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Angle Measuring

[Project]

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Introduction

Measuring angles is a fundamental task in many fields, including engineering, robotics, astronomy, and more. Accurate angle measurements can be used to determine the position, orientation, and motion of objects and systems.

There are various methods for measuring angles, including using a protractor, spirit level, or specialized measuring tools such as digital angle finders. However, in modern applications, electronic sensors such as accelerometers, gyroscopes, and magnetometers are often used to provide more accurate and reliable measurements.

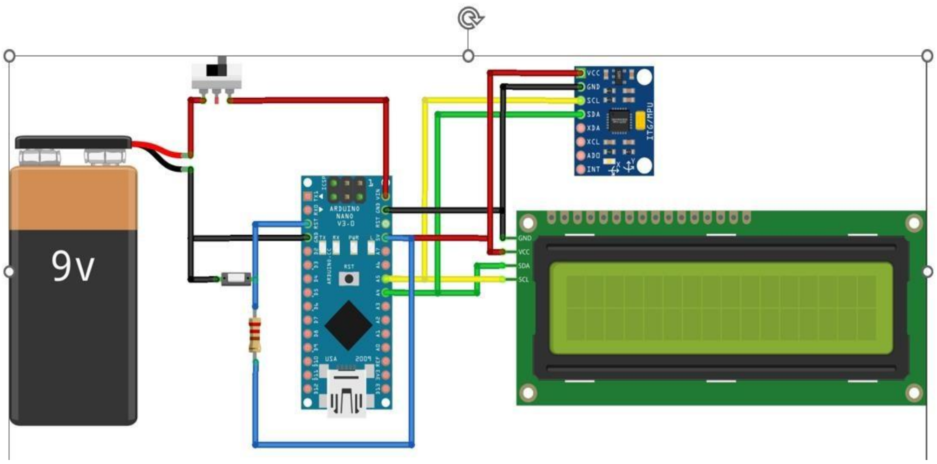
In a typical angle measurement project, the sensor data is collected and processed using algorithms such as complementary filters or Kalman filters. These algorithms take into account the strengths and weaknesses of each sensor and use them to provide a more accurate and stable measurement of the angle.

Angle measurement projects can be applied in a wide range of fields, such as robotics, where accurate measurement of joint angles is crucial for controlling the movement of robotic arms and legs. In astronomy, angle measurement is used to determine the position of celestial objects and to track their movement. In engineering, angle measurement can be used to ensure the precise alignment of components and machinery.

Overall, measuring angles is an important task in many fields, and with the increasing availability of electronic sensors and algorithms, it has become easier to obtain accurate and reliable angle measurements for a variety of applications.

We want to start with this diagram

Wiring Digram



This picture illustrates how the components, which consist of

A. MPU-6050 6DOF 3-Axis Gyro With Accelerometer Sensor
B. Arduino Nano
C. I2C Serial interface Adapter Module
D. LCD
E. Battery
F. Switch and resistance

are connected to each other.

1-MPU-6050 6DOF 3-Axis Gyro With Accelerometer Sensor :

- The MPU-6050 is a popular sensor for a variety of applications, including robotics, gaming, and virtual reality. It is relatively inexpensive and easy to use.
- It is a sensor used to detect the motion of an object (its speed and direction)
- It is capable of calculating the acceleration of an object in three axes (X ,Y ,Z), as well as the rotation of the object around these axes (X,Y,Z).
- Roll Angle (Rotation around X-axis): The roll angle is the angle of rotation of an object around its X-axis, which is an imaginary line running from the front to the back of the object. In aviation and aerospace, the roll angle is an important parameter used to describe the orientation and motion of aircraft and spacecraft.
- Pitch Angle (Rotation around Y-axis) : The pitch angle is the angle of rotation of an object around its Y-axis, which is an imaginary line running from side to side through the object. In aviation and aerospace, the pitch angle is an important parameter used to describe the orientation and motion of aircraft and spacecraft.
- Yaw Angle (Rotational around Z-axis) : The yaw angle is the angle of rotation of an object around its vertical axis, which is an imaginary line running from the top to the bottom of the object. In aviation and aerospace, the yaw angle is an important parameter used to describe the orientation and motion of aircraft and spacecraft. It is often measured using sensors such as magnetometers and gyroscopes. The yaw angle is also relevant in many other fields, such as robotics, where it is used to control the orientation and movement of robotic vehicles and other equipment.
- MPU 6050 have an analog to digital converter Because of SOC (System on chip) do not have analog to digital converter such as Raspberry pi

This sensor belongs to a family of MEMS Sensor

MEMS sensors (Micro-Electro-Mechanical Systems sensors) are a type of miniature sensors that use microfabrication technology to produce tiny mechanical and electromechanical components on a silicon wafer. These sensors are widely used in various applications such as mobile devices, automotive, robotics, aerospace, and healthcare.

MEMS sensors can measure different physical quantities such as acceleration, rotation, pressure, magnetic fields, and temperature. They are small in size, low-power, and have high sensitivity and accuracy, which make them suitable for many applications where size, power consumption, and precision are critical.

Some examples of MEMS sensors include accelerometers, gyroscopes, magnetometers, pressure sensors, and microphones. These sensors have revolutionized the field of sensing and have enabled the development of many new technologies and products.

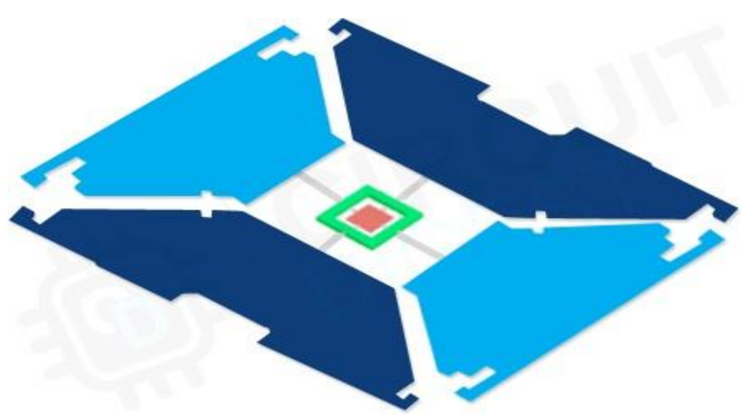
We can calculate the angle by MPU 6050 With Two Method

1- Gyroscope rotation and integration
2- Accelerometer trigonometry

1-How Does MEMS Gyroscope Work?

