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# Estimating Orientation Using IMU Module for Autonomous Underwater Vehicle (AUV)

**Puteri Nurnabila Isma Ishak**[1], **Herdawatie Abdul Kadir**[1]*

[1]Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia, Parit Raja 86400, Johor, MALAYSIA

*Corresponding Author Designation

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**Abstract**: In this paper, a high-rate Inertial Unit Measurement (IMU) with accelerometers, magnetometers and gyroscopes, as well as Arduino UNO is used to gather data referring to the objectives. However, there could be some errors accumulated due to the external environmental factor. Orientation accuracy heavily affects positioning accuracy. The project is to design an efficient control system for the orientation and path-following of an AUV using the MPU-9250 sensor with the AHRS algorithm in MATLAB. This work will focus on the orientation module using IMU based on the AUV motion behavior. There are two classifications of measurements that are without the usage of the AHRS filter and with the usage of the Attitude and Heading Reference System (AHRS) filter to test the overall performance of the IMU module by observing the accuracy, precision, and stability. The result of the precision of yaw at -90° oriented without the AHRS filter in the IMU module is 0.90 and with the AHRS filter, IMU is 0.99. Other than that, the percentage of accuracy of yaw at -90° without the AHRS filter is 96.33% and with the AHRS filter is 99.99%. This means that the data obtained of yaw at -90° with the usage of the AHSR filter has a more accurate result. Pitch and roll data can be obtained in the results. Hence, the AHRS filter has improved the accuracy, precision and stability of the IMU module. Many possible improvements can be made to improve the accuracy, precision, and stability of the IMU MPU9250 module sensor. For instance, use other types of filters or test the orientation module at a place that has less magnetic disturbance to reduce the noise readings of the IMU.

**Keywords**: AHRS, IMU, MATLAB, AUV, Orientation, Yaw, Pitch, Roll

## 1. Introduction

AUV is a programmed robot that travels independently underwater. They are unmanned vehicles that are used in various fields such as maritime, geologic, and military industries. Nowadays, the importance of underwater data has surged for the ecosystem and mineral sources [1]. AUVs are useful to collect data from hazardous investigated environments without risking humans [2]. Also, the AUV

**Corresponding author: watie@uthm.edu.my*

is constructed with an Inertial Measurement Unit (IMU) sensor that is exclusively for the orientation of the underwater vehicle.

Usually, the IMU sensor consists of an accelerometer, gyroscope, and magnetometer that are used to measure acceleration, angular velocity, and magnetic field in the x-axis, y-axis, and z-axis. MPU-9250 IMU sensor is proposed for the use of this project. However, there could be some noise and accumulated error over time due to external environmental factors such as underwater currents. This has led to decreased tracking performance as the AUV tends to drift after a certain period. Orientation accuracy heavily affects positioning accuracy. Hence, the data value measured is inaccurate [3].

## 2. Materials and Methods

This methodology will include three stages of this project which are the design, development and testing of the real-time embedded system for the orientation and path-following of an AUV. It has been compressed by referring to the system architecture, block diagrams, and flowcharts of the orientation module.

### 2.1 Overall Project Design

Figure 1 shows the system architecture of the orientation module used for the AUV. The orientation module consists of Arduino UNO, MPU9250 sensor and the calibration process. The MPU9250 sensor communicates with the Arduino UNO using I2C Bus Protocol. Then, the angles of yaw, pitch and roll will be calibrated and transformed the sensor outputs something closer to the actual values using filtering techniques [4].

