link to which the sensor was attached. Since this rotation was performed only on the vector from the previous time step, the system was susceptible to drift due to the existing noises. To account for this drift, the algorithm simultaneously used the magnetometer and accelerometer data to create a right handed coordinate system using cross products. At each time step, a new coordinate system was created in the same manner. The rotation was found from the new coordinate system to the initial coordinate system, and was applied to the initial position of the vector. The rotated orientations found from both methods were then averaged. The result from the magnetometer and accelerometer readings were only viable for low accelerometer readings where the total acceleration was close to that of the gravity. Thus, the algorithm implements calculations to only use the magnetometer and accelerometer data at low to zero angular rates to rid the system of drift and use more of the gyroscope data when accelerometer readings were high.

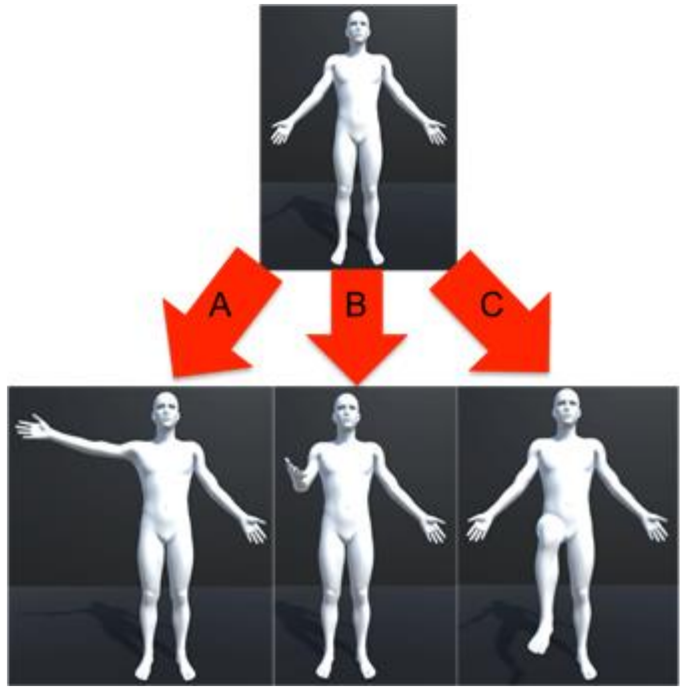

Figure 1: The tasks performed by the subject.

To test the accuracy of this novel system, we simultaneously collected kinematic data using our device along with an optical motion capture system (Qualisys Oqus, Göteborg, Sweden). The optical motion capture had 30 markers on the bony landmarks of the body to collect the full-body kinematics at 100Hz. The markers were placed bilaterally on toe tip, heel, medial/lateral malleolus, medial/lateral condyle of tibia, trochanter, ASIS, PSIS, acromion, medial/lateral humeral epicondyle, and ulnar/radial styloid process, plus unilateral C7 and T10 markers. One recruited subject performed three tasks (Fig. 1, A, B, C). Starting from reference anatomic position, task A encompassed ten consecutive bilateral shoulder abduction/adductions (90 degrees), task B included ten bilateral elbow flexion/extension (90 degrees), and task C was to perform ten hip flexion/extensions (90 degrees, right limb first then left limb). During each task, subject were asked to keep other parts as still as possible.

The IMU data was processed using Microsoft C# (Redmond, WA) and used to calculate join angles. The data was then filtered (4th order zero-lag Butterworth, cutoff 1Hz) using MATLAB (v2016a, Mathworks, Natick, MA) [2]. Optical motion capture data was processed offline using MATLAB and the corresponding joint angles were calculated using costume codes.

Finally, the RMS error and the Pearson's correlation coefficients (*r*) were calculated to reveal the accuracy of the IMU-based motion capture system.

RESULTS AND DISCUSSION

Table 1: RMS errors (deg) and *r* values.

