Human Gait Analysis

Using IMU Sensors and Android

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Data Collection

1. IMU (Inertial Measurement Unit)
    a. Accelerometer
    b. Gyroscope
    c. Magnetometer
2. Configuration:
    a. Acceleration: (±2 g to ±16 g)
    b. Gyroscope: (± 250 dps to ± 2000 dps)
    c. Sampling Frequency: (5 Hz to 300 Hz)
3. Orientation Calculation
4. Local Data Storage

EXEL s3 IMU Sensor
Source: http://www.exelmicroel.com/

Placement of Sensors on Thigh and Shank of right Leg. (along with Optical Markres).

IMU vs Optical

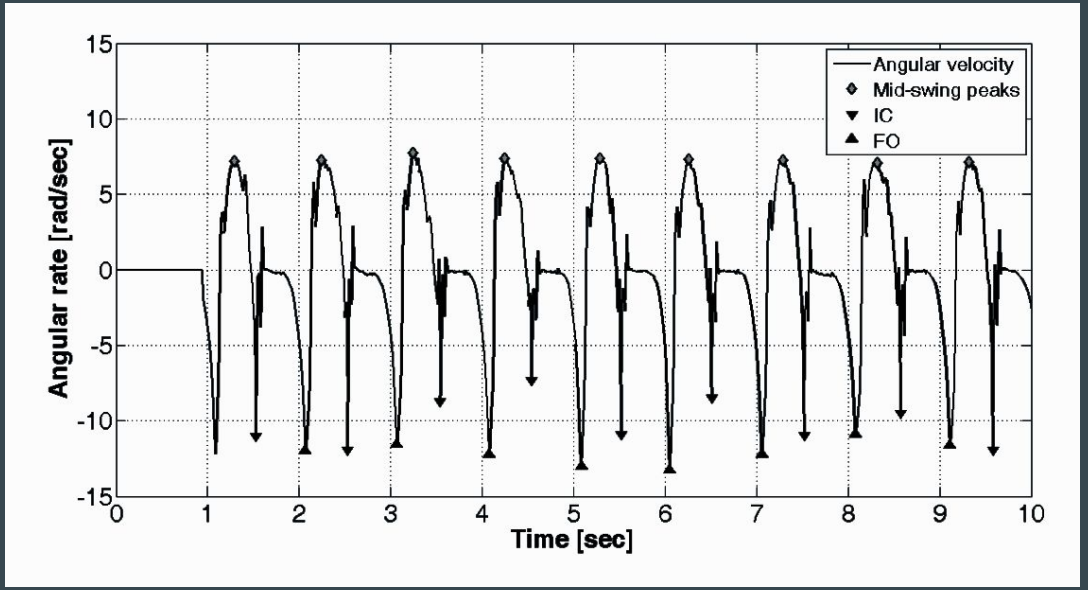
1. Optical System
    a. Costly
    b. Light Markers, Ideal lighting
    c. Limited Coverage
    d. Time Consuming
    e. Very High Accuracy
2. IMU Advantages
    a. Flat surface instead of a room.
    b. Flexible Placement.
    c. Long Distances.
    d. Relative Low cost.

A Typical Optical Gait Lab

Source: http://www.mdpi.com/sensors/sensors-14-03362/article_deploy/html/images/sensors-14-03362f11-1024.png

Heel Strike (HS) and Toe Off (TO) Detection[2]

1. Important parameter:
    a. Mark the Start and End of a Gait Cycle.
    b. Other Gait parameters are calculated using this.
2. Cross verification of results.
    a. Foot sensor and Shank sensor can be used independently to detect the Heel Strike and Toe Off.
3. Curve Patterns
    a. The algorithm depends on the pattern of the curves to find HS and TO.



Heel Strike and Toe Off Detection using the Angular Velocity of the Foot Sensors.

Joint Axis Direction Detection[1]

1. Basic Idea of Detecting Joint:
    a. Hinge Joint Assumption
    b. Condition to hold: The angular velocity of the two segments differ only by the joint angle velocity and a rotation matrix. Their projection into the joint plane (plane to which joint axis vector is normal) will have same length.
    c. After the collection of data, we look for joint axes (respective to both the sensors) which hold this condition true to the closest.