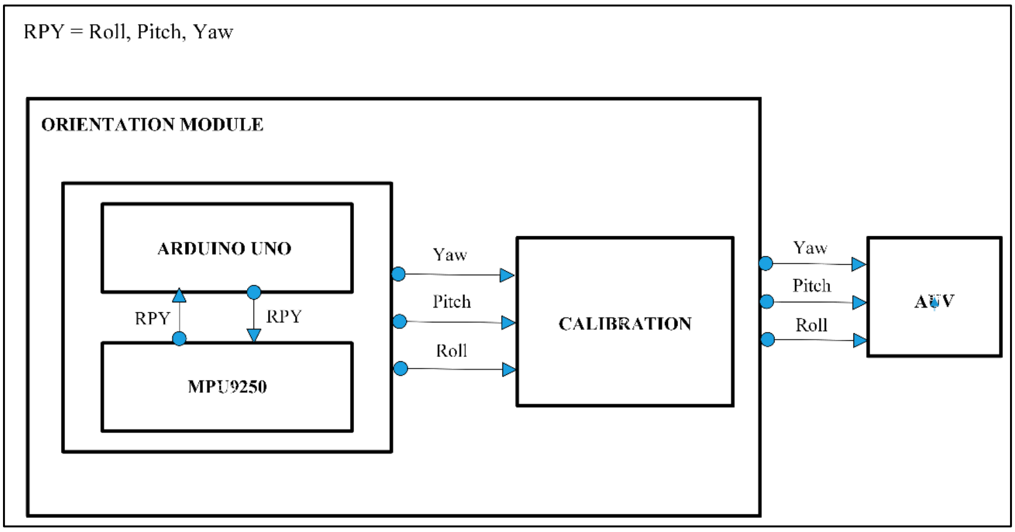


**Figure 1: System Architecture of Orientation Module**

Figure 2 shows the block diagram for the orientation module. The inputs are the values of the accelerometer, magnetometer and gyroscope data from the MPU9250 sensor [5]. Arduino UNO will process the signal which has been collected and measured from the IMU module [6]. Support package for Arduino hardware and Sensor Fusion and Tracking Toolbox needs to be installed in the Arduino UNO as libraries to process the data and convert them into the output signals. Next, the AHRS filter will be used to reduce the noise of the IMU. Lastly, the result will be displayed on the MATLAB window command as the displayed outputs. The data will be recorded and saved using Microsoft Excel.

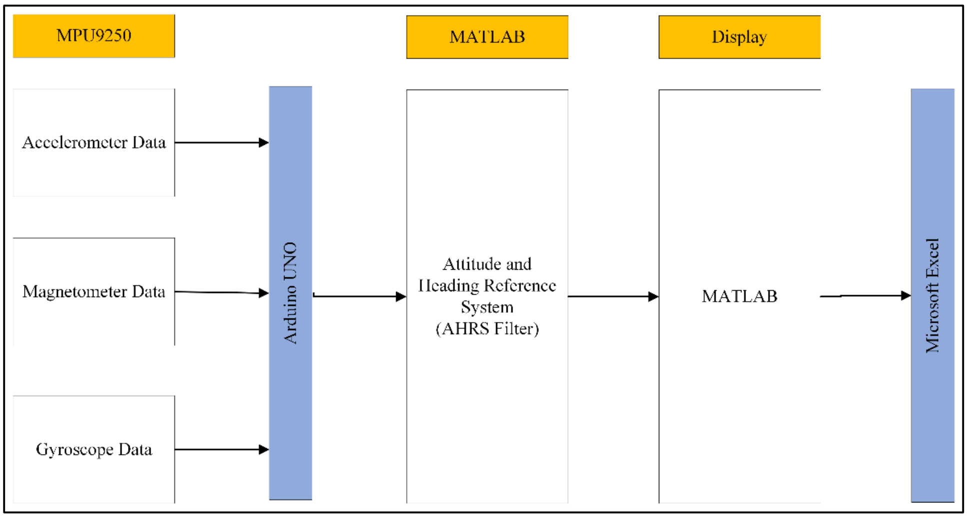


**Figure 2: Block diagram for the orientation module**

## 2.2 Attitude and Heading Reference System (AHRS) Filter

AHRS Filter fuses accelerometer, magnetometer, and gyroscope sensor data to estimate device orientation. It uses the data from an orthogonal sensor combination of three accelerometers, three magnetometers and three gyroscopes. This estimation technique uses raw measurements to derive an optimized estimate of the attitude, given the assumptions outlined for each sensor. The AHRS filter estimates the gyro bias, or drift error of the gyroscope, in addition to the attitude. The gyro bias can then be used to compensate for the raw gyroscope measurements and aid in preventing the drift of the gyroscope over time. By combining the data from each of these sensors into an AHRS filter, a drift-free and high-rate orientation solution for the system can be obtained [7].

