Comparing Knee Angle for Subject IMU Self-Placement

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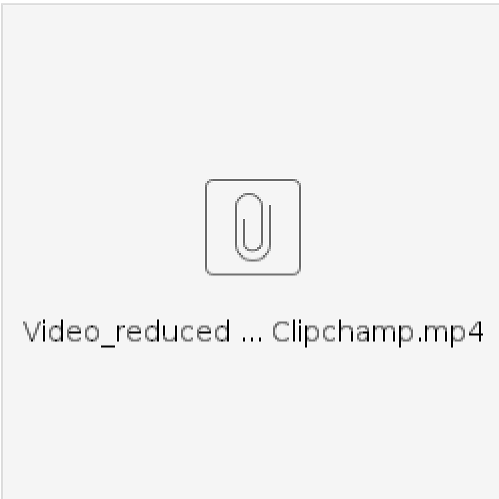
Project Video



Background

Motion capture data is used extensively in biomechanics to study movement, characterize gait abnormalities, estimate joint loading, etc. and this tool is made all the more powerful when used in conjunction with forward simulations that model musculoskeletal systems and can perform purely simulated optimization studies. Unfortunately, motion capture requires costly equipment-cameras, markers, ground force plates-and requires that experiments be performed in small, controlled spaces, which limits their accessibility and application in the real world.

For the reasons listed above, it is desirable to develop the technology and practices to perform similar studies with inertial measurement units (IMUs) which are cheap, compact, and already located integrated into cell phones, wristwatches, and some sportswear. In order to determine kinematics, IMUs use accelerometers, gyroscopes, and (usually) compasses to measure linear and angular accelerations, which are then double-integrated to obtain changes in position.

Though simple in theory, using accelerations to calculate kinematics is difficult in practice. Because position and orientation between IMU's can change and there is no way for them to account for such internally, initial position calibration is critical to the accuracy of measurements; however, subjects with movement disorders cannot always hold such positions. For this reason, in order for patients eventually to be able to record kinematic data at home for extended studies, it is critical to quantify the reliability of IMU kinematic data that relies solely upon repeated IMU placement.

In this study, we shall analyze a common and important lower limb parameter-maximum knee angle-during gait cycles of two healthy subjects and determine how the variability in kinematic data changes with respect to physiological norms when subjects place the IMU's on themselves.

Research Question(s)

1. How much variability in kinematic data can one expect from the imperfect self-placement of IMU's by subjects who cannot hold a standard calibration position?

Methods

Participants wore 11 IMU's-one just below the navel and one on each shank, thigh, hand, forearm and upper arm-and then performed 40 strides back-and-forth (5 strides followed by turnaround, 8 times.)This process was repeated by two subjects, alternating for a total of 3 trials, each requiring complete removal and replacement of the IMU's.

Data was collected using Xsens' MTw Awinda wireless IMU system in conjunction with their MT Manager software package. The kinematic data was then exported and processed into a kinematic simulation using a custom C++ code and model (see below) and then exported to Excel and OpenSim for post-processing and analysis.

Insert .cpp code and full pelvis model

Results

Below is a sample of knee angles of the left and right leg during one trial. Each peak and valley corresponds to a single stride while the repeatedly smaller peaks correspond to the turnarounds during the experiment.

Furthermore, a knee angle of zero corresponds to a fully extended knee; therefore, negative values are physically impossible. To correct this immediate error, all data was translated upwards by the maximum negative value, keeping the knee angle ranges the same, but preventing hyper-extension. Correction of the same data set as above is plotted below.

In order to minimize the effect of braking and accelerating immediately before and after the turnarounds, only the knee angles for the middle three strides were used for analysis.

Subject 1 had an average maximum knee angle of 79.2 degrees with a total range of 69-90 degrees. Subject 2 had an average maximum knee angle of 68.9 degrees with a total range of 55-81 degrees.

Experimentally verified maximum knee angle during healthy gait is 70-80 degrees with a typical variation between stries of 5 degrees. On average, this IMU data falls within the expected range; however, our variability (+/- 13 degrees) far exceeds the physiological variability. Part of this variability can be explained by integration drift of the IMU's; however, across all trials, the average increase in maximum and minimum knee angles was only 3 degrees. Taking this into account, the average variability caused by imperfect IMU positioning was 5-10 degrees.

Given the small sample size and number of trials performed, these results are statistically insignificant. Furthermore, this experiment did not control walking speed or definitively quantify the effect of drift. Nevertheless, our results suggest that self-placement of IMU's will induce unacceptably large variability in data.

Future Work

As mentioned, this study failed to account for varying walking speed and IMU drift. Both of these issues could be mitigated (if not resolved) by the simultaneous use of motion capture during trials. Drift could also be addressed using an algorithm that recalibrates according to a recognizeable event every gait cycle (such as heel strike.) Even correcting for the above, it appears that self-placement of IMU's will produce unacceptably large variability in kinematic data; therefore, we suggest development and study of the efficacy of IMU-specific accessories/apparel, such as flexible knee sleeves with IMU-pockets or Velcro patches.

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