Research Track Project

IMU-Based Measurement System for Kinematic Estimation of Knee Joint Motion and Analysis

Date: 12th February 2020

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Outlook

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- Knee joint kinematic estimation
- Methodology and System design
- I2C Communication
- Measurement Design and Setup
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- Discussion and Conclusion
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Objective of the Study

- Setting up a hardware system to measure knee joint motion
- Based on two IMU sensors (xsens)
- Establish i2c communication between pi and sensors
- Measuring the inertial measurement motion data of knee joint
  - Accelerometer, Gyroscope, Magnetometer
- Validation by comparing with a reference system

Introduction

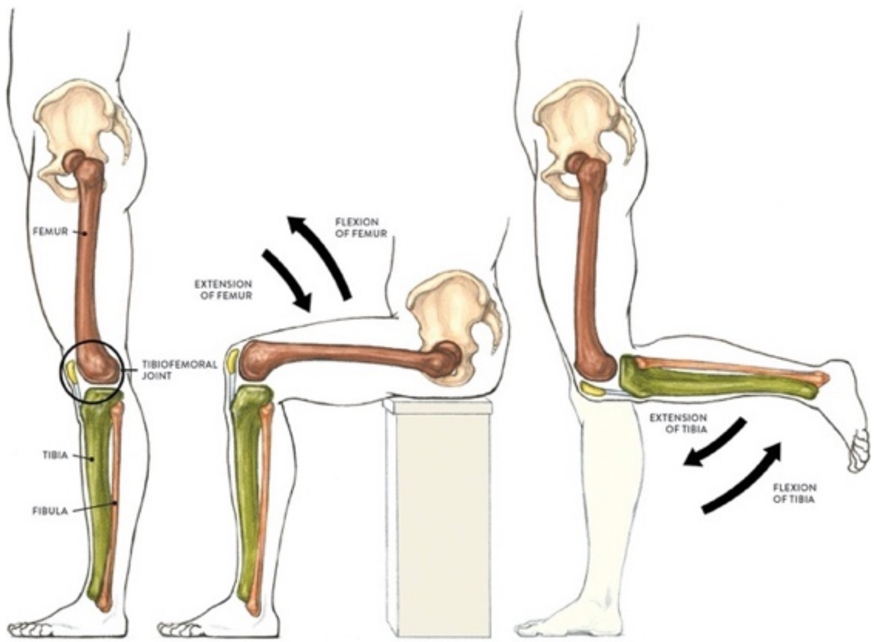

Figure 1: Possible Flexion-Extension of knee joint [5].

Measurement of motion produced by the knee joint as its moves.

- ✓ flexion-extension of tibial movement
- ✓ flexion-extension of femoral movement

Knee joint kinematic estimation

- Optical measurement system
  - reliable lightweight measurement system produces high sensitivity and accuracy
  - ambient light interference can affect the measurement which limited the dynamic range

- Goniometric measurement system
  - main challenge of using this technic is positioning
  - time consuming and less efficient

Figure 2: Optical fiber sensors [2]

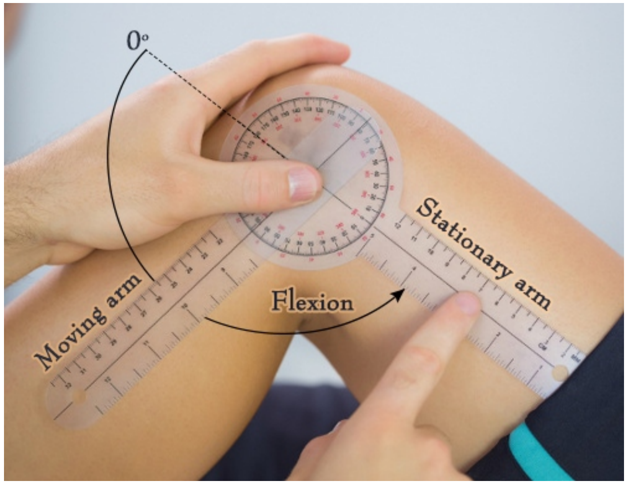

Figure 3: Measuring motion of knee flexion-extension using Goniometer [3]

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Knee joint motion measurement

- Knee joint produces motion for relative movement
- Measurement of relative motions for knee joint
- Inertial measurement data can be investigated [8]
- By analysing this motion we can estimate
  - ✓ activity level of knee
  - ✓ the status of knee health
  - ✓ the intensity of training
- Such potential diagnostic tool
- Inexpensive technique and totally radiation free

Xsens as IMU

- Inertial Measurement Unit: Inertial sensing technology
- Linear acceleration, rate of turn / angular velocity, magnetic field, quaternion
- Sensors used to detect the motion are embedded into a system called IMU

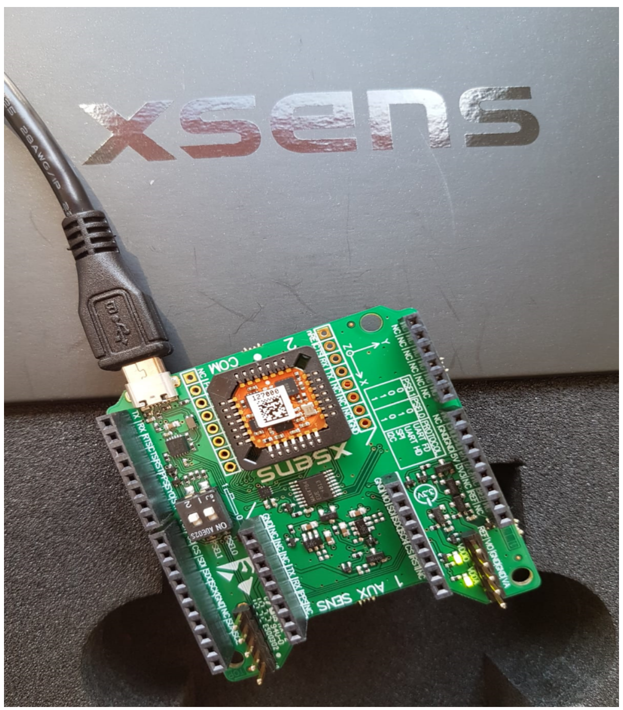

Figure 4: Xsens motion Sensor (MTi 1-series)[4]

- MEMS based inertial measurement unit
- Motion tracking technology
- MTi 1-series is an excellent choice for use in high-volume applications
- Industrial grade accuracy
- Comes with development kit