## 2.3 Coordination of AUV

The connection of the MPU9250 IMU module with the Arduino UNO in the box located at the center of the AUV is shown in Figure 3. Other than that, it shows the orientation axis of the AUV.

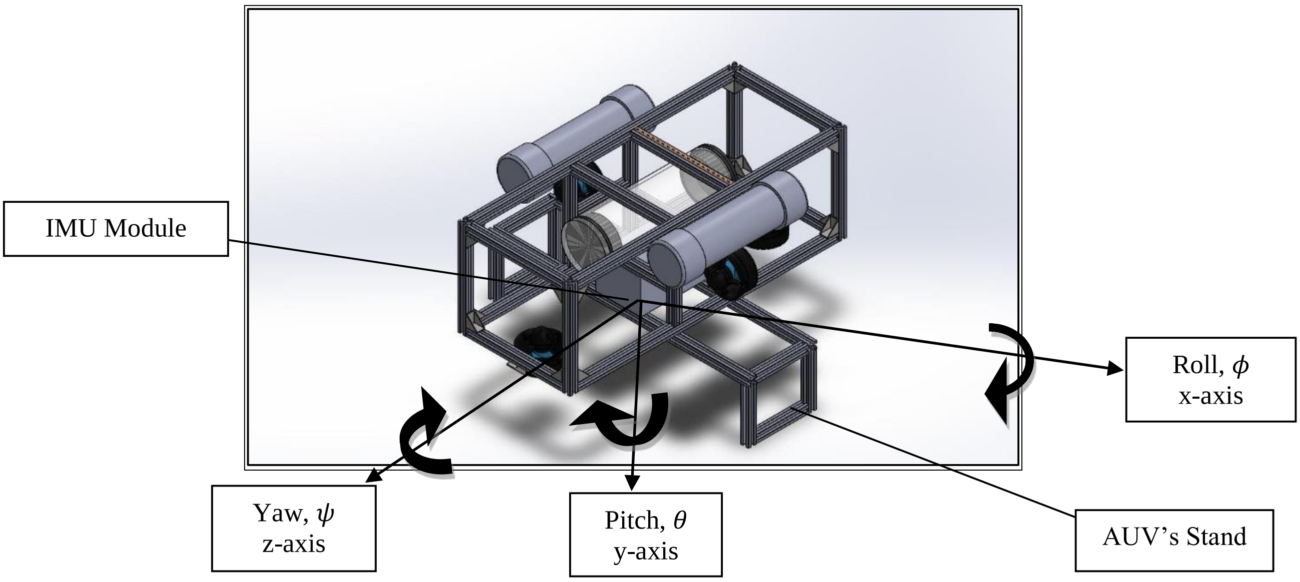


**Figure 3: IMU module integrated with AUV (Isometric View)**

The x-axis coordinate is the longitudinal transition of the AUV vehicle with forwarding direction while the y-axis coordinate is directly perpendicular to the x-axis over the longitudinal surface while can be labeled as the left and right movement of the AUV.

The z-axis coordinate characterizes the vertical transition of the AUV or can be indicated as the AUV's depth. The z-axis is zero pointing downwards from the surface of the water thus it is positive as the depth increases. The Euler angle is the extension of the already composed x, y and z spatial coordinates.

Euler angles revolve in a 360º degree of angle around the x, y and z-axis. Yaw is the 360º angle around the z-axis, the pitch is the 360º angle around the y-axis and roll is the 360º angle around the x-axis. To calculate the value for yaw, pitch and roll, the specific measurement must first be met which is the 3-axis accelerometer and 3-axis gyroscope and this measurement can be measured by using the MPU9250 component.

Roll is defined as 0º degree of angle whenever the AUV is placed parallel to the surface and is revolved around the x-axis and can reach a maximum of 360º degree of angle. Pitch angle is also stated as 0º degree of angle when the AUV is parallel to the surface however it revolves 360º degrees of angle around the y-axis. The roll and pitch angle are used to indicate the position of the AUV in more detail to achieve the optimum state of stability.

