Locating the Leg Joints Using Magneto-Inertial Sensors for Adjusting the Segmental Lengths of a Lower-limb Exoskeleton

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Background

- The joints of a lower-limb exoskeleton must match a user's hip, knee, and ankle joints precisely to avoid injury.
- The manual method to determine the length between joints requires two people and is time consuming.
- The location of the hip joint has been found for a mechanical model using Magneto-inertial measurement units (MIMUs)[1]; however, no test had been done on human subjects.

Methods

- We replicated the algorithm used in [1] and tested it on a model of a knee joint as wells as on a subject's hip and knee for the first time.
- We modeled each segment of the human leg as a rigid body moving about a center of rotation CoR corresponding to a leg joint while in motion.

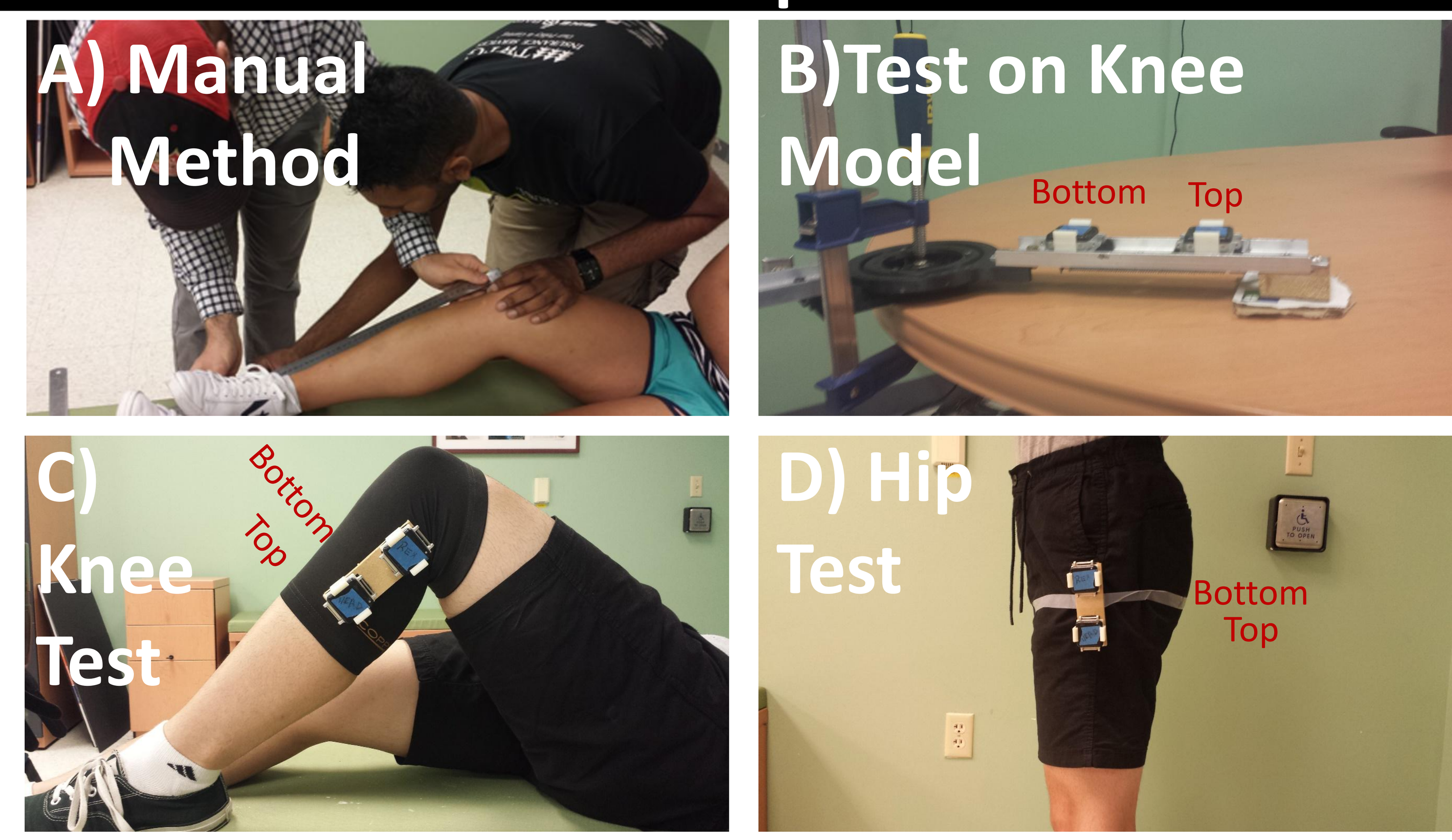
A. **Manual Method**: Joints found using body landmarks.