Methodology

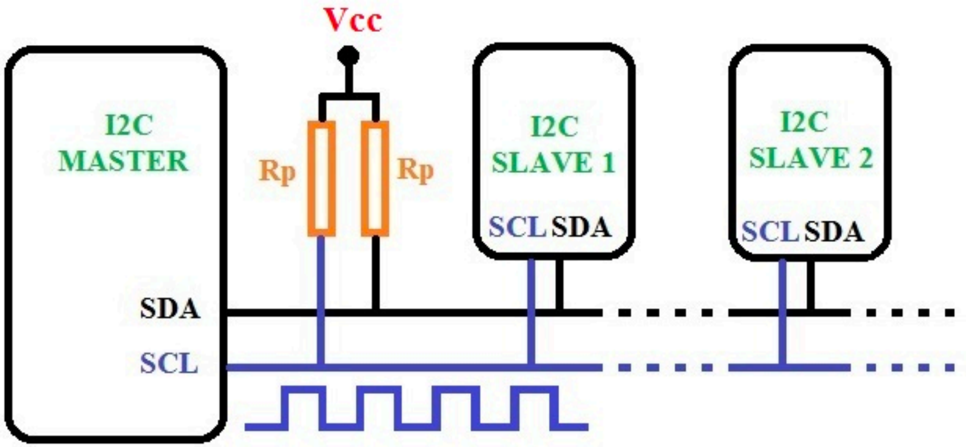

Figure 5: I2C interfacing between master as Raspberry Pi zero and slave as IMU sensors (xsens)

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System design

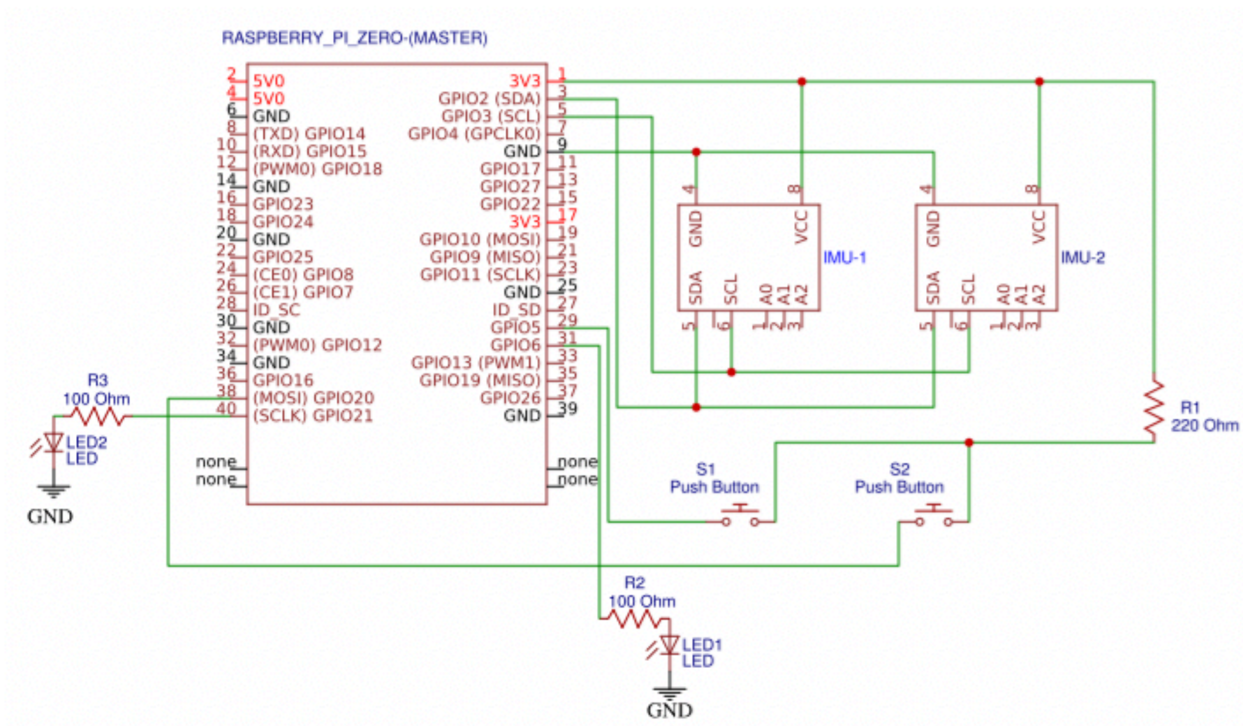


Figure 6: Circuit diagram for I2C interfacing between Raspberry Pi zero and two IMU sensors