Furthermore, accuracy is the degree of exactness or closeness of a measurement compared to the desired value [8]. Next, precision is a measure of the consistency or repeatability of the instrument output for a given value of the input. A graphical method is used to test the stability of the object based on the value set of data obtained by each angle. The type of graphical method used is line graphs [9]. Next, the formula of accuracy and precision can be calculated by the following formula of Equation 1 and Equation 2 [10].

$$Accuracy = 1 - \left|\frac{Yn - Zn}{Yn}\right| \qquad Eq. 1$$

where,

$Yn$ = Expected value

$Zn$ = Measured value

$\%Accuracy = 100\% \, x \, Accuracy$

$$Precision = 1 - \left|\frac{Xn - \overline{Xn}}{Xn}\right| \qquad Eq. 2$$

where,

$Xn$ = Value of the $n^{th}$ measurement

$\overline{Xn}$ = Average of the set of n measurements

## 3. Results and Discussion

The results obtained from the IMU module with Arduino IDE and MATLAB are divided into 2 conditions based on the without AHRS filter and with the AHRS filter of MPU-9250 IMU with different sides. The result is obtained from the command window of MATLAB.

### 3.1 Accuracy and Precision Test

Table 1 and Table 2 had been tabulated from the result of the MPU9250 test to consider the difference between the measurement of the IMU with and without the usage of the AHRS filter. The highest percentage of accuracy without the usage of the AHRS filter is 98.32% with the lowest of 83.10% while the highest value of the percentage of accuracy for the IMU reading with the usage of the AHRS filter is 99.99% with the lowest of 94.87%.

Other than that, the highest precision value without the usage of the AHRS filter is 1.00 with the lowest of 0.58 while the highest value of the precision for the IMU reading with the usage of the AHRS filter is 1.00 with the lowest of 0.34. This indicates that the measurement of the yaw angle at 180° has consistent measurement. Thus, the AHRS filter has increased its accuracy, and precision.

**Table 1: Analysis of MATLAB test without AHRS Filter for yaw angle**

| Desired yaw value | Average measured value (º) | Standard deviation | Variance | Precision | Percentage of accuracy (%) |
|---|---|---|---|---|---|
| Yaw (0º) | 5.07 | 3.77 | 14.20 | 0.58 | 83.10 |
| Yaw (90º) | 85.04 | 2.17 | 4.72 | 0.97 | 94.49 |
| Yaw (180º) | 176.97 | 0.74 | 0.55 | 1.00 | 98.32 |
| Yaw (-90º) | -93.30 | 3.97 | 15.73 | 0.90 | 96.33 |

**Table 2: Analysis of MATLAB test with AHRS Filter for yaw angle**

| Desired yaw value | Average measured value (º) | Standard deviation | Variance | Precision | Percentage of accuracy (%) |
|---|---|---|---|---|---|
| Yaw (0º) | 1.54 | 2.70 | 7.31 | 0.34 | 94.87 |
| Yaw (90º) | 89.65 | 2.07 | 4.28 | 1.00 | 99.62 |
| Yaw (180º) | 178.84 | 0.68 | 0.46 | 1.00 | 99.35 |
| Yaw (-90º) | -89.99 | 1.95 | 3.78 | 0.99 | 99.99 |

Table 3 and Table 4 had been tabulated from the result of the MPU9250 test to consider the difference between the measurement of the IMU with and without the usage of the AHRS filter. The highest percentage of accuracy without the usage of the AHRS filter is 95.29% with the lowest of 58.90% while the highest value of the percentage of accuracy for the IMU reading with the usage of the AHRS filter is 99.73% with the lowest of 98.27%.

Other than that, the highest precision value without the usage of the AHRS filter is 1.00 with the lowest of 0.97 while the highest value of the precision for the IMU reading with the usage of the AHRS filter is 1.00 with the lowest of 0.99. This indicates that the measurement of pitch angle at 0° has a consistent measurement. Thus, the AHRS filter has increased its accuracy, and precision.