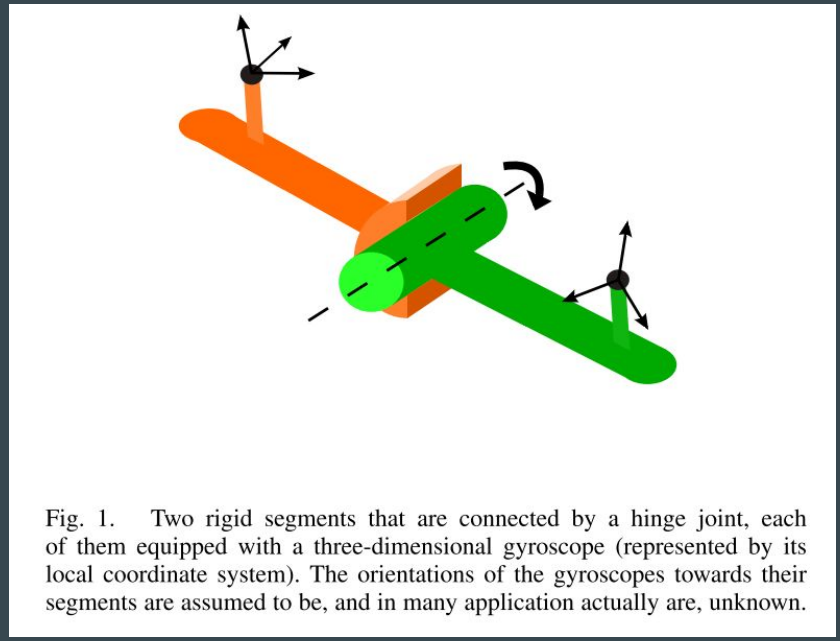
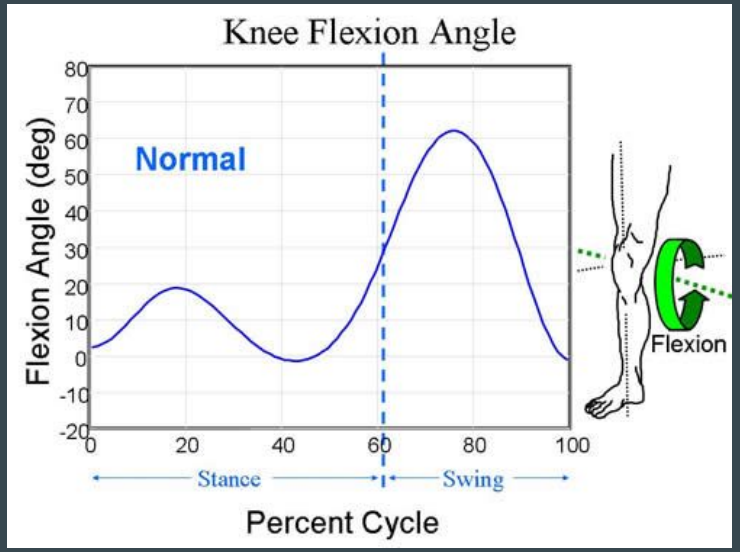


Fig. 1. Two rigid segments that are connected by a hinge joint, each of them equipped with a three-dimensional gyroscope (represented by its local coordinate system). The orientations of the gyroscopes towards their segments are assumed to be, and in many application actually are, unknown.

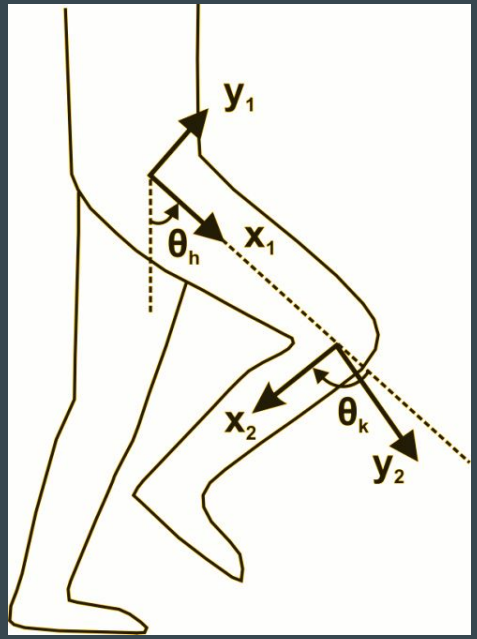
Knee joint is modeled as a hinge joint. Using certain properties of Hinge Joint we can find Joint Axis and Joint Center using the Gyroscope and Accelerometer data.