System design

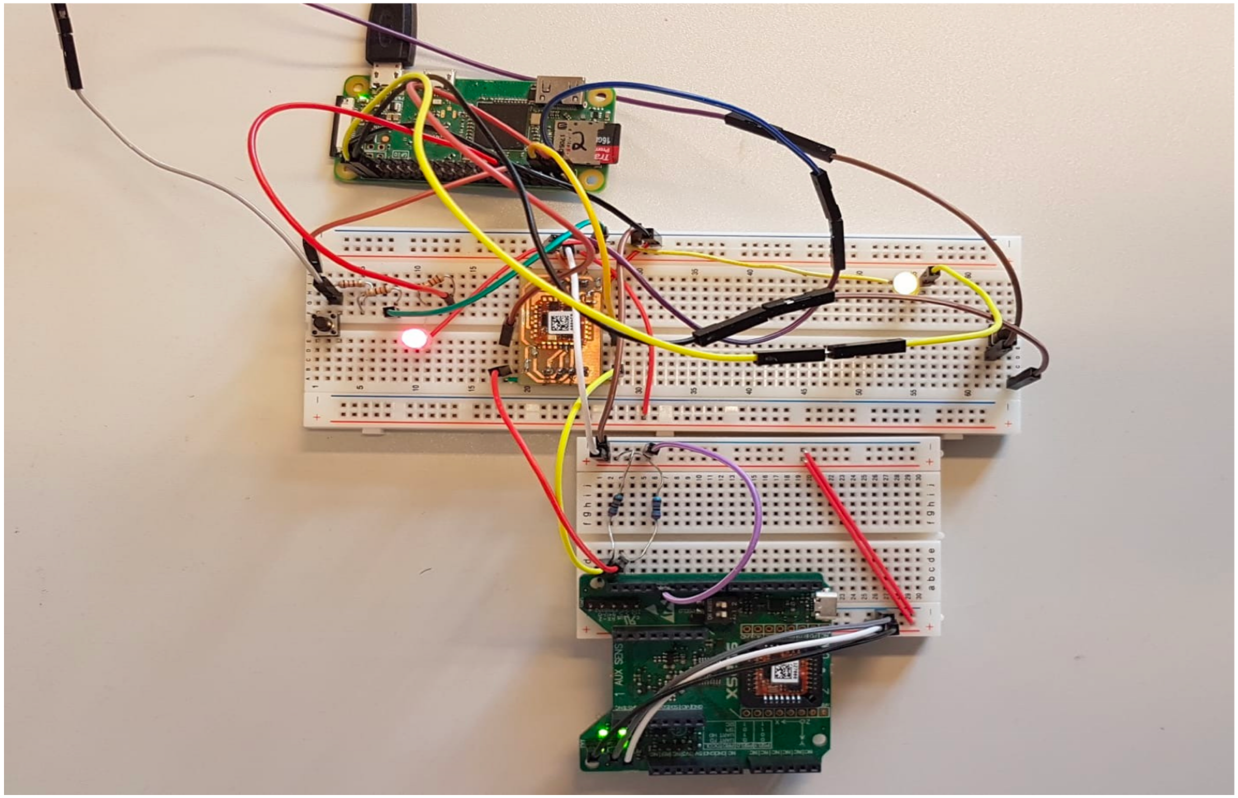


Figure 7: Physical I2C connection of raspberry pi zero (Master) and two IMU sensors (slaves)

PCB design

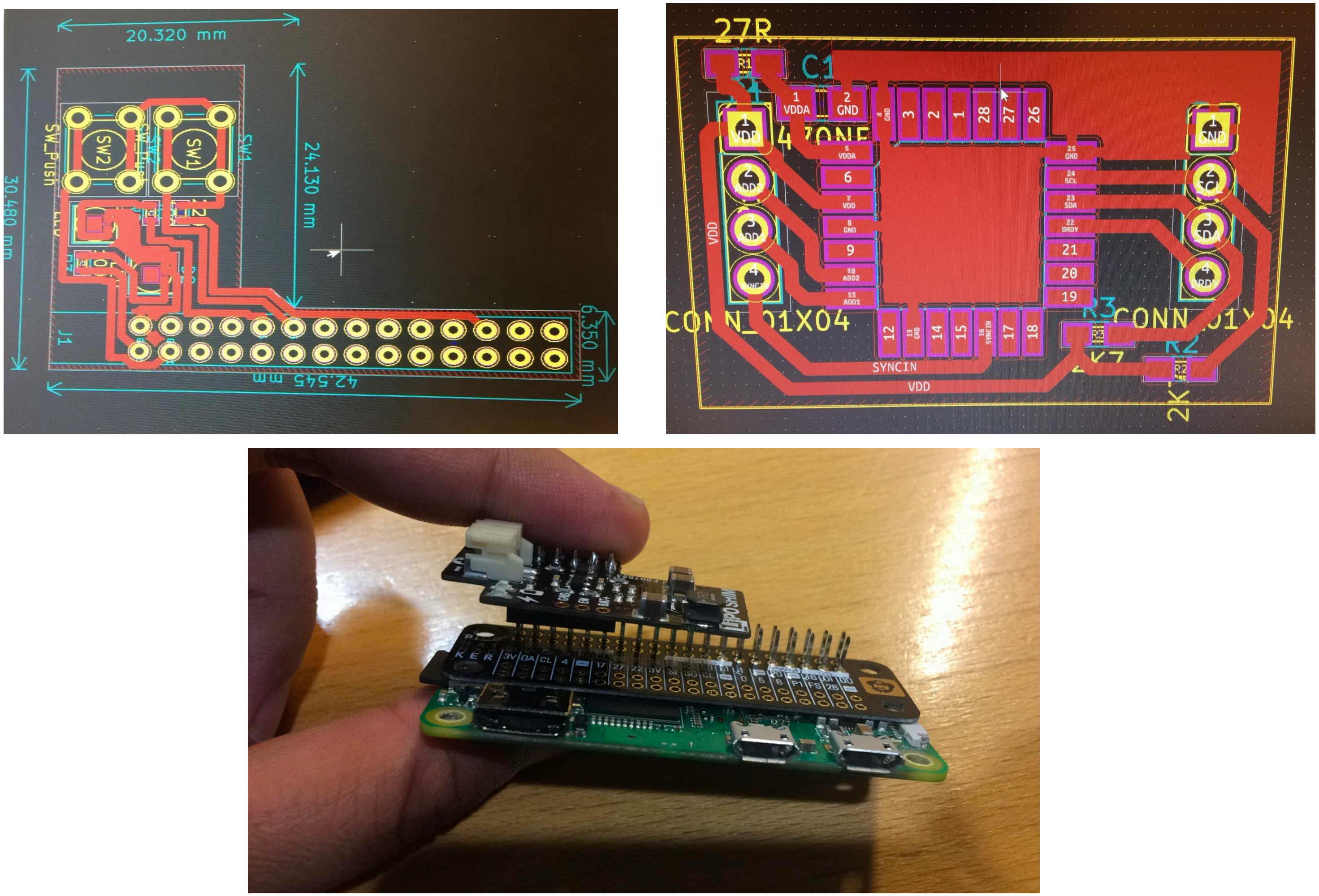


Figure 8: PCB design of the system (Interface and sensor)