**Table 3: Analysis of MATLAB test without AHRS Filter for pitch angle**

| Desired pitch value | Average measured value (º) | Standard deviation | Variance | Precision | Percentage of accuracy (%) |
|---|---|---|---|---|---|
| Pitch (0º) | 12.33 | 0.02 | 0.00 | 1.00 | 58.90 |
| Pitch (90º) | 83.30 | 1.95 | 3.79 | 0.97 | 92.56 |
| Pitch (-90º) | -85.76 | 1.98 | 3.91 | 1.00 | 95.29 |

**Table 4: Analysis of MATLAB test with AHRS Filter for pitch angle**

| Desired pitch value | Average measured value (º) | Standard deviation | Variance | Precision | Percentage of accuracy (%) |
|---|---|---|---|---|---|
| Pitch (0º) | 0.08 | 0.00 | 0.00 | 1.00 | 99.73 |
| Pitch (90º) | 88.44 | 0.37 | 0.14 | 1.00 | 98.27 |
| Pitch (-90º) | -89.04 | 0.90 | 0.81 | 0.99 | 98.93 |

Table 5 and Table 6 had been tabulated from the result of the MPU9250 test to consider the difference between the measurement of the IMU with and without the usage of the AHRS filter. The highest percentage of accuracy without the usage of the AHRS filter is 93.99% with the lowest of 68.70% while the highest value of the percentage of accuracy for the IMU reading with the usage of the AHRS filter is 99.82% with the lowest of 98.93%.

Other than that, the highest precision value without the usage of the AHRS filter is 1.00 with the lowest of 0.88 while the highest value of the precision for the IMU reading with the usage of the AHRS filter is 1.00 with the lowest of 0.99. This indicates that the measurement of roll angle at 90° and 180° has consistent measurement. Thus, the AHRS filter has increased its accuracy, and precision.

**Table 5: Analysis of MATLAB test without AHRS Filter for roll angle**

| Desired roll value | Average measured value (º) | Standard deviation | Variance | Precision | Percentage of accuracy (%) |
|---|---|---|---|---|---|
| Roll (0º) | -9.39 | 0.01 | 0.00 | 1.00 | 68.70 |
| Roll (90º) | 81.33 | 0.38 | 0.14 | 1.00 | 90.37 |
| Roll (180º) | 142.67 | 0.65 | 0.43 | 1.00 | 79.26 |
| Roll (-90º) | -95.41 | 8.50 | 72.32 | 0.88 | 93.99 |

**Table 6: Analysis of MATLAB test with AHRS Filter for roll angle**

| Desired roll value | Average measured value (º) | Standard deviation | Variance | Precision | Percentage of accuracy (%) |
|---|---|---|---|---|---|
| Roll (0º) | 0.22 | 0.00 | 0.00 | 1.00 | 99.27 |
| Roll (90º) | 90.16 | 0.21 | 0.04 | 1.00 | 99.82 |
| Roll (180º) | 178.60 | 0.17 | 0.03 | 1.00 | 99.22 |
| Roll (-90º) | -89.03 | 1.21 | 1.47 | 0.99 | 98.93 |

### 3.2 Stability Test

The stability result is analyzed using a graphical method. Figure 4 shows the graph of MPU9250 at 0° orientation calculated from the MPU9250 reading without the usage of the AHRS filter versus 30 amounts of data during the IMU test by using MATLAB.

From the graph, the graph of pitch and roll has stable and steady lines. The uneven lines of yaw orientation are because of disturbance of the surrounding. Without the calibration, the degree of orientation of yaw, pitch and roll are far from the desired angle of orientation but with the calibration as in Figure 5, the degree of orientation pitch and roll were near 0°. This shows that the AHRS filter has successfully predicted the next state for the MPU9250 thus increasing its stability.