Knee Flexion Extension Angle Detection [3]



A Typical graph of the Knee Flexion Extension Angle of a Healthy Person

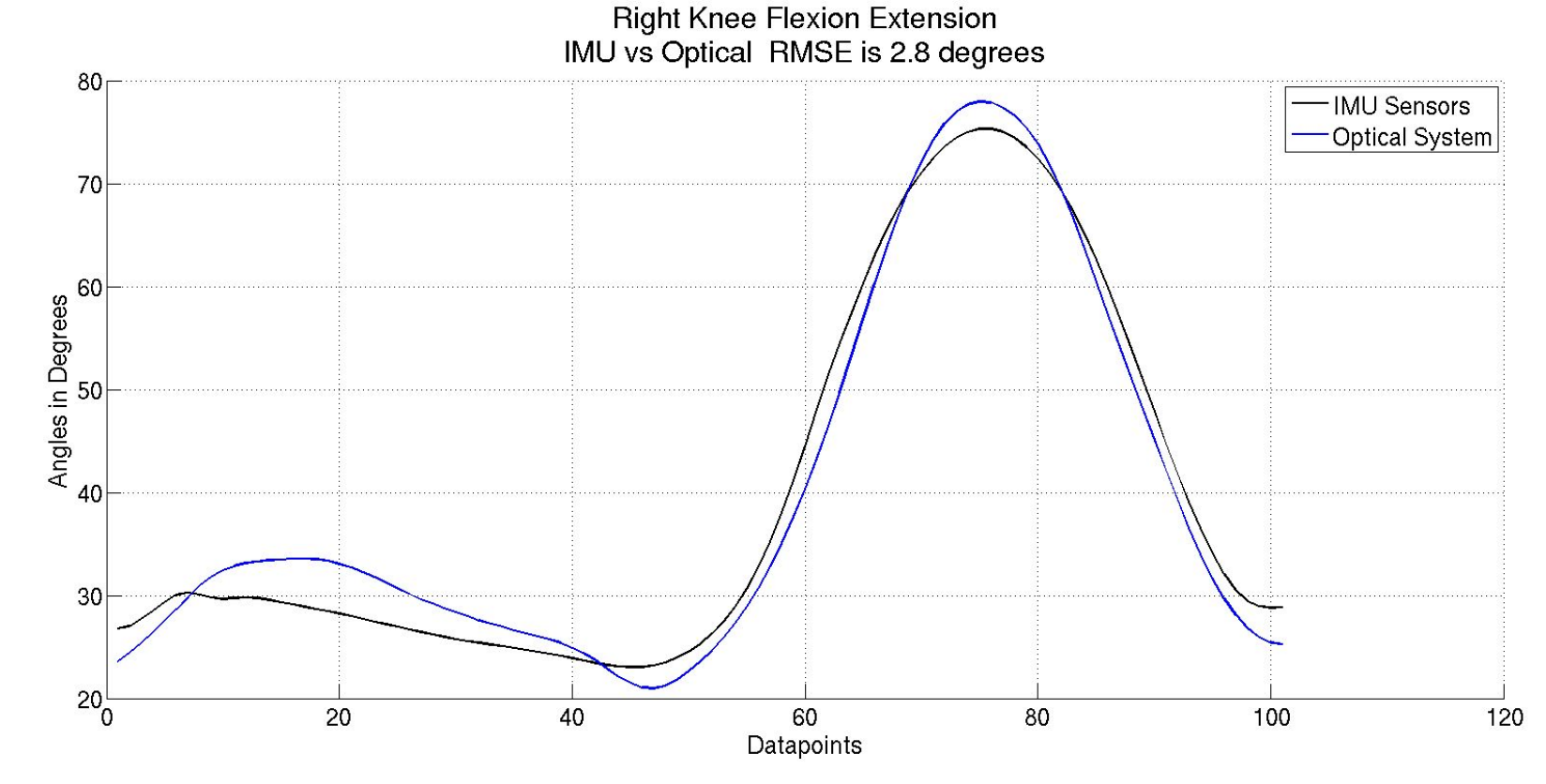
Source: http://me.queensu.ca/People/Deluzio/images/KneeFlexionAngle.jpg