The MEMS Gyroscope working is based on the Coriolis Effect. The Coriolis Effect states that when a mass moves in a particular direction with velocity and an external angular motion is applied to it, a force is generated and that causes a perpendicular displacement of the mass. The force that is generated is called the Coriolis Force and this phenomenon is known as the Coriolis Effect. The rate of displacement will be directly related to the angular motion applied.

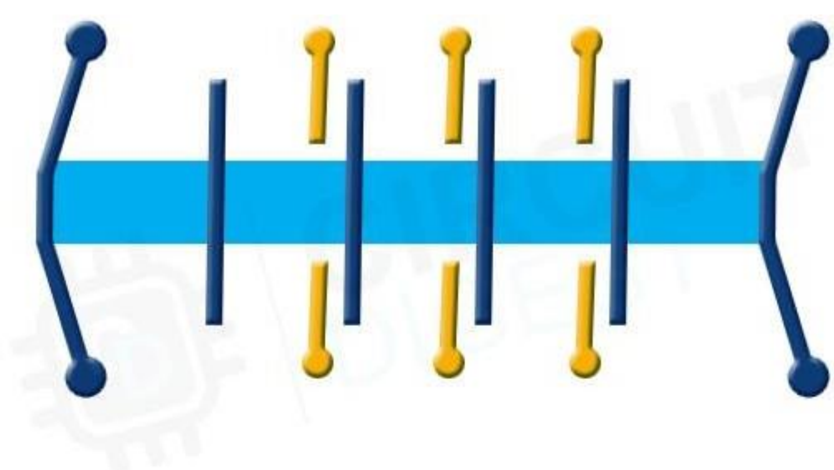
The MEMS Gyroscope contains a set of four proof mass and is kept in a continuous oscillating movement. When an angular motion is applied, the Coriolis Effect causes a change in capacitance between the masses depending on the axis of the angular movement. This change in capacitance is sensed and then converted into a reading. Here is a small animation showing the movement of these proof masses on the application of an angular movement for different axis.



2-How Does MEMS Accelerometer Work?

MEMS accelerometers are used wherever there is a need to measure linear motion, either movement, shock, or vibration but without a fixed reference. They measure the linear acceleration of whatever they are attached to. All accelerometers work on the principle of a mass on a spring, when the thing they are attached to accelerates, then the mass wants to remain stationary due to its inertia and therefore the spring is stretched or compressed, creating a force which is detected and corresponds to the applied acceleration.

In MEMS accelerometer, precise linear acceleration detection in two orthogonal axes is achieved by a pair of silicon MEMS detectors formed by spring 'proof' masses. Each mass provides the moving plate of a variable capacitance formed by an array of interlaced finger loke structures. When the sensor is subjected to a linear acceleration along its sensitive axis, the proof mass tends to resist motion due to its inertia, therefore the mass and its fingers become displaced concerning the fixed electrode fingers. The gas between the fingers provides a damping effect. This displacement induces a differential capacitance between the moving and fixed silicon fingers which is proportional to the applied acceleration. This change in capacitance is measured with a high-resolution ADC and then the acceleration is calculated from the rate of change in capacitance. In MPU6050 this is then converted into readable value and then it's transferred to the I2C master device.



Sensor Applications

The MPU-6050 is a popular 6 Degree of Freedom (6DOF) sensor module that combines a 3-axis gyroscope and a 3-axis accelerometer in a single package. It is commonly used in various applications that require motion sensing, such as robotics, drones, gaming, and navigation systems. Here are some examples of applications that use the MPU-6050 sensor module:

1. Inertial measurement units (IMUs) - The MPU-6050 is often used as a core component of IMUs, which are used in robotics, drones, and other applications to measure the orientation and motion of devices. The accelerometer measures linear acceleration, while the gyroscope measures rotational velocity.

2. Virtual reality (VR) and augmented reality (AR) - The MPU-6050 can be used to track the motion of a user's head or body, allowing for more immersive VR and AR experiences.

3. Gaming controllers - The MPU-6050 can be used to detect motion and tilt in gaming controllers, allowing for more intuitive and immersive gameplay.

4. Smartphones and tablets - The MPU-6050 is commonly used in smartphones and tablets to detect orientation and motion, enabling features such as screen rotation, gesture recognition, and gaming.

5. Navigation systems - The MPU-6050 can be used in navigation systems to measure motion and orientation, providing data to help determine location and direction.

6. Fitness trackers - The MPU-6050 can be used in fitness trackers to monitor movement and activity, allowing for features such as step counting and calorie tracking.

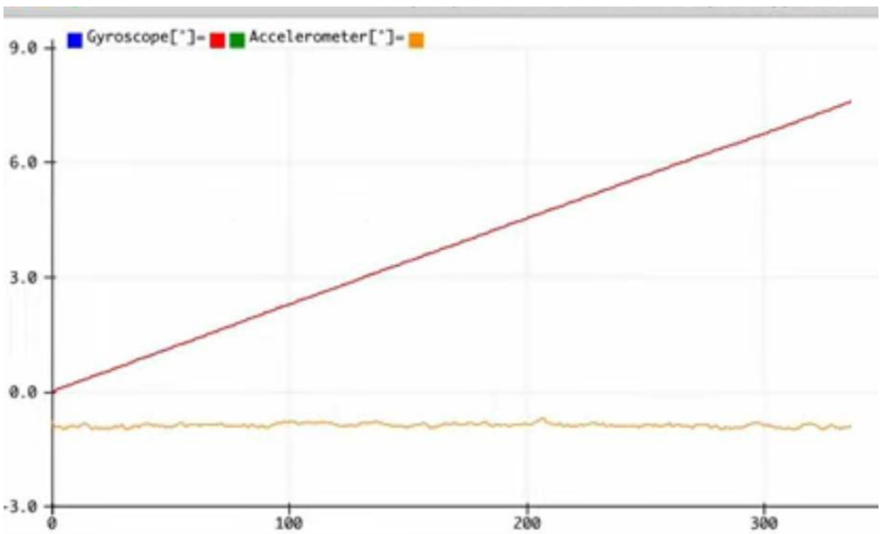
7. Robotics - The MPU-6050 can be used in robotics to measure the orientation and motion of robot arms, legs, and other components, allowing for more precise and accurate movements.