B. **Test on Knee Joint Model**: MIMUs attached to two links that created back and forth circular movement.

C. **Test on Knee**: MIMUs attached below the knee. We tried to replicate the planar movement from the experimental setup. Different techniques were attempted.

D. **Test on Hip:** MIMUs attached below the hip. We tried both planar and three-dimensional movements.

Setup

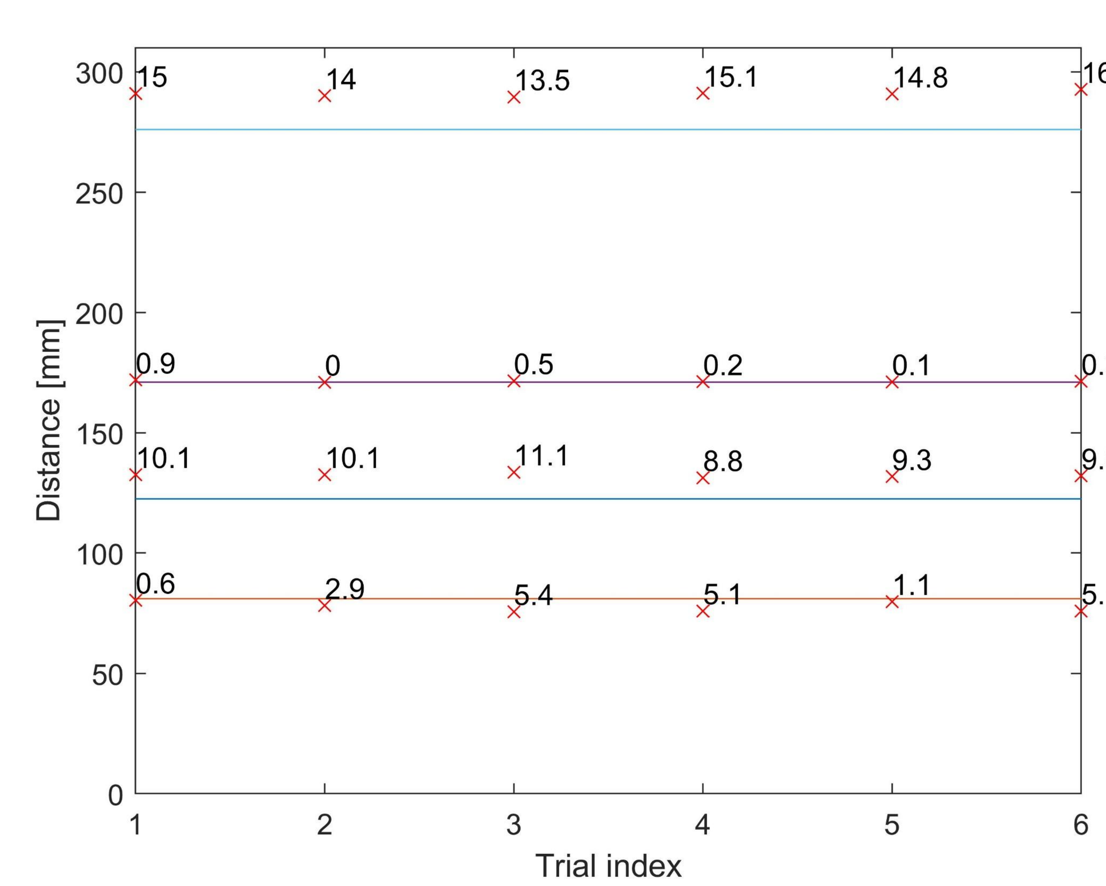


Results

- The distance to the CoR was measured using a ruler and is labeled below as our reference distance.
- The data on the last column is incorrect due to an error during data collection, but the results give an estimation of accuracy.