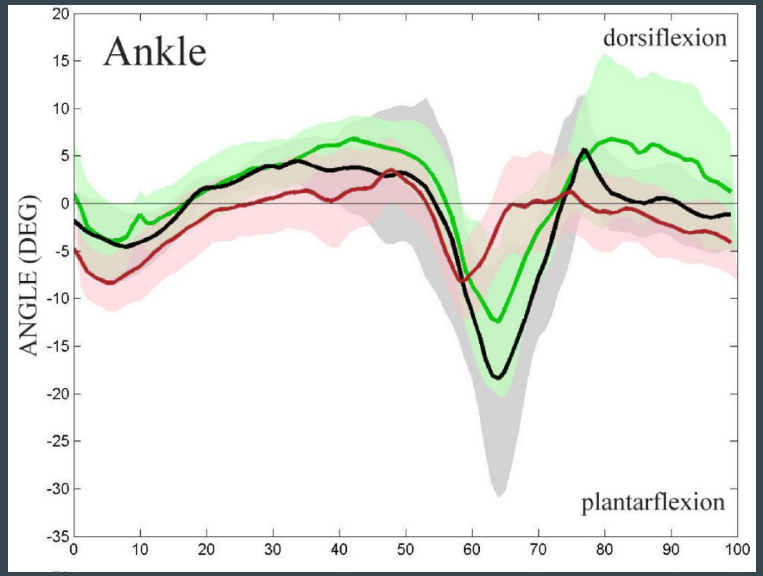
Measured Knee Angle (θ_k)

Source: http://www.intechopen.com/

Results

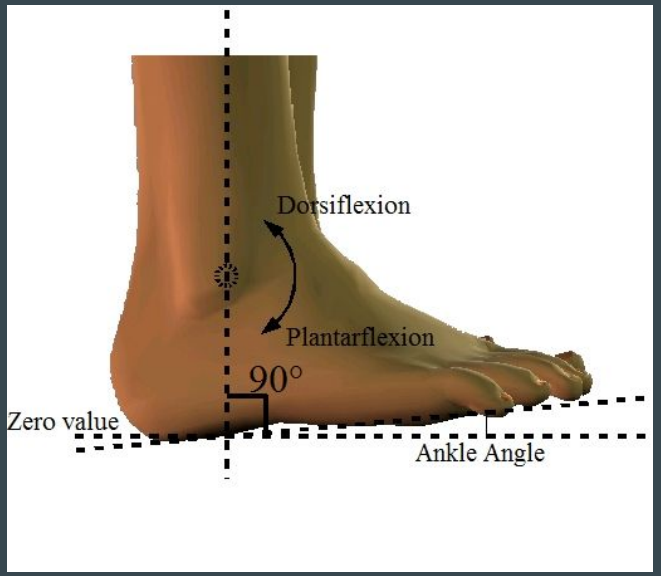

Right Knee Flexion Extension
IMU vs Optical RMSE is 2.8 degrees
IMU Sensors
Optical System
Angles in Degrees
Datapoints
80
70
60
50
40
30
20
0
20
40
60
80
100
120

Ankle Dorsiflexion Plantarflexion Angle Detection [3]