Device Design

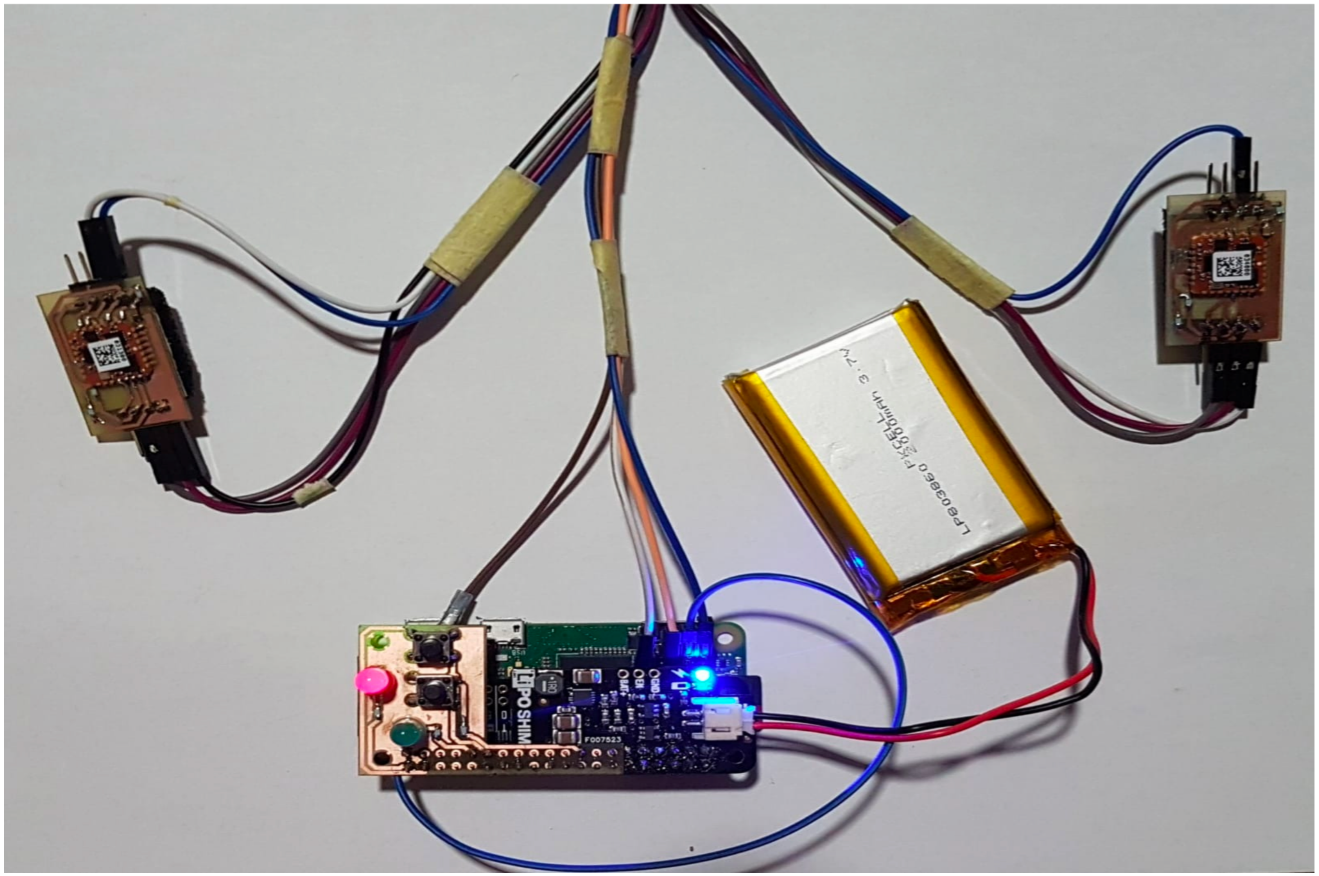


Figure 9: Final prototype design for measurement

I2C Communication

1. **Initialization**: selecting the i2c sensor addresses
    - Reset
    - read NotificationPipe
    - If MID of Notification = = WakeUp

2. **Configuration**: set the config mode for desired data output.

3. **Measure mode**: put the sensors to measure mode through an infinity loop

   False - program stops and close the i2c sensors

   True - sensors get measured

Measurement Design

- Flexion-extension of tibial movement
- Movement is 0°- knee is at transverse plane

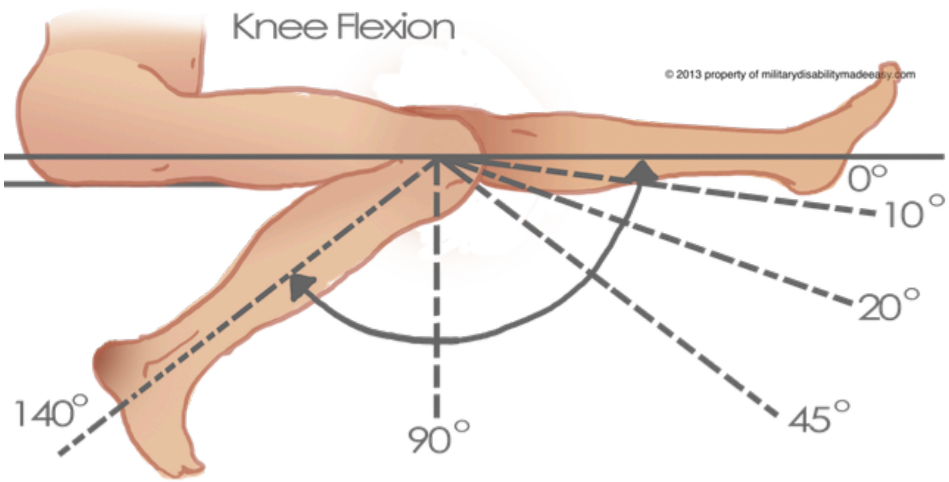


Figure 10. Range of knee joint motion [6]

Measurement setup

- 1st sensor on the upper leg to track the movement of femur
- 2nd sensor is on the lower knee for the movement of tibia

Keeping the leg in transverse plane, second sensor mostly track the flexion-extension of tibial movement respect to the first sensor.

Figure 11: Sensors placement locations and measurement procedure

Measurement setup as Reference

- Consider Xsens MVN Analyze motion tracker as reference
- It ensures real-time, reliable and accurate human motion analysis
- Performed the measurement synchronously