These are just a few examples of the many applications that can be built using the MPU-6050 sensor module. Its small size, low power consumption, and high accuracy make it a versatile and practical choice for a wide range of projects.

- Calibration Sensor

we also found out that both methods have disadvantages

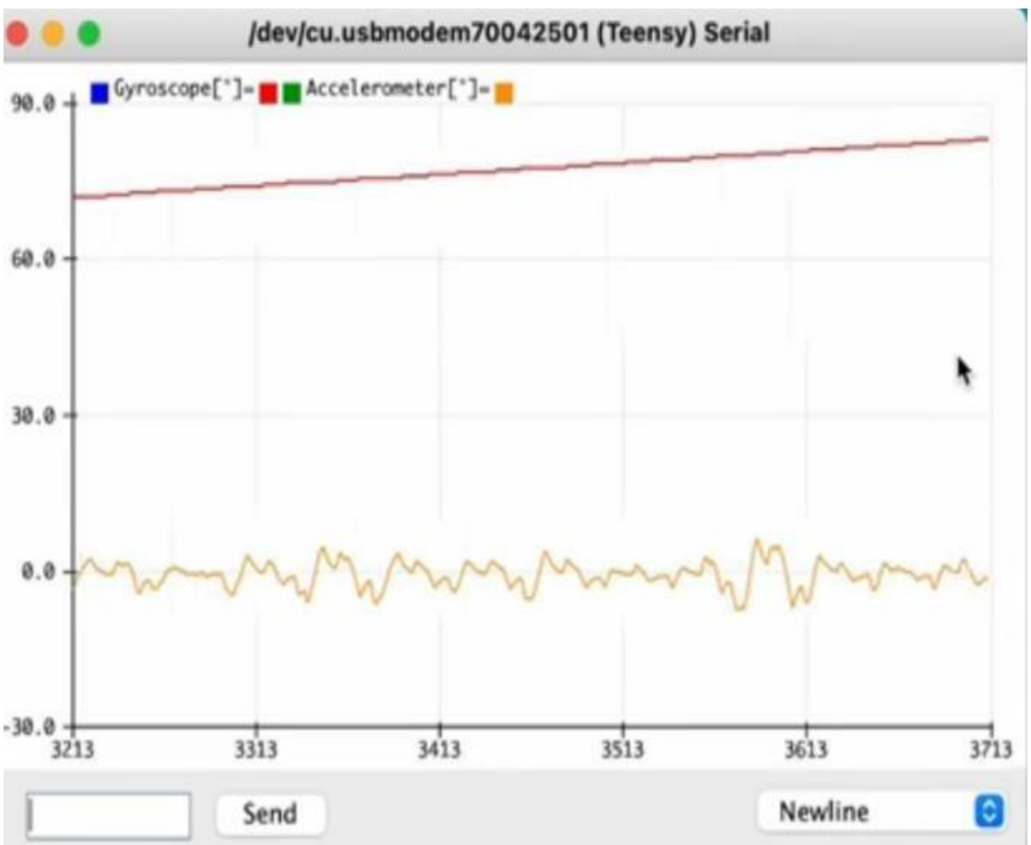
(Note that red graph is Gyroscope and orange graph is Accelerometer)



This graph illustrates the two processes at the beginning of the measurement operation.

with accelerometer trigonometry

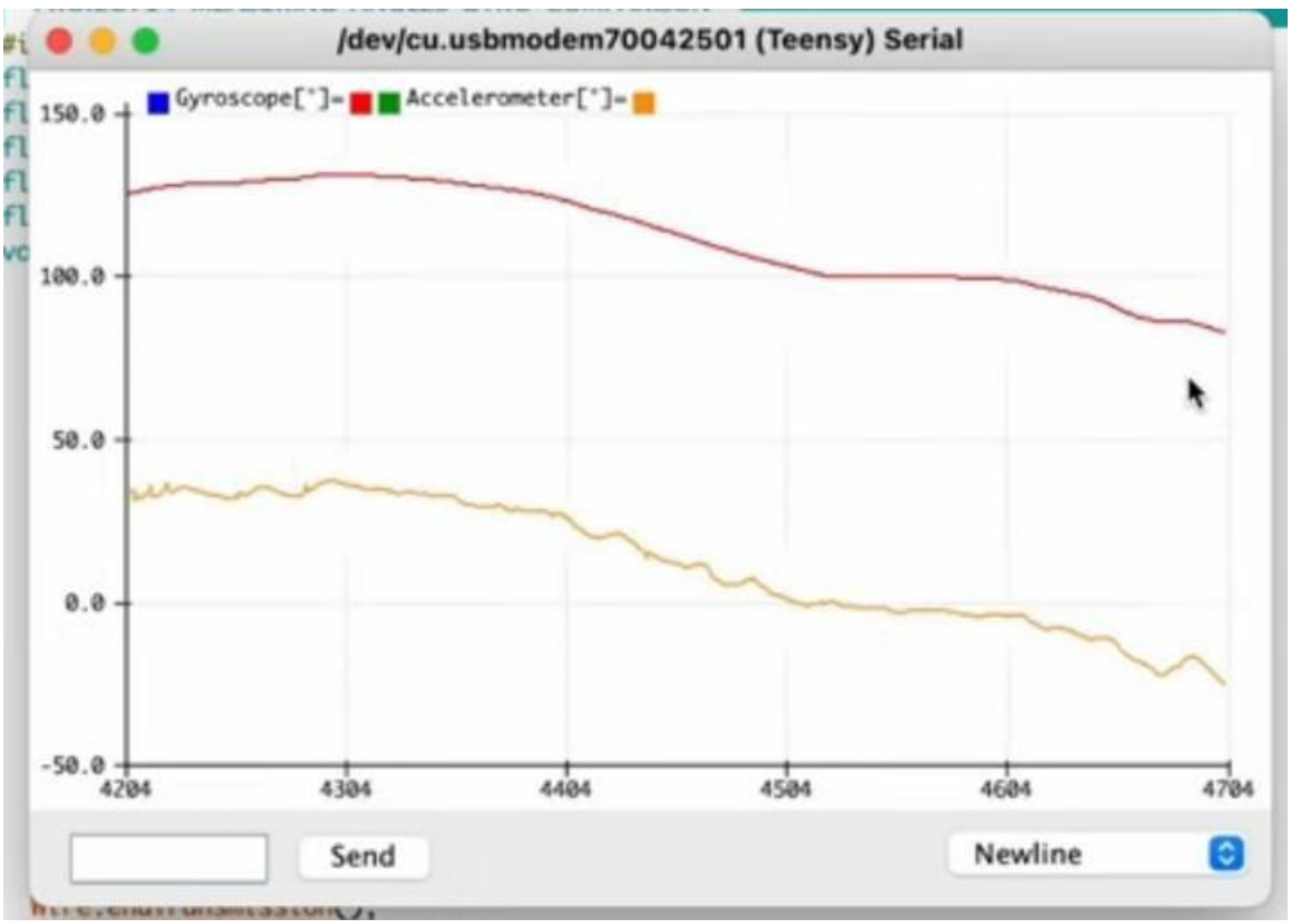
The vibrations have a huge impact on the angle as you can see on the orange graph