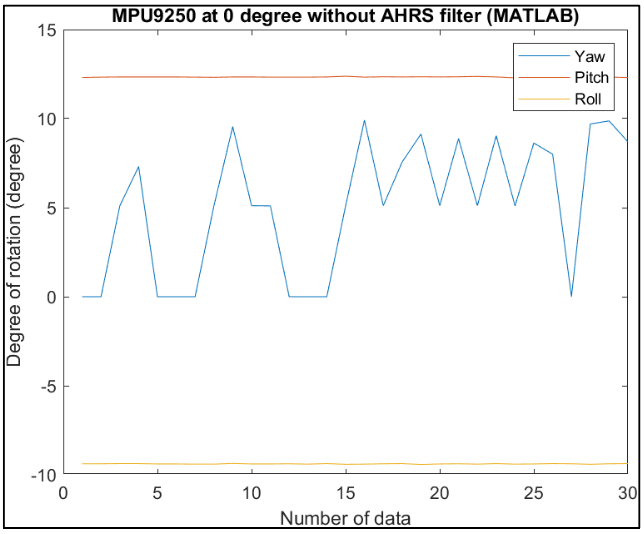


**Figure 4: Graph of the orientation of IMU module at 0° without AHRS filter**

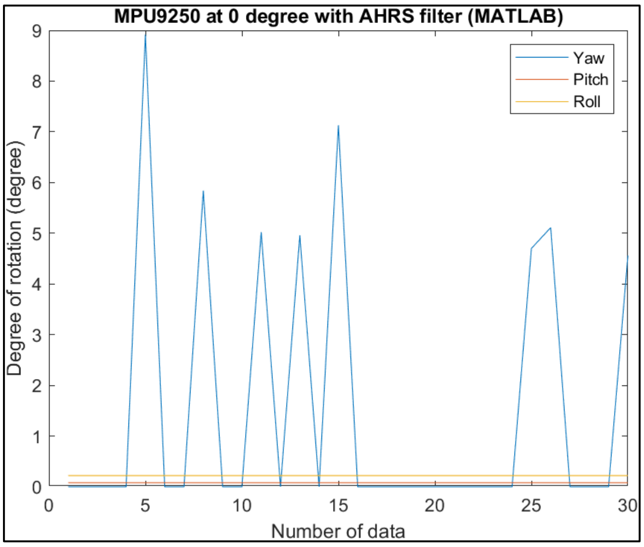


**Figure 5: Graph of the orientation of IMU module at 0° with AHRS filter**

The stability is analyzed using a graphical method. Figure 6 and Figure 7 show the graph of MPU9250 at 90° orientation calculated from the MPU9250 reading without and with the usage of the AHRS filter versus 30 amounts of data during the IMU test by using MATLAB.

From the graph in Figure 6, without the usage of the AHRS filter, the graph of the roll has fewer uneven lines. Pitch and roll angle were fluctuating and unstable. This is because of the disturbance from the surroundings. With the usage of the AHRS filter in Figure 7, the degree of orientation of pitch and roll is more stable and closer to the desired angle of orientation. Yaw has a fluctuating line, but the degree of orientation is near to the desired angle. This shows that the AHRS filter has successfully predicted the next state for the MPU9250 but with less stability.