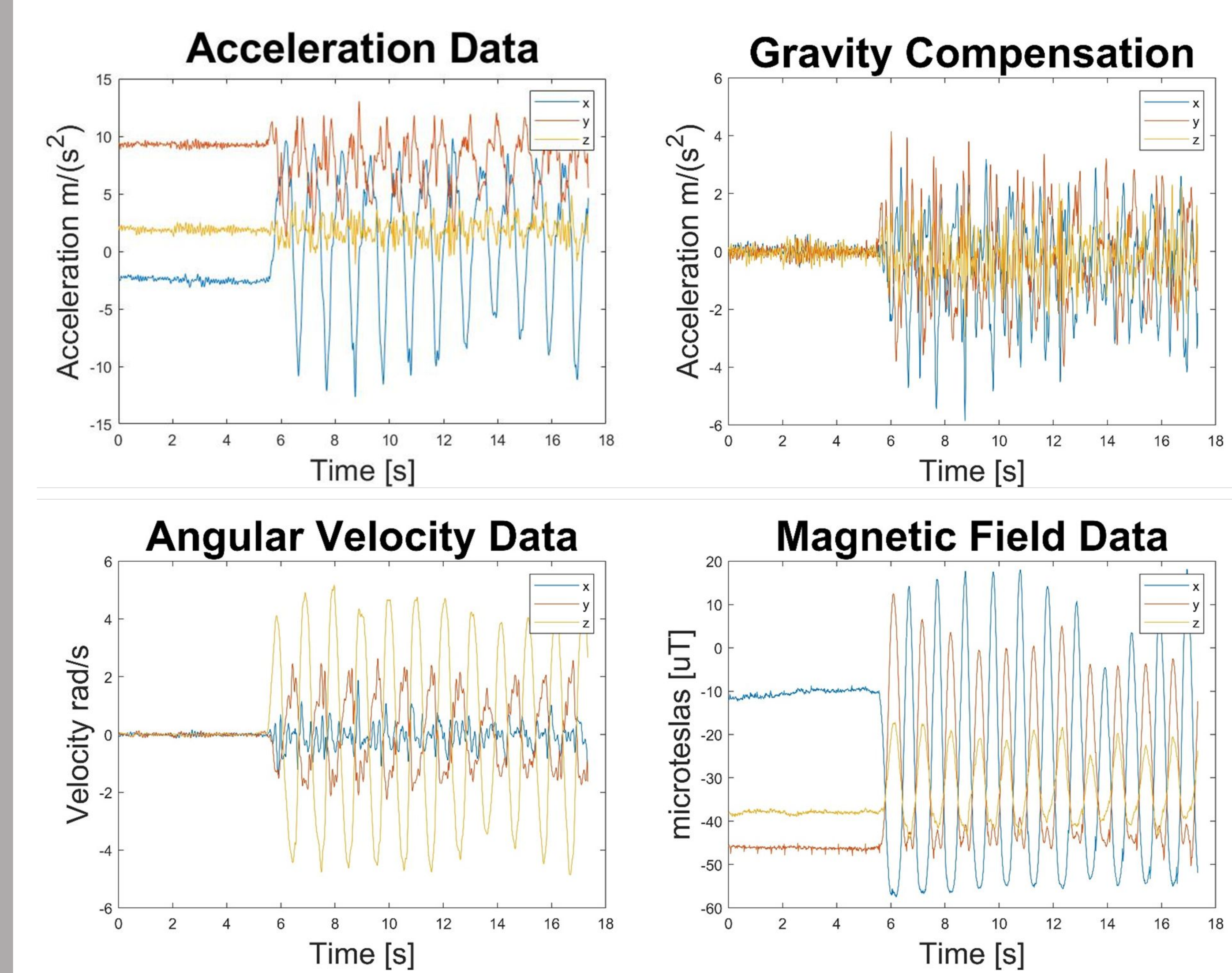
Test for	Number of Trials	MIMU Location	Reference Distance [mm]	Standard Deviation of the Test [mm]	Average Error of the Test [mm]
Model (B)	6	Bottom	81	2.1	3.4
Model (B)	6	Top	171	0.3	7.7
Model (B)	6	Bottom	122	0.8	9.8
Model (B)	6	Top	276	1.1	14.8
Knee (C)	5	Bottom	81	4.0	24.2
Knee (C)	5	Top	158	3.2	55.5
Hip (D)	5	Bottom	196	6.1	103.0
Hip (D)	5	Top	263	7.1	103.0

- Below is a representation of the four tests for the model (B) shown in the top four rows of the previous table.
- Each line represents the reference value with the marks as each trial and the distance away from the reference in mm.



Discussion and Analysis

- To assess performance we mainly analyzed the standard deviation within all the trials of each test.
- The original method to locate joints takes three trials to measure the segmental length and uses the average. Some measurements have differed by up to nine mm.
- We tried different techniques for movement of the leg for tests C and D. The table shows the best techniques that had the least standard deviation.
- Factors that could alter the performance of a MIMU include gyroscopic bias, compensating for gravity and the environment's magnetic field.
- Below we show plots of one MIMU at bottom location for one of the knee tests.



Conclusions and Future Work

- The small standard deviation between trials suggests locating the leg joints is possible, but the error in the reference values make the results inconclusive.
- Future work should investigate ways to compensate for the non-idealities of leg motion such as non-planar movements and techniques for applying the test for subjects with disabilities.

References

[1] D. P. R. C. M. Crabolu, "Estimation of the center of rotation using wearable magneto-inertial sensors," *Journal of Biomechanics,* vol. 49, no. 16, pp. 3982-3933, 2016.

[2] "E-missions," [Online]. Available: http://www.e-missions.net/cybersurgeons/?/musc_student/. [Accessed 17 August 2018].

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