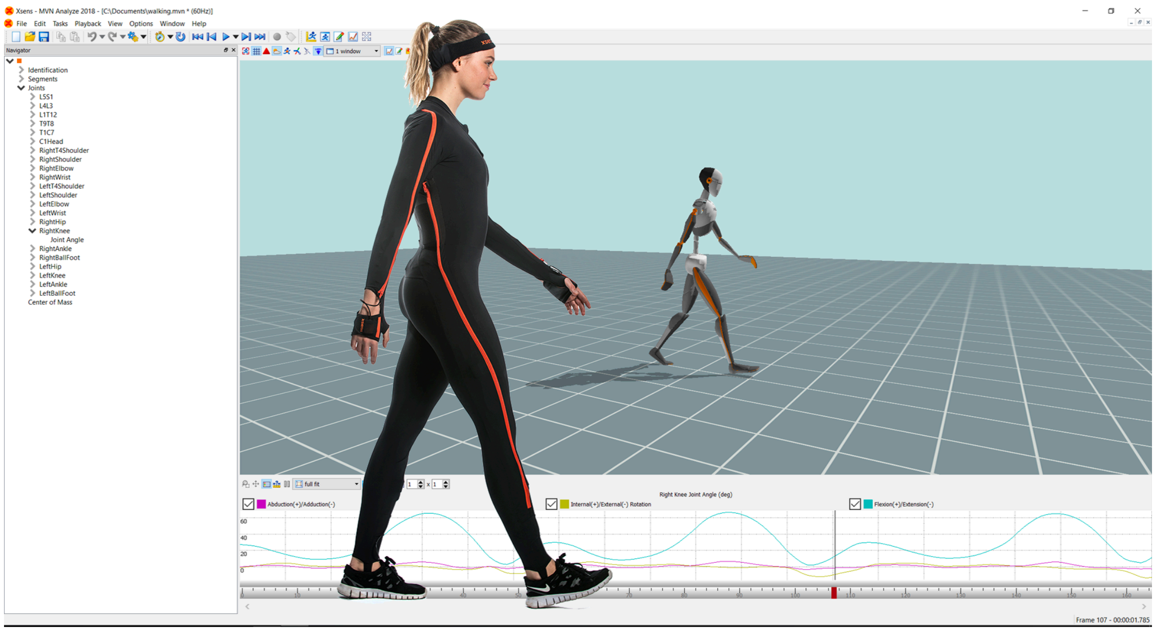


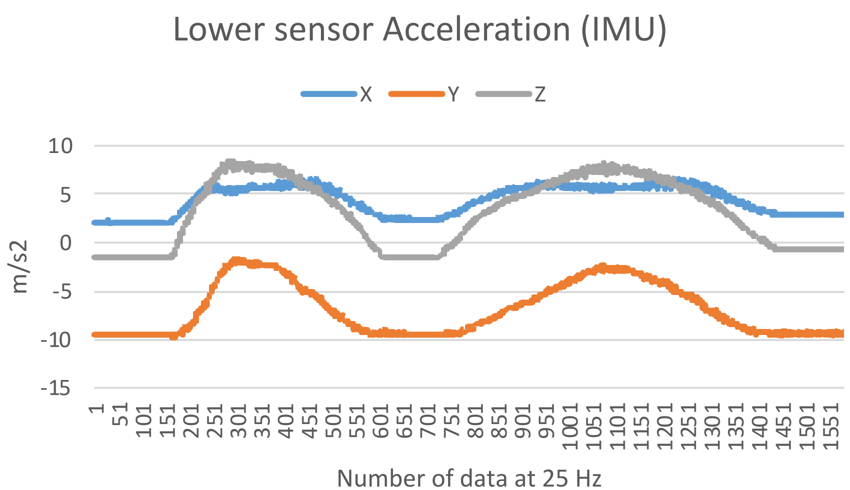
Figure 12: Representation of Xsens MVN Analyze motion tracker as reference [10]

Results

- Put these sensors ideally and measured synchronously
- Setup for live data measurement
- Plotted the individual experimental data
- Compared between IMU data and standard output of MVN sensor to validate
- Reference system measures data at 240Hz
- Though our IMU sensor measures at 100Hz
- Maximum possible output of raspberry pi zero is 25Hz
- Hard to compare data for 240Hz vs 25Hz
- But must show a similar graphical representation.

Acceleration

- The rate of change of velocity of the knee movement with respect to time.



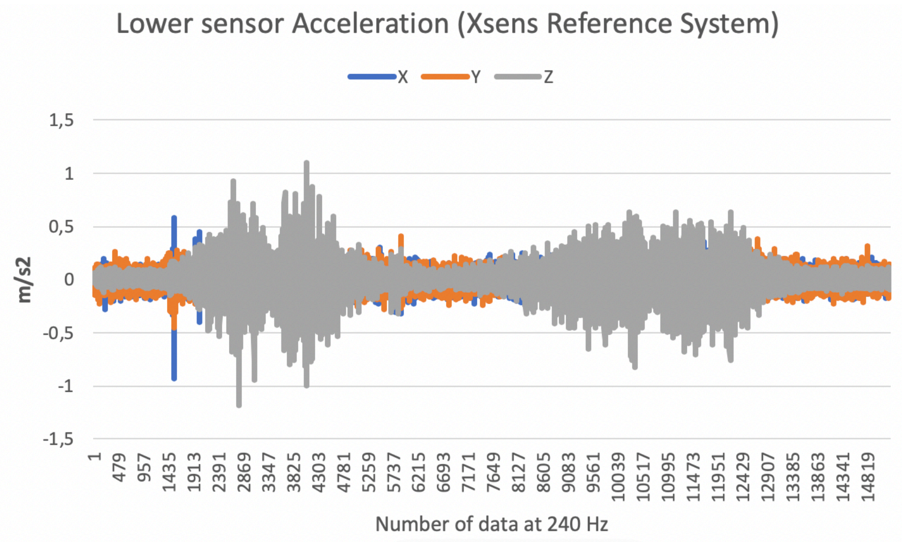
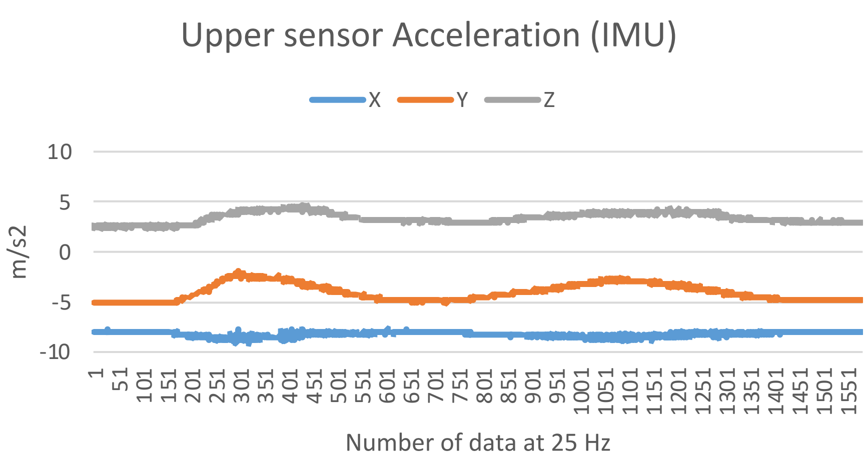


Figure 13: Rate of change of velocity of relative motion a) IMU b) MVN lower sensor

- Measurement time around 63 second
- Lower sensor must show some changes in the axis for the tibial movement
- Both sensors show same graphical representation.