Task	Right Shoulder		Left Shoulder	
A	**RMSE**	**Correlation**	**RMSE**	**Correlation**
	10.73	0.95	2.56	0.99
B	**Right Elbow**		**Left Elbow**	
	RMSE	**Correlation**	**RMSE**	**Correlation**
	9.00	0.99	8.55	0.99
C	**Right Knee**		**Left Knee**	
	RMSE	**Correlation**	**RMSE**	**Correlation**
	5.93	0.99	5.58	0.99

Results revealed small RMS errors as well as a strong correlation between the majorly activated joints (Table 1) of each task (e.g. shoulder in task A). The IMU-based MCS was able to calculate the joint angles with less than 10° of error and a correlation over 95% in all cases.

Other non-essential joints for each test showed a lower correlation due to the noticeable noise. However, this happened only when the body segment has no significant movement or is stationary. When the body segment is moving, we saw the high correlation between the two systems (Fig. 2). Note that unilateral plots were chosen due to the symmetry.

The errors can be due to the inappropriate filtering (e.g., too low cutoff frequency) and misalignment of local coordinate systems between the optical MCS and the IMU-based MCS. Further refinement and calibration will be performed to enhance the accuracy of the IMU-based MCS. More experimental validation with various tasks including walking will be tested.

CONCLUSIONS

The system developed in this study uses IMU sensors to capture human kinematics. The preliminary test involving shoulder abduction, elbow flexion, and hip flexion revealed strong correlations and minimal RMSE values. These results substantiate feasibility of usage of IMU-based MCSs due to their ease of use with their only draw-back being their minor inaccuracy. Future works will include refinement of filtering and examination of various tasks including walking trials and more elaborate motor-tasks. Upon completion, the codes will be made open-source for public use and desired customizations.

REFERENCES

1. Pavol MJ, *Journal of Gerontology: Medical Sciences* **59**, 2004.
2. Parijat P, *Annals of Biomedical Engineering* **40**, 2012.

ACKNOWLEDGMENTS

This MCS was developed and tested by undergraduate students (Tyler Marr, Wyatt Hahn) in the Department of Mechanical Engineering at Texas A&M University.

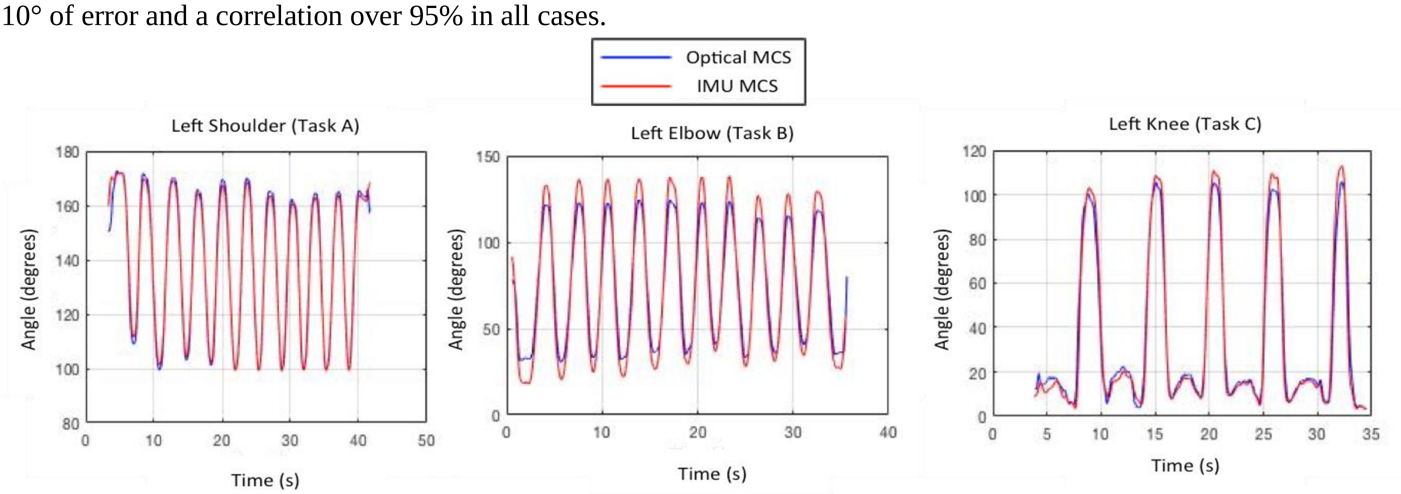

Figure 2: The major joint angles during each task.