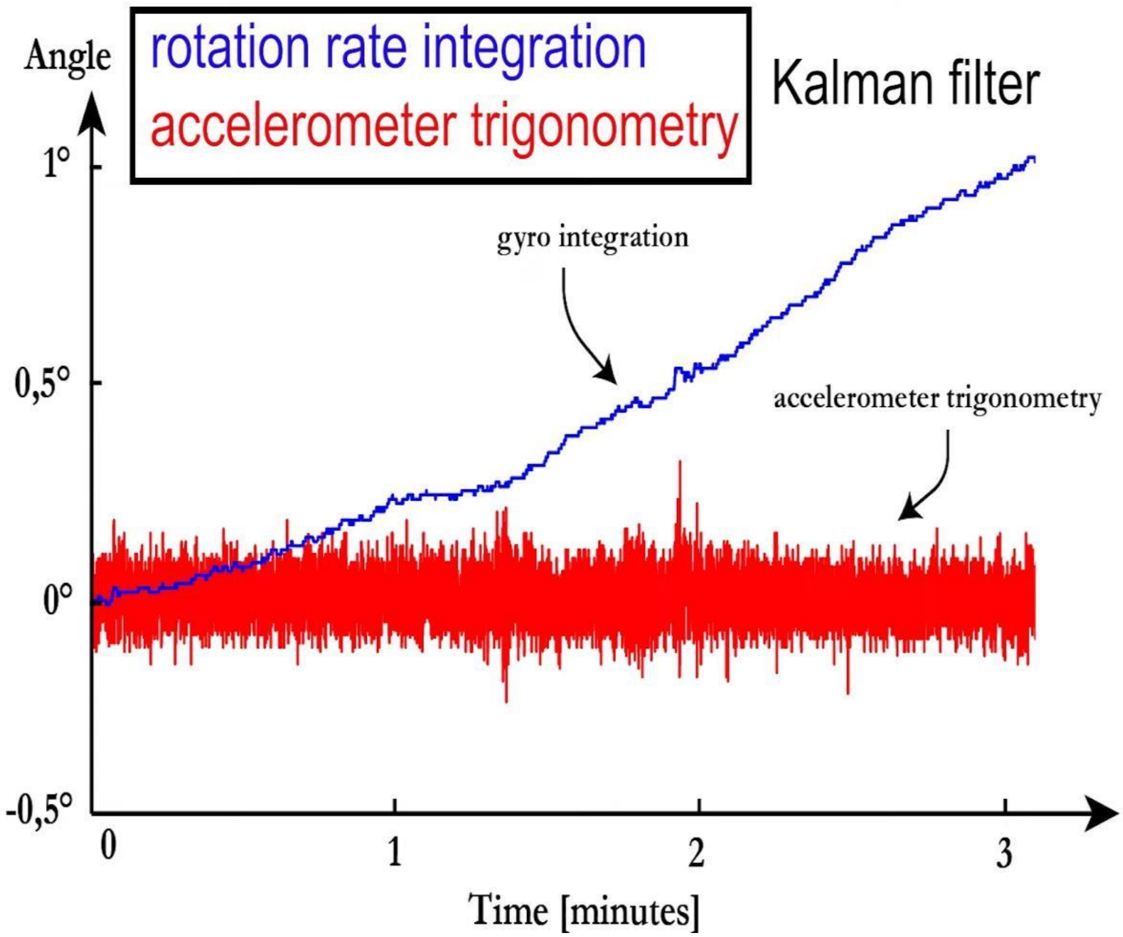
with Gyroscope rotation and integration

we have an ever increasing error on the angle because you keep dragging all past

errors with you this is clearly visible on the red graph



fortunately there exists a mathematical method that allows you to combine both measurements without their visual disadvantages the Kalman filter



- Kalman Filter

- The Kalman filter is a mathematical algorithm used to estimate the state of a system from a series of noisy measurements. It is widely used in control systems, signal processing, and navigation applications, where it is used to estimate the position, velocity, and other parameters of a system based on sensor measurements.

- The Kalman filter works by combining the predictions of a mathematical model of the system with the measurements from sensors. The filter uses a set of equations to estimate the true state of the system based on the model and the measurements. The filter also estimates the uncertainty of the state estimate, which allows it to take into account the noise and errors in the measurements and the model.