Acceleration



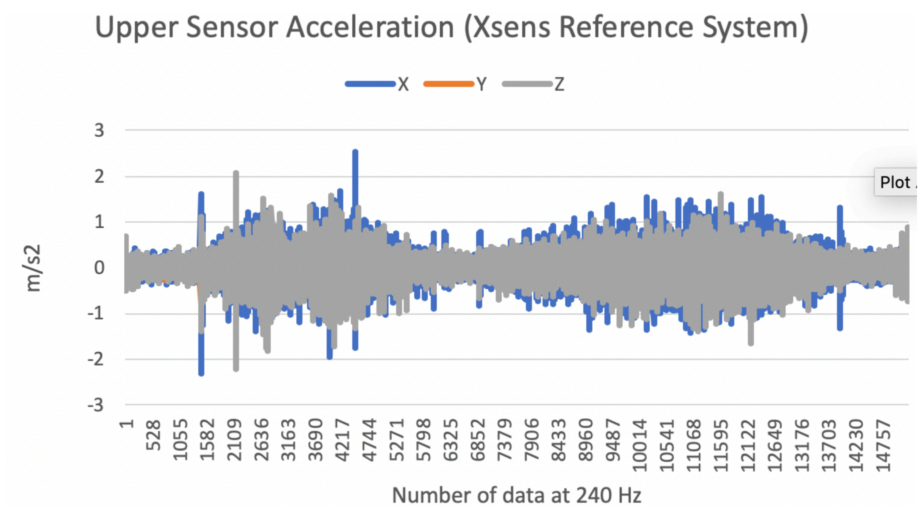


Figure 14: Rate of change of velocity of relative motion a) IMU b) MVN upper sensor

- No movement in the upper sensor for the tibial 90° movement
- Some noises for the both cases.

Angular Velocity

- Gyroscope sensor measure the orientation and angular velocity, where how fast the knee moves and changes its angle position with respect to time (degree per second).

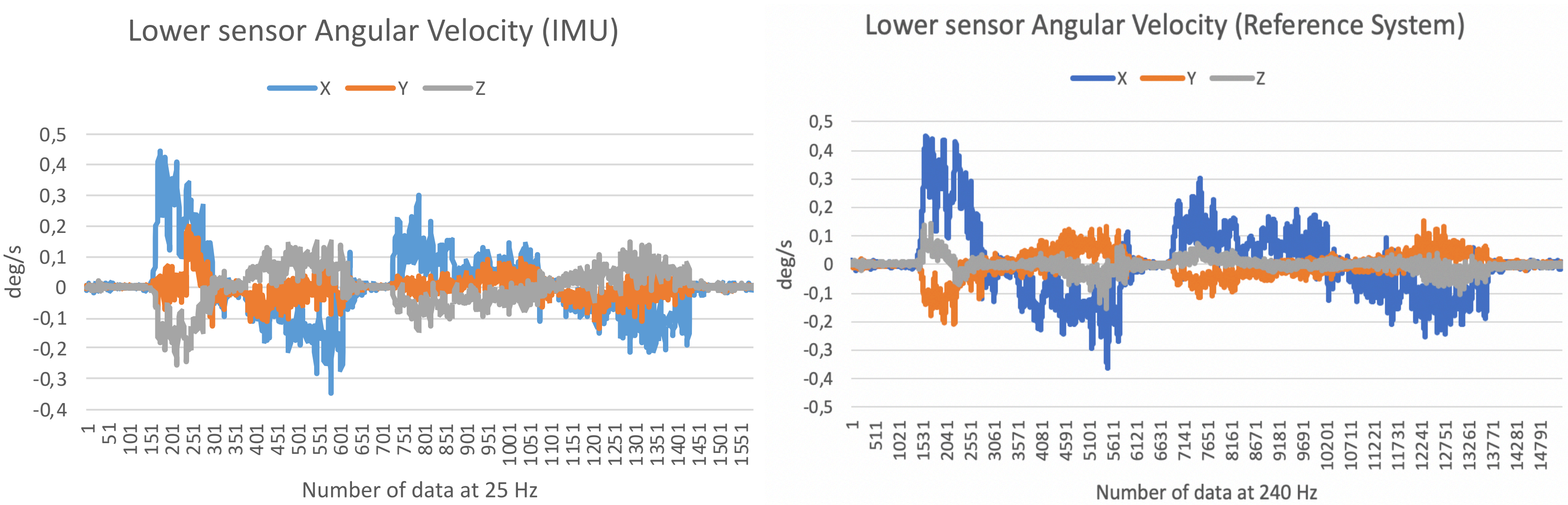


Figure 15: Angular velocity plot of the knee movement for a) IMU b) MVN lower sensor

- Lower sensor must show some changes in velocity for the tibial movement
- Both sensors show same graphical representation.