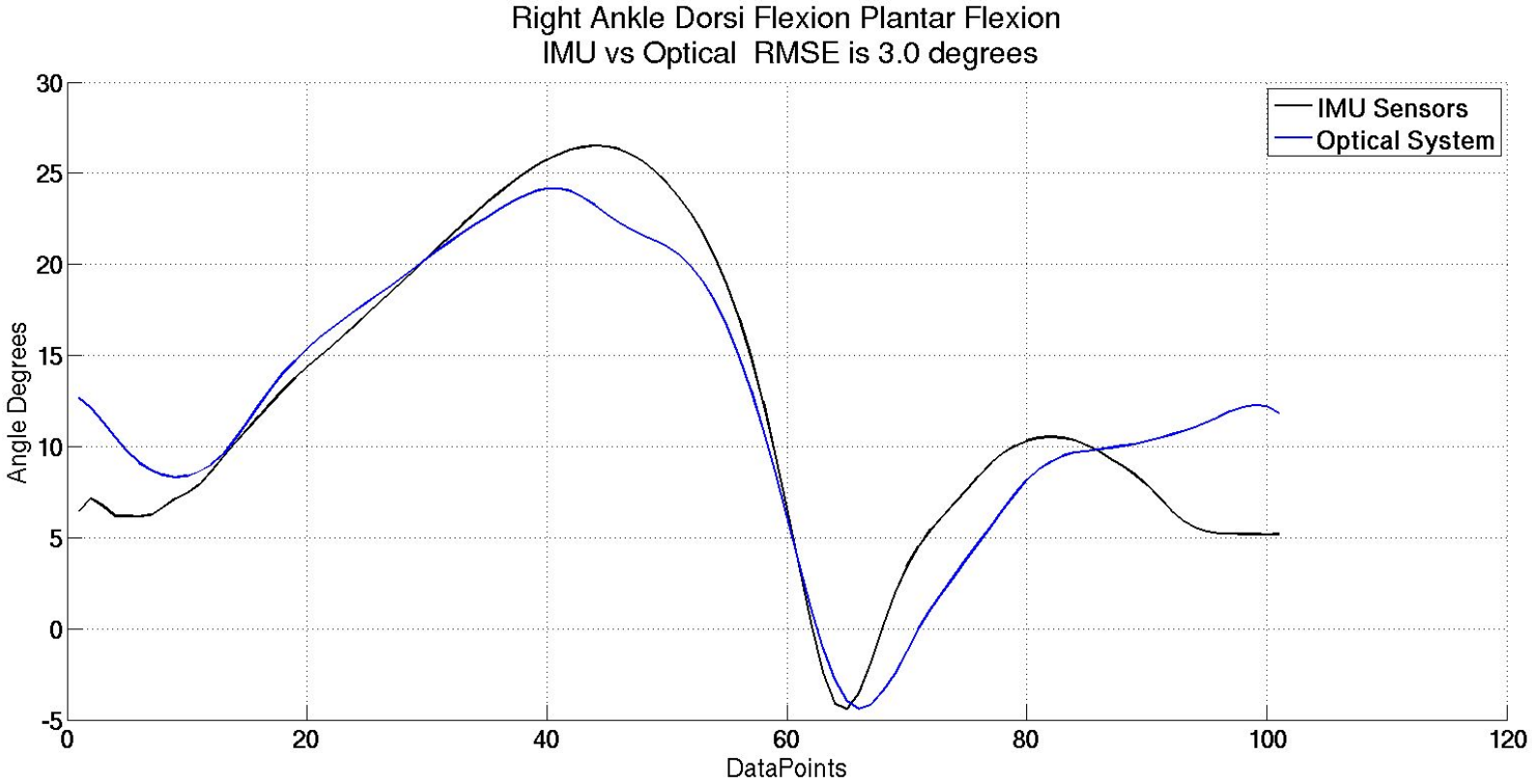
A Typical graph of the Ankle Dorsiflexion and Plantarflexion Angle for a Healthy Person