- One of the main advantages of the Kalman filter is its ability to provide accurate and stable estimates even in the presence of noise and errors. It can also adapt to changes in the system dynamics and the measurement noise, making it a versatile and robust algorithm.

rotation rate [°/s] measured by the gyroscope

$$Angle_{pitch} = \int_0^{k \cdot T_s} \boxed{Rate_{pitch}} \cdot dt$$

$$Angle_{\underline{pitch}}(k) = Angle_{\underline{pitch}}(k-1) + \boxed{Rate_{\underline{pitch}}(k)} \cdot T_s$$

$$Angle_{\underline{kalman}}(k) = Angle_{\underline{kalman}}(k-1) + T_s \cdot \boxed{Rate(k)}$$

rotation rate [°/s] measured by the gyroscope

$$\boxed{Angle_{kalman}(k) = Angle_{kalman}(k-1) + T_s \cdot \underline{Rate(k)}}$$

prediction of the angle, but not the final value

$$\boxed{Uncertainty_{angle}(k) = Uncertainty_{angle}(k-1) + T_s^2 \cdot 4^2}$$

uncertainty of the angle prediction

$$\boxed{Angle_{kalman}(k) = Angle_{kalman}(k) + Gain_{kalman} \cdot (\underline{Angle(k)} - Angle_{kalman})}$$

new angle prediction

angle [°] measured by the accelerometer

$$Gain_{kalman} = \frac{Uncertainty_{angle}(k)}{Uncertainty_{angle}(k) + 3^2}$$

std dev angle(k) = 3° (accelerometer)

$$\boxed{Uncertainty_{angle}(k) = (1 - Gain_{kalman}) \cdot Uncertainty_{angle}(k)}$$

uncertainty of new the angle prediction

This equations calculate the Kalman Filter

B- Arduino Nano

Arduino boards are equipped with microcontrollers, which are small computers that can be programmed to perform specific tasks. The Arduino software allows you to write code for your Arduino board using a text editor. Once you have written your code, you can upload it to your Arduino board using a USB cable.

In our project the Arduino nano work as signal processing element which is the element that take the output of signal form MPU 6050 and convert it into form suitable for presentation purpose

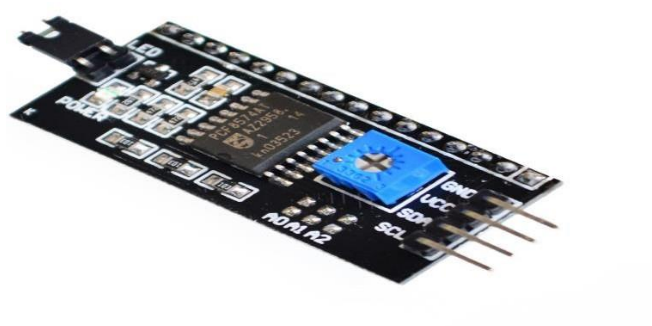
C- I2C Serial interface Adapter Module :

The I2C (Inter-Integrated Circuit) or IIC Serial Interface Adapter Module is a common component used in Arduino projects to communicate with other devices using I2C protocol. The I2C protocol is a two-wire communication protocol that allows multiple devices to be connected on the same bus, and is particularly useful when a large number of sensors or other devices need to be connected to an Arduino board.

The I2C Serial Interface Adapter Module acts as a bridge between the Arduino and the I2C bus, allowing the Arduino to communicate with other I2C devices such as sensors, EEPROMs, LCD displays, and many others. It provides an easy-to-use interface for the Arduino to send and receive data on the I2C bus, and

The I2C Serial Interface Adapter Module typically includes a microcontroller that handles the I2C communication, as well as a voltage level shifter to ensure compatibility with different I2C devices. It also provides pull-up resistors to ensure reliable communication on the I2C bus.

Overall, the I2C Serial Interface Adapter Module is a useful component in Arduino projects that require communication with multiple I2C devices. It simplifies the process of connecting and communicating with these devices, and allows for more efficient and streamlined Arduino projects.



1-What is the I2C communication protocol ?

I2C (Inter-Integrated Circuit) is a communication protocol that allows multiple devices to communicate with each other using a two-wire serial interface. It was developed by Philips Semiconductors (now NXP Semiconductors) in the 1980s and has since become a widely used protocol in the electronics industry.

The I2C protocol uses two wires, a clock line (SCL) and a data line (SDA), to transfer data between devices. The clock line is controlled by the master device, while the data line can be controlled by both the master and the slave devices.

In I2C communication, each device on the bus has a unique address that is used to identify it. The master device initiates communication by sending a start condition on the bus, followed by the address of the slave device it wants to communicate with. The slave device with the matching address then responds with an acknowledgement (ACK) signal.