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Angular Velocity

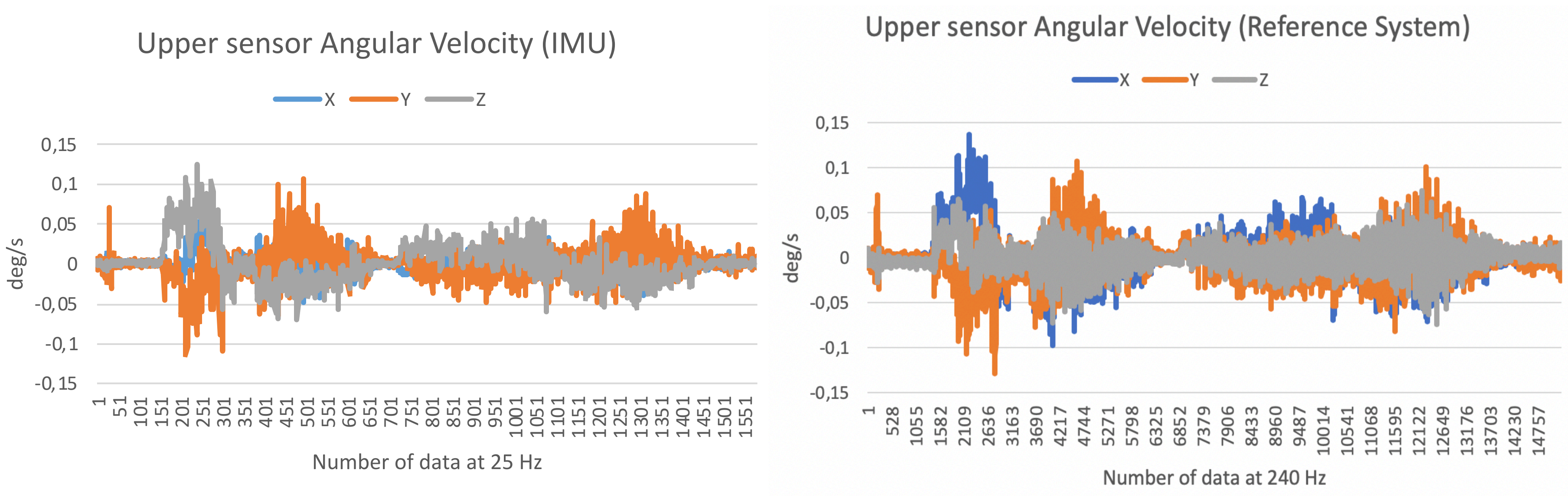
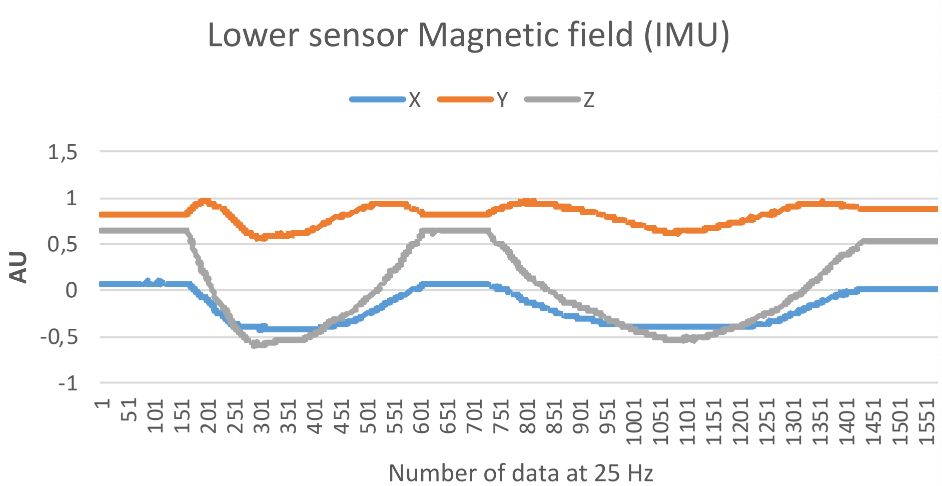


Figure 16: Angular velocity plot of the knee movement for a) IMU b) MVN upper sensor

- No change in velocity
- Same graphical representation.

Magnetic field

- Mechanical motion produces magnetic field and measured the strength
- MTI-series1 is integrated with Magnetometer sensor can detect and measure



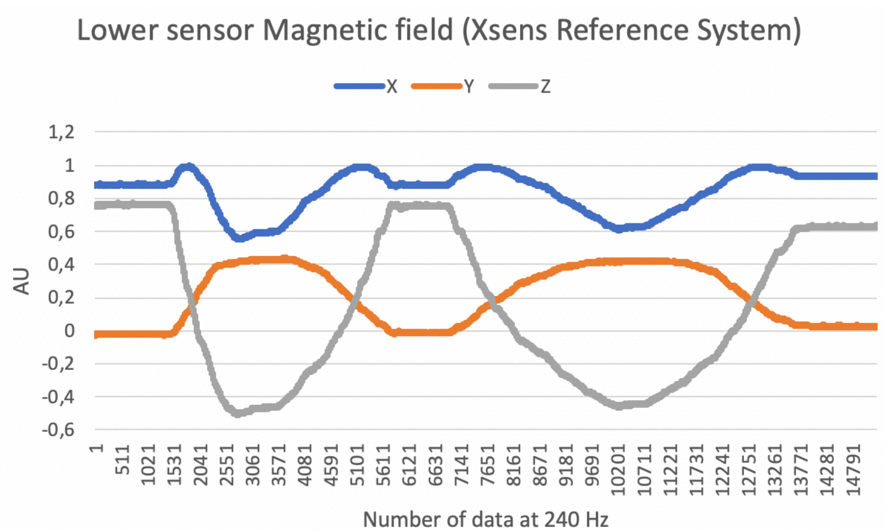
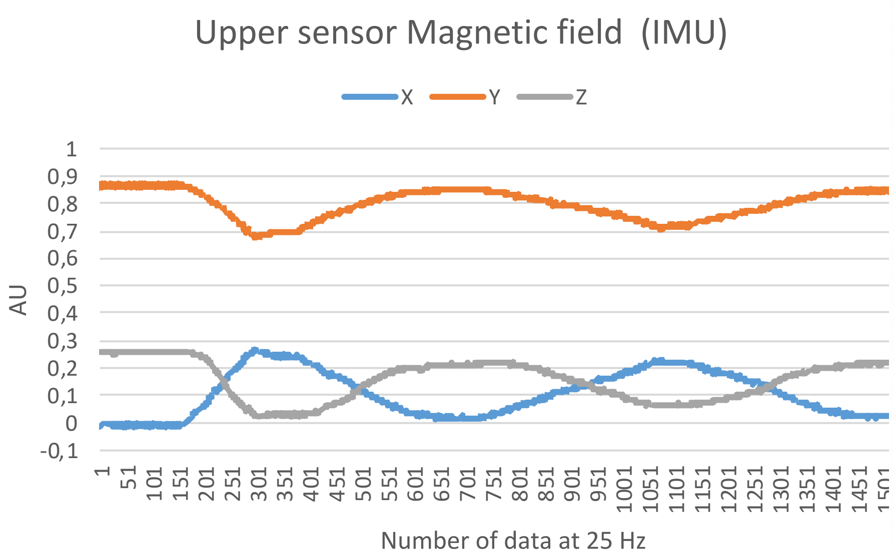


Figure 17: Magnetic field measured by the a) IMU b) MVN lower sensor

- Change in magnetic field
- Same graphical representation

Magnetic field

- Mechanical motion produces magnetic field and measured the strength
- MTI-series1 is integrated with Magnetometer sensor can detect and measure