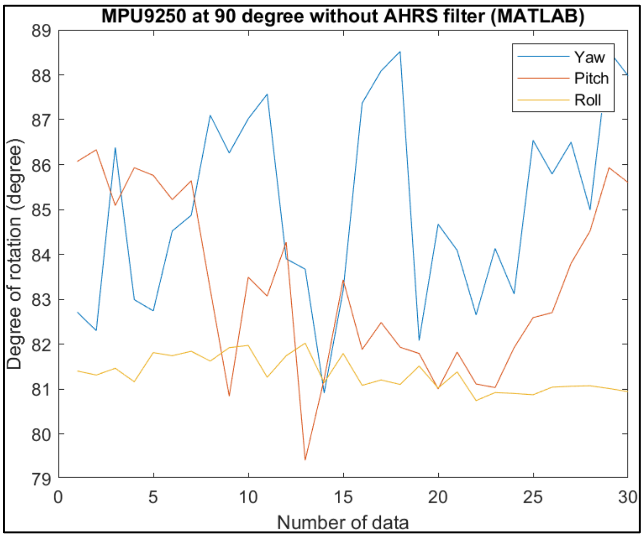


**Figure 6: Graph of the orientation of IMU module at 90° without AHRS filter**

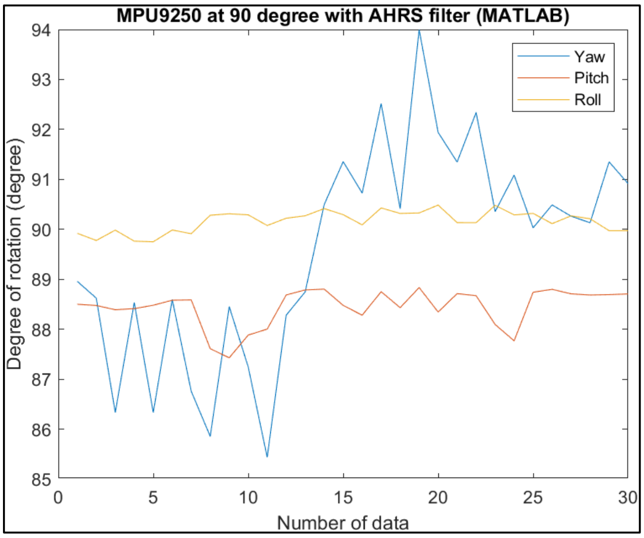


**Figure 7: Graph of the orientation of IMU module at 90° with AHRS filter**

The stability is analyzed using a graphical method. Figure 8 and Figure 9 show the graph of MPU9250 at 180° orientation calculated from the MPU9250 reading without and with the usage of the AHRS filter versus 30 amounts of data during the IMU test by using MATLAB.

From the graph in Figure 8, without the usage of the AHRS filter, the graph of the roll obtained is distant from the desired angle but with the usage of the AHRS filter in Figure 9, the degree of orientation of the roll is close to the desired angle of orientation. Next, without the usage of the AHRS filter, yaw has a more stable line compared with the usage of the AHRS filter. But yaw with the AHRS filter approached near the desired angle compared to without the AHRS filter. The uneven lines of yaw and roll orientation are because of disturbance of the surrounding. This shows that the AHRS filter has successfully predicted the next state for the MPU9250 but with less stability.

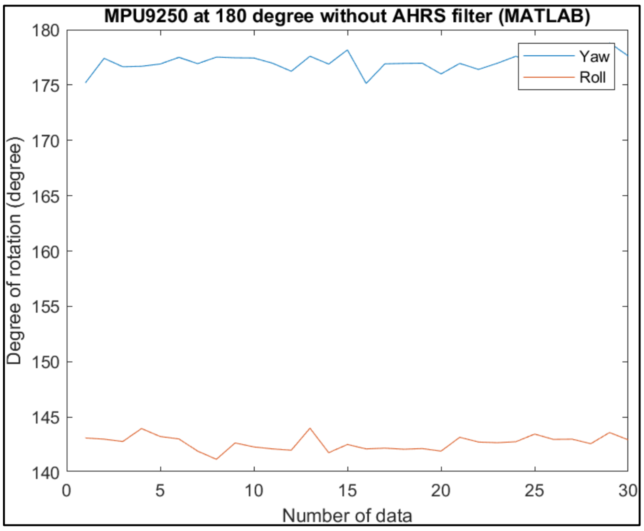


**Figure 8: Graph of the orientation of IMU module at 180° without AHRS filter**

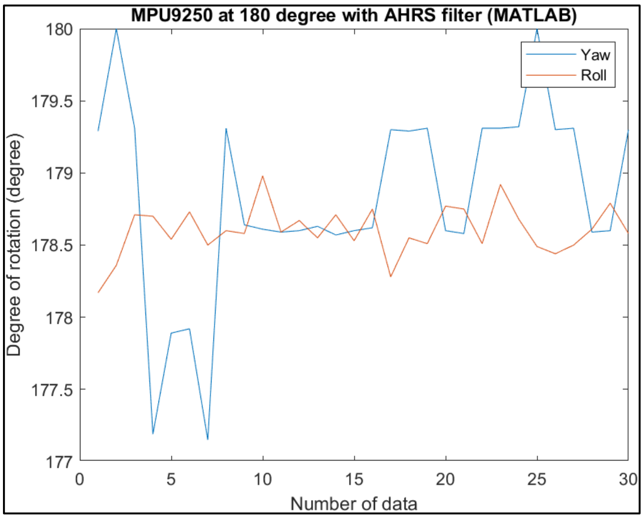


**Figure 9: Graph of the orientation of IMU module at 180° with AHRS filter**

The stability is analyzed using a graphical method. Figure 10 and Figure 11 show the graph of MPU9250 at -90° orientation calculated from the MPU9250 reading without and with the usage of the AHRS filter versus 30 amounts of data during the IMU test by using MATLAB.