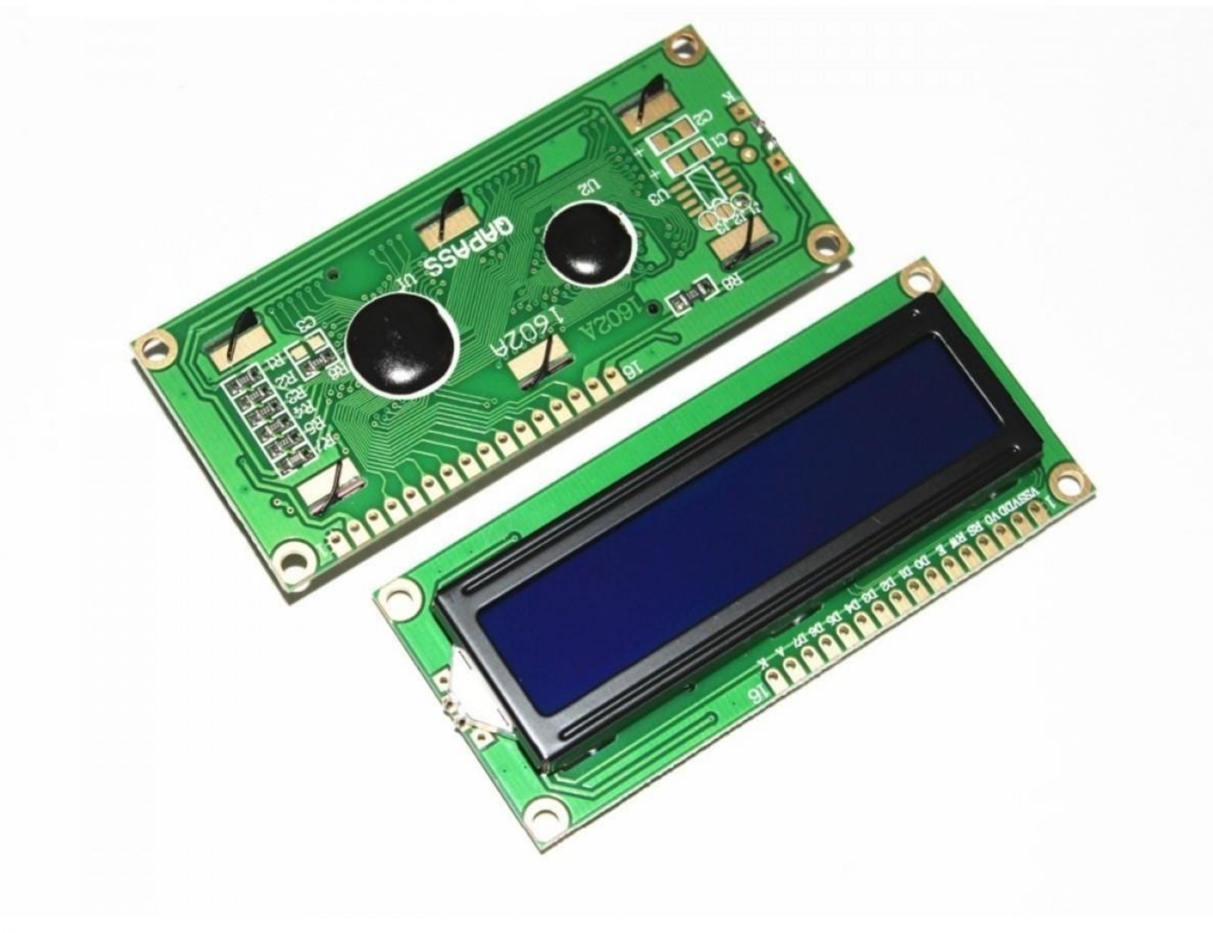
Once communication has been established, the master device can send or receive data from the slave device by toggling the clock line while keeping the data line stable. The data is transmitted in eight-bit packets, with each packet being acknowledged by the receiving device.

After the communication is complete, the master device sends a stop condition on the bus to signal the end of the transaction.

Overall, the I2C protocol is a simple and efficient way for multiple devices to communicate with each other using a two-wire interface. It is widely used in a variety of applications, including sensors, displays, and memory devices.

D- LCD :

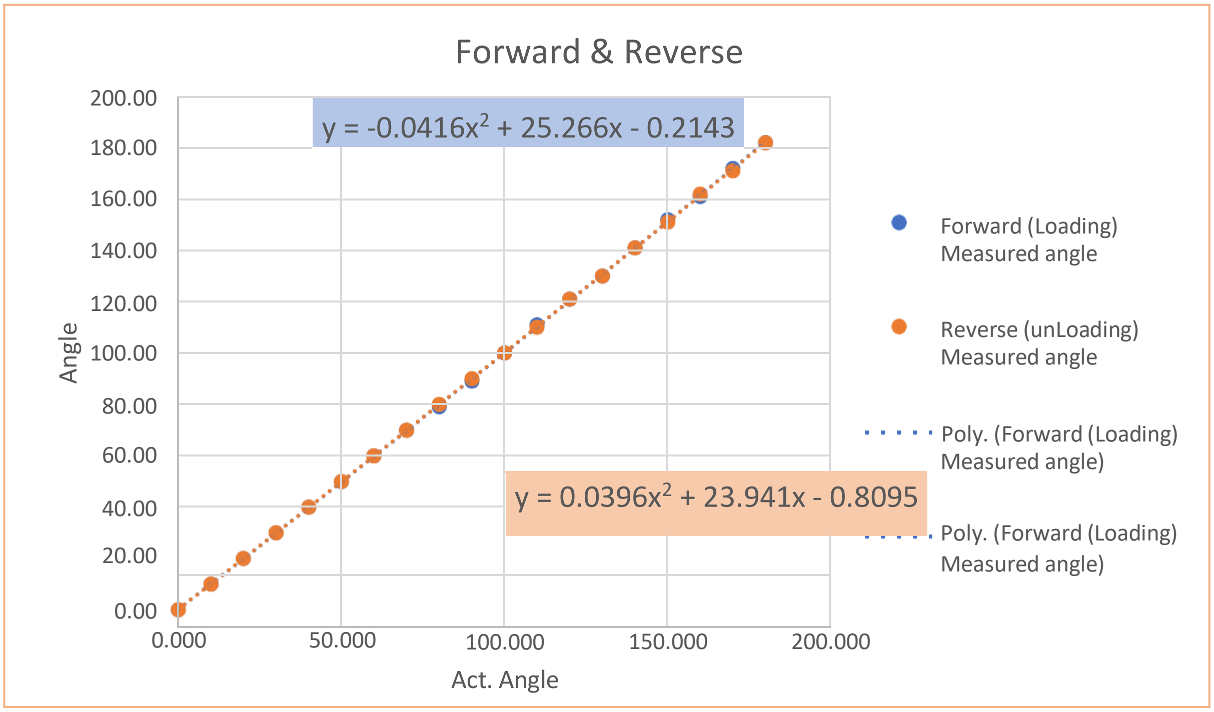
It is the data presentation element which the element that present the measured value in form easy to be recognized by the observer