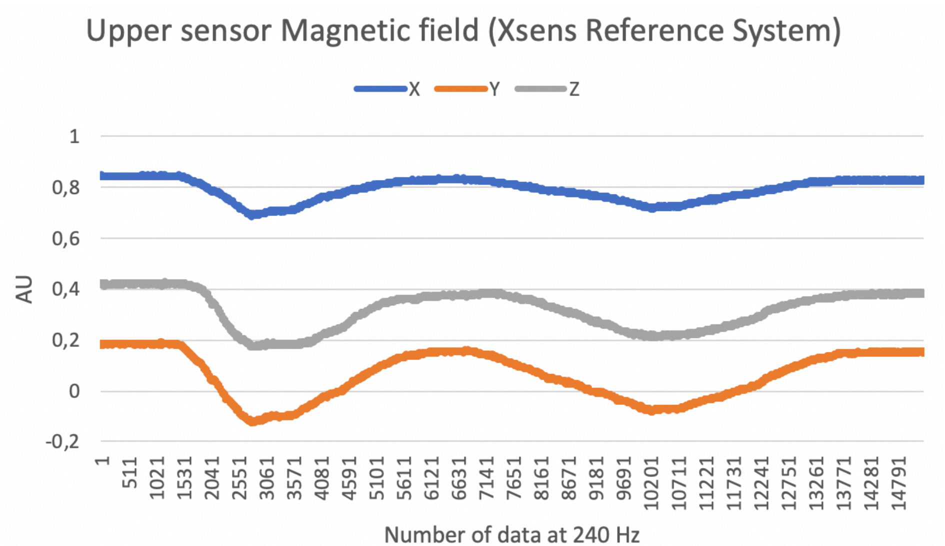


Figure 18: Magnetic field measured by the both sensors

- No movement of femoral part.
- So, magnetic field strength constant for both cases.

Quaternion

- Axis can can rotate in three dimensions around a given force.

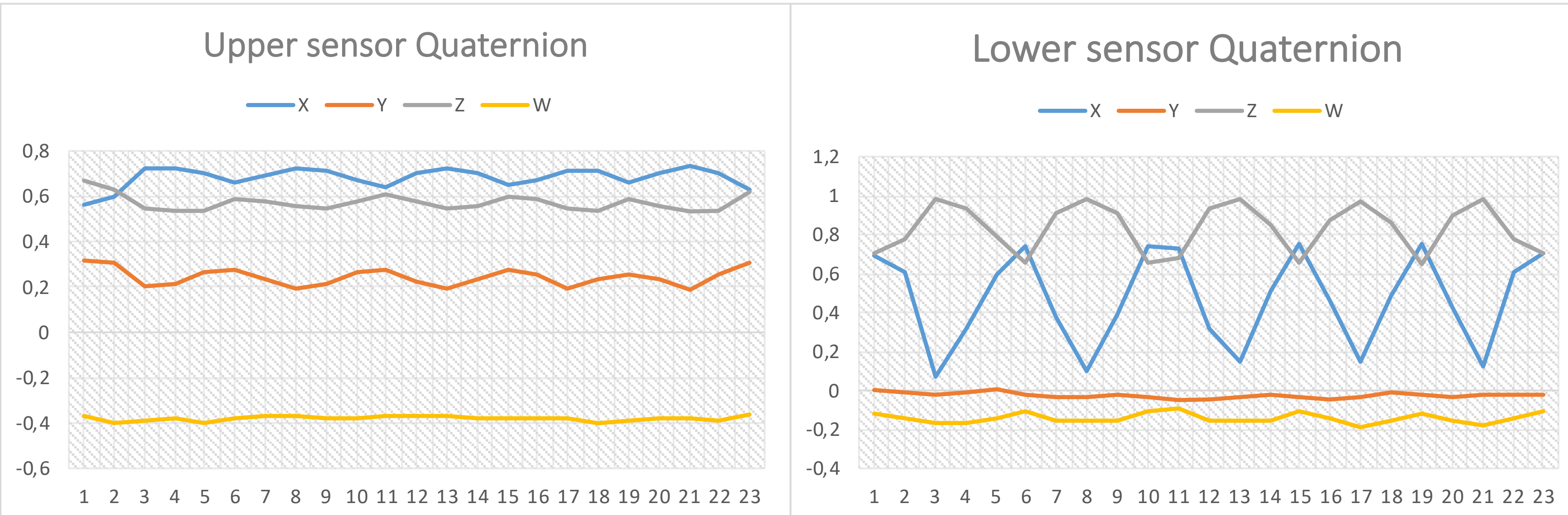


Figure 19: Quaternion data plotted for the both sensors

- There is no movement in 3-D space
- For directional flexion and extension, it shows only 2-Dimentional movement

Discussion and Conclusion

- Developed a wearable knee joint measurement system
- Two xsens sensors for the knee motion tracking and measurement
- Set output motion data at 25Hz, since the maximum output range of MIT-1 is 100Hz
- We measured the knee motion for flexion-extension of knee tibial movement

- For validation, standard output of MVN Analyze motion tracker took into consideration
- According to the movement, sensors shows almost same graphical representation
- Conclude: Changes of motion for the upper and lower sensors respectively, can be proposed a potential diagnostic tool.

Summary

- ✓ Wiring connection (I2C interfacing)
- ✓ System and hardwire design with two push buttons and two LED’s
- ✓ I2C communication between raspberry pi (master) and the sensors (slave)
- ✓ Setting up the system for knee joint motion
- ✓ Integration of the system in a wearable device
- ✓ Measurement of knee joint motion data
- ✓ Evaluation of the system (Validation)

Limitations and Future work

Limitations

- Hardware selection (Raspberry pi zero)
  - Slow
  - Limited data output
- SPI or UART instead of I2C
  - Must faster
  - Highest no. of data output

Future work

- Appropriate calibration method proposes
- Final evaluation of accuracy

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References

1. https://www.injurymap.com/diagnoses/osteoarthritis-of-the-knee
2. https://www.researchgate.net/publication/309619219_Optical_Sensors_And_Their_Use_In_Medical_Field
3. https://www.slideshare.net/StephanvanBreenenCli/occupational-therapy-goniometry-measurement-range-of-motion
4. https://www.xsens.com/products/mti-1-series
5. https://doctorlib.info/anatomy/classic-human-anatomy-motion/3.html
6. https://boneandspine.com/knee-range-of-motion/
7. https://www.youtube.com/watch?v=d-MkrjkwKT8&t=208s
8. Bachmann, E., Yun, X., & Brumfield, A. (2007). Limitations of Attitude Estimation Algorithms for Inertial/Magnetic Sensor Modules. IEEE Robot. Autom. Mag., 76–87.
9. https://myworskhopnotes.wordpress.com/tag/i2c-read/
10. https://www.xsens.com/products/mvn-analyze

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Thanks for your attention !

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