From the graph in Figure 10, without the usage of the AHRS filter, the graph of roll obtained is distant from the desired angle but with the usage of AHRS filter in Figure 11, the degree of orientation of yaw, pitch and roll are nearly close to the desired angle of orientation. The uneven lines of yaw, pitch and roll orientation are because of disturbance of the surrounding. Hence, the data were unstable. This shows that the AHRS filter has successfully predicted the next state for the MPU9250 but with less stability.

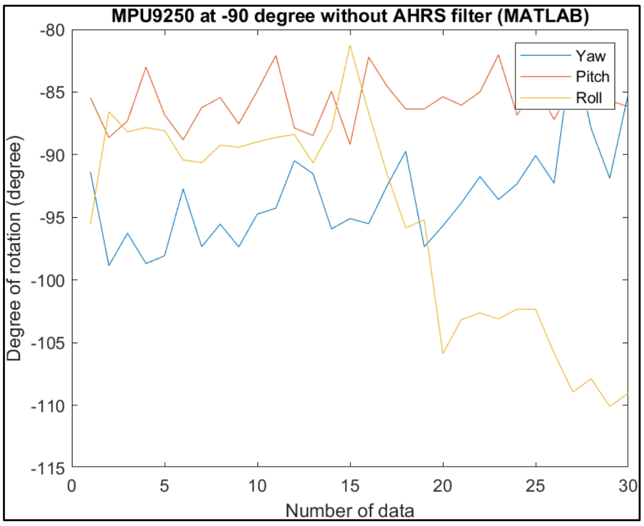


**Figure 10: Graph of the orientation of IMU module at -90° without AHRS filter**

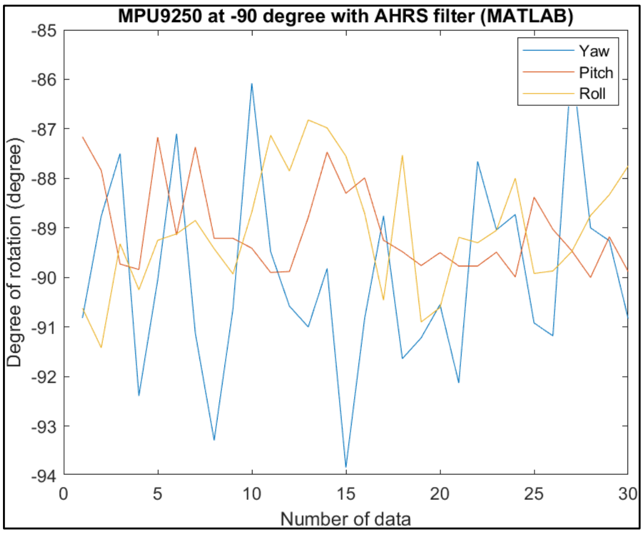


**Figure 11: Graph of the orientation of IMU module at -90° with AHRS filter**

## 4. Conclusion

In this project, the IMU sensor tested the estimation orientation by using MATLAB software to collect the angle data. It can be concluded that the system of the IMU achieved the objectives of the project. The IMU module was developed with an Arduino UNO microcontroller and MATLAB. Furthermore, the system examined the presence of the AHSR filter and without the AHRS filter by using the formula of accuracy, precision and graphical method that would ensure there is less inaccuracy between ground truth and estimated position. Hence, the graph pattern of the position is different among the phenomenon with the presence of the AHSR filter and without the AHRS filter.

The result of the experiment with the AHRS filter module showed that the orientation estimation at different Euler's angles mostly has higher accuracy and precision. The stability of the estimation orientation at different Euler's angles has fewer stable data of the IMU module due to the noise disturbance of the surroundings.

When the IMU module direction changes due to any external environmental factor such as underwater currents, it will be noisy and accumulate errors over time. So, it will decrease the tracking performance as the AUV tends to drift after a certain period. Hence, filtering and calibrating the module will improve the accuracy, precision, and stability to maintain the AUV in its direction.

From the overall point of view, it can be concluded that the estimation orientation module for AUV modeling achieved the objectives of the system. The objectives of this project were to design an orientation module using an IMU sensor, to build an orientation module for AUV by using MATLAB, and to test the overall performance of the IMU module by observing the accuracy, precision, and stability of the measurements.

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