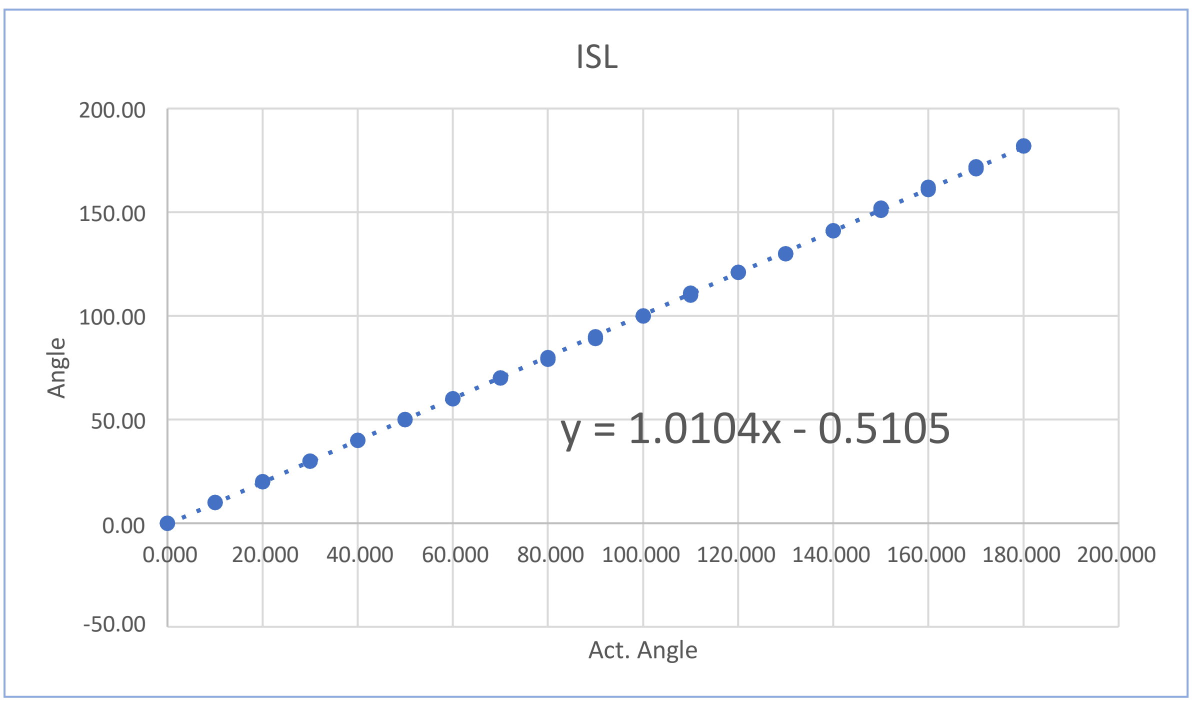


Calibration

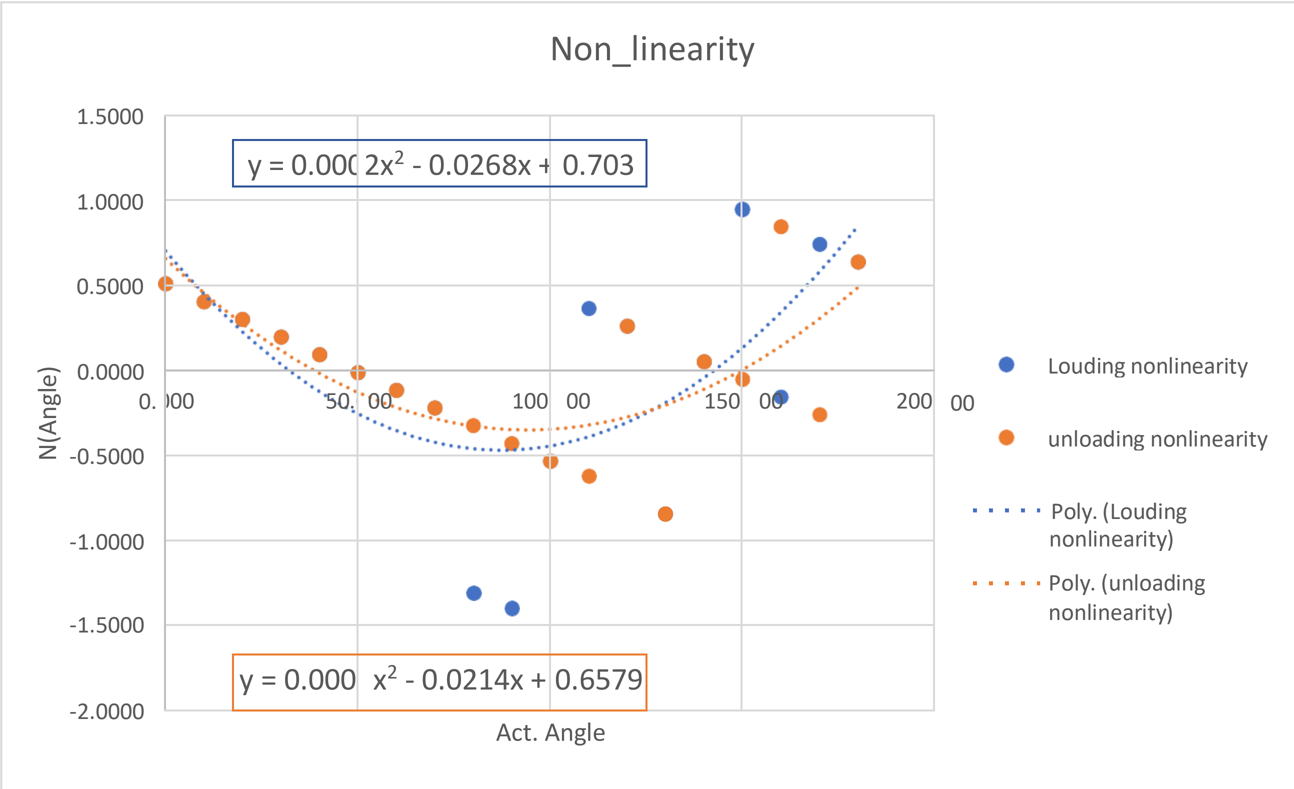
We have calibrated the device by measuring an angle with a known value and comparing the measured value to the true value. We have then arrived at the following results by using Excel