Source: https://static-content.springer.com/

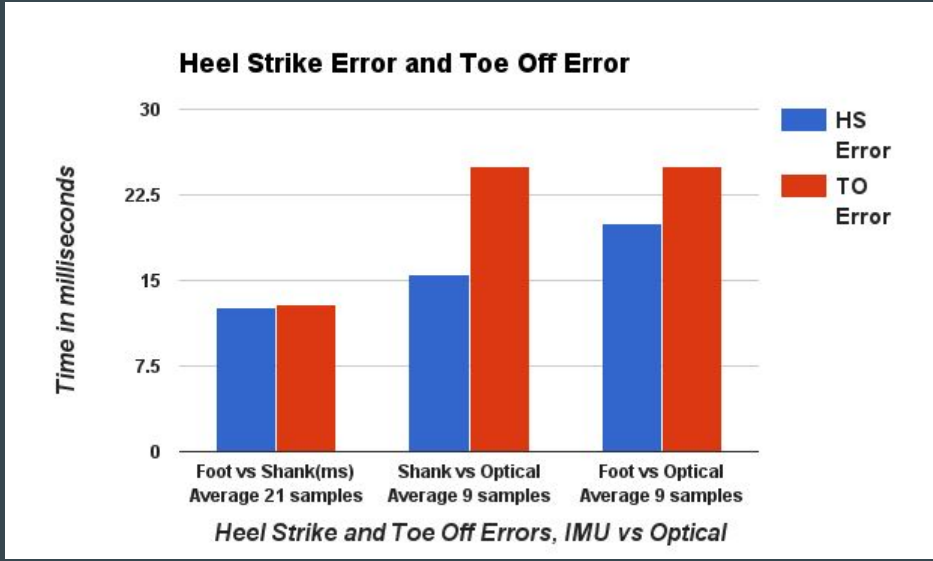


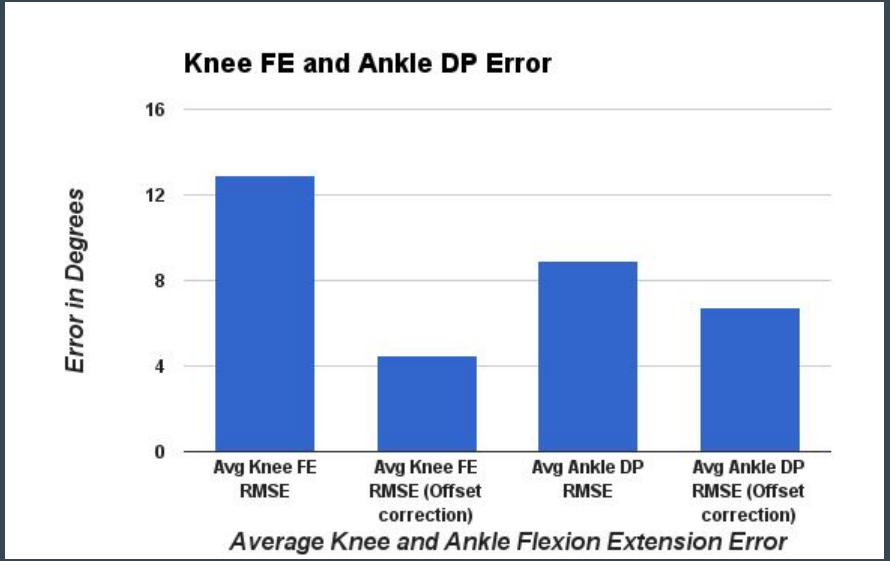
Measured Ankle Angle

Source: https://www.dh.aist.go.jp/database/properties/a/Def-Weiss-86-1.jpg


Right Ankle Dorsi Flexion Plantar Flexion
IMU vs Optical RMSE is 3.0 degrees
IMU Sensors
Optical System
Angle Degrees
DataPoints
30
25
20
15
10
5
0
-5
0
20
40
60
80
100
120

Comparison: Against Optical System*





* Gait Optical System available at BIMRA (Bangalore Institute of Movement and Research Analysis, Whitefield, Bangalore, India

Video: Android Gait Analysis App (Alpha Version)

1. Makes the whole system portable.
2. Easy to Setup and Use.
3. Low Cost.
4. Smartphone Fast enough to perform the calculations.

Gait Analysis Using IMU and Android

Video: Android App

1. Features:
    a. Heel Strike and Toe Off (Shank Sensor).
    b. Knee Flexion Extension Angle.
    c. Average Knee FE Angle.

1. Known Issues:
    a. Packet Loss.
    b. Checksum Failures.
    c. Issue while converting the Quaternion values.

Video Showing working of the App.
(Watch on YouTube)

Future Work:

1. Hip Angle Calculation by adding more sensors.
2. Use Sensors on Both of the Leg.
3. Make Android App more Robust.
4. Algorithm for Abnormal Gait.
5. Analysis of the Gait, using Machine Learning techniques, when we have enough data.
6. Test of the Algorithms and App on patients.

References

1. T. Seel, T. Schauer and J. Raisch, "Joint axis and position estimation from inertial measurement data by exploiting kinematic constraints," Control Applications (CCA), 2012 IEEE International Conference on, Dubrovnik, 2012, pp. 45-49.doi: 10.1109/CCA.2012.6402423
2. Casamassima, F.; Ferrari, A.; Milosevic, B.; Ginis, P.; Farella, E.; Rocchi, L. A Wearable System for Gait Training in Subjects with Parkinson's Disease. Sensors 2014, 14, 6229-6246.
3. Seel, T.; Raisch, J.; Schauer, T. IMU-Based Joint Angle Measurement for Gait Analysis. Sensors 2014, 14, 6891-6909.

Thank You.

Comparison: Gold Standard (Optical System)

	Foot vs Shank(ms) Average 21 samples	Shank vs Optical Average 9 samples	Foot vs Optical Average 9 samples
Heel Strike Error	12.6190	15.5556	20
Toe Off Error	12.8571	25	25

Heel Strike and Toe Off Errors, IMU vs Optical

Avg Knee Angle RMSE	Avg Knee RMSE (Offset correction)	Avg Ankle RMSE	Avg Ankle RMSE (Offset correction)
12.93 degrees	4.5 degrees	8.93 degrees	6.73 degrees

Average Knee and Ankle Flexion Extension Error