A preliminary study of a motion capture system using smartphones for the ankle joint analysis

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Introduction

Motion capture systems are used in a number of fields to analyze human movement by collecting data points for motion analysis. Unfortunately, the most widely used motion capture technology (e.g., Vicon) is prohibitively expensive and requires a well-controlled space to be utilized. As a part of an undergraduate education project (i.e., Aggie Challenge at Texas A&M University), in this study, we implemented and verified the feasibility of a design for a smartphone-based motion capture system to analyze the ankle joint kinematics in an easy manner.

Methods

In this study, we used conventional smartphones to capture the object that we desire. The required number of smartphones is dependent on the number of points to capture. In this case, we used two smartphones to capture four ping-pong balls (Figure 1: green) to analyze the ankle joint. In order to calibrate the motion capture system, we used the direct linear transformation (DLT) method, which relates camera images to real world objects using DLT parameters [1]. A 3D calibration bar with 8 ping-pong balls was used as a global coordinate reference for finding the DLT parameters. Based on the recorded data from two different stationary smartphones, two DLT parameter sets were obtained from each camera by a least squares method. These parameter sets allow us to estimate objects' 3D position from their 2D position in the frame of each camera.

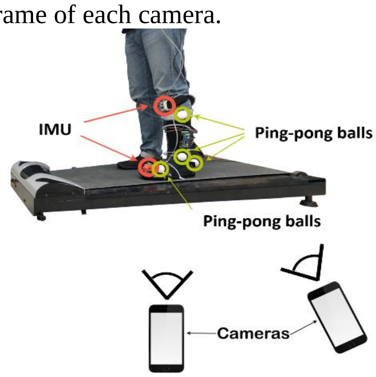

Figure 1: Motion capture experiment setup for the ankle joint angle using two independent capture systems: IMU and smartphone-based system.

To validate the system, a treadmill walking experiment was conducted with a healthy young subject (male, 31 yrs. 1.70 m, 70 kg) in order to capture ankle behavior. The subject was asked to walk at his preferred speed (0.5 m/s). During the experiment, four ping-pong balls and two inertial measurement units (IMUs) were attached to the subject's lower leg and foot as shown in Figure 1. The experiment was recorded with the cameras in the same positions as the calibration process. The resulting videos were time-synchronized in post-processing by cross-correlation of the velocity of a ball located at the heel. The IMU system is commonly used to capture joint kinematics [2] and was used here to verify the proposed smartphone-based system.

After recording the experiment, the movement of each ball was tracked using motion tracking software (OpenCV) to obtain their image plane [u,v] coordinates. Using the DLT parameters from the calibration, the moving image plane data was then converted to three-dimensional coordinates [x,y,z] which were used to calculate joint angles.

Results and Discussion

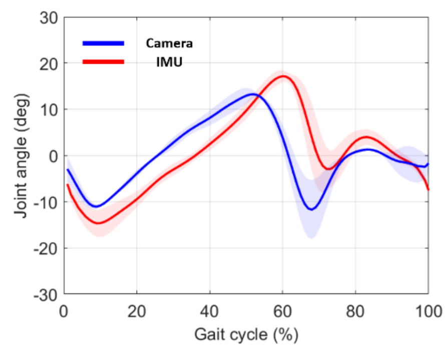

Figure 2: Ankle joint angle estimation from two different methods: IMU system (red) and camera-based system (blue). Bold lines and shaded regions refer to the average and ± 1 s.d. of five consecutive steps, respectively.

Figure 2 shows the ankle joint angle in the sagittal plane as measured by the two different methods. This data confirms preliminary feasibility. Compared to the result from the IMU system, the proposed result shows a qualitatively similar trend for the entire gait cycle, especially in showing ankle dorsiflexion and push-off. The discrepancies in angle can be explained by sensitivity to placement both for the IMU sensors and our markers. We expect that we can account for these with modification to the algorithm and marker design, yielding improvements in accuracy. The performance of the improved system will be gauged against the Vicon capture system.

Significance

This study shows the feasibility of using smartphones for motion capture purposes. Once the accuracy of our motion capture system is improved, it can potentially make motion capture experiments easier, portable, and more accessible, since users only require relatively inexpensive phones with minor preparation for the test. Most importantly, this study provided an educational experience for the undergraduate students at Texas A&M University who completed this work.

References

[1] Y. Kwon (1998), http://kwon3d.com/theory/dlt/dlt.html

[2] W. Hong, et al. (2019), *International Conference on Robotics and Automation*