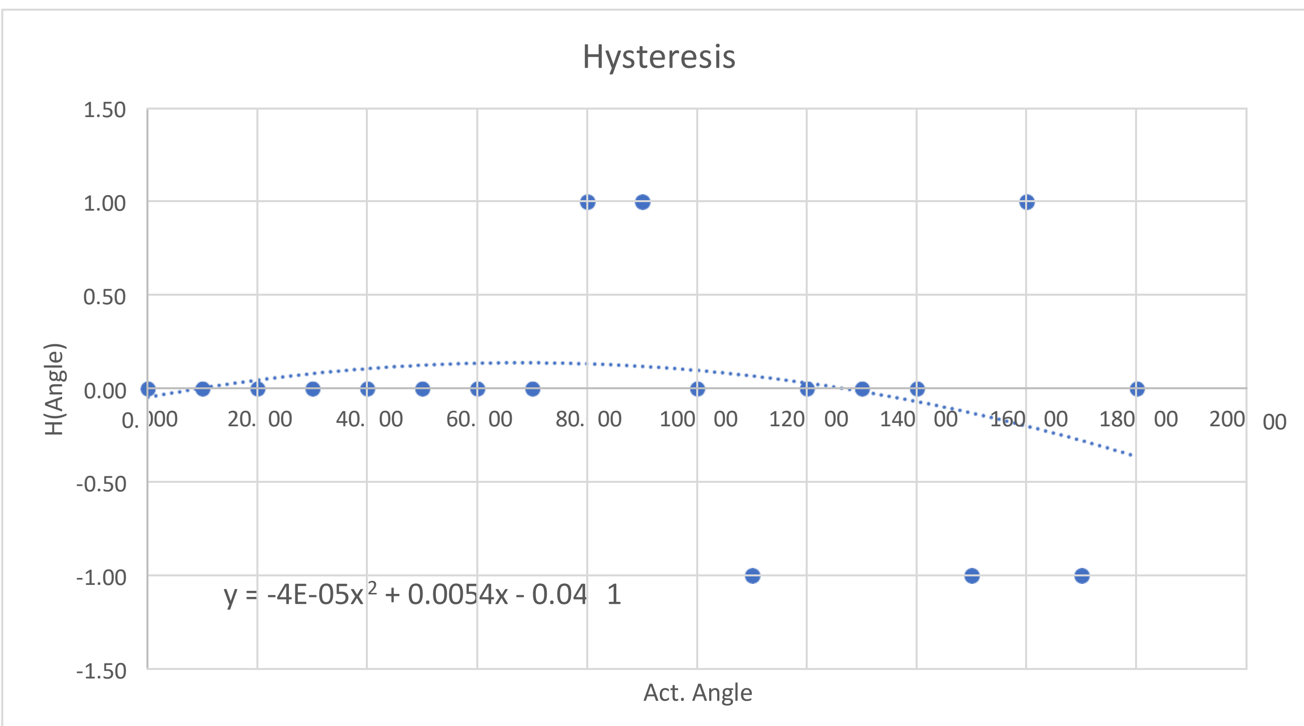
Actual angle	Forward (Loading) Measured angle	Reverse (unLoading) Measured angle
0.000	0.00	0.00
10.000	10.00	10.00
20.000	20.00	20.00
30.000	30.00	30.00
40.000	40.00	40.00
50.000	50.00	50.00
60.000	60.00	60.00
70.000	70.00	70.00
80.000	79.00	80.00
90.000	89.00	90.00
100.000	100.00	100.00
110.000	111.00	110.00
120.000	121.00	121.00
130.000	130.00	130.00
140.000	141.00	141.00
150.000	152.00	151.00
160.000	161.00	162.00
170.000	172.00	171.00
180.000	182.00	182.00
0.000	0.00	
10.000	10.00	
20.000	20.00	
30.000	30.00	
40.000	40.00	
50.000	50.00	
60.000	60.00	
70.000	70.00	
80.000	80.00	
90.000	90.00	
100.000	100.00	
110.000	110.00	
120.000	121.00	
130.000	130.00	
140.000	141.00	
150.000	151.00	
160.000	162.00	
170.000	171.00	
180.000	182.00	


Forward & Reverse
y = -0.0416x2 + 25.266x - 0.2143
y = 0.0396x2 + 23.941x - 0.8095
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Angle
0.000
50.000
100.000
150.000
200.000
Act. Angle
Forward (Loading) Measured angle
Reverse (unLoading) Measured angle
Poly. (Forward (Loading) Measured angle)
Poly. (Forward (Loading) Measured angle)


ISL
y = 1.0104x - 0.5105
200.00
150.00
100.00
50.00
0.00
-50.00
Angle
0.000
20.000
40.000
60.000
80.000
100.000
120.000
140.000
160.000
180.000
200.000
Act. Angle

Actual angle	ISL	Hysteresis	Forward nonlinearity	Reverse nonlinearity
0.000	-0.5105	0.00	0.5105	0.5105
10.000	9.5935	0.00	0.4065	0.4065
20.000	19.6975	0.00	0.3025	0.3025
30.000	29.8015	0.00	0.1985	0.1985
40.000	39.9055	0.00	0.0945	0.0945
50.000	50.0095	0.00	-0.0095	-0.0095
60.000	60.1135	0.00	-0.1135	-0.1135
70.000	70.2175	0.00	-0.2175	-0.2175
80.000	80.3215	1.00	-1.3215	-0.3215
90.000	90.4255	1.00	-1.4255	-0.4255
100.000	100.5295	0.00	-0.5295	-0.5295
110.000	110.6335	-1.00	0.3665	-0.6335
120.000	120.7375	0.00	0.2625	0.2625
130.000	130.8415	0.00	-0.8415	-0.8415
140.000	140.9455	0.00	0.0545	0.0545
150.000	151.0495	-1.00	0.9505	-0.0495
160.000	161.1535	1.00	-0.1535	0.8465
170.000	171.2575	-1.00	0.7425	-0.2575
180.000	181.3615	0.00	0.6385	0.6385


Non_linearity
N(Angle)
Act. Angle
y = 0.000 2x2 - 0.0268x + 0.703
y = 0.000 x2 - 0.0214x + 0.6579
Louding nonlinearity
unloading nonlinearity
Poly. (Louding nonlinearity)
Poly. (unloading nonlinearity)


Hysteresis
H(Angle)
Act. Angle
y = -4E-05x2 + 0.0054x - 0.04 1