Application Note

3D Hall-Sensor Application in Vacuum Robots Collision

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Position Sensing

ABSTRACT

In most instances, Vacuum robots detect collisions by switch signal. Switch is not only high-cost due to harsh working environment, but also big collision noise, and direction of the collision can only be given roughly by switch installation direction. This document presents and validates a solution for detecting collisions by 3D linear hall sensor, which is not only inexpensive, but also low noise by using flexible connections, and achieve for relatively accurate collision angle values.

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1 Introduction

Vacuum robots have had a great market growth in recent years, with an increasing number of people opting to buy a vacuum robot instead of manual sweeping. Autonomous systems, like vacuum robots, contain a lot of sensors to detect their working environment. Giving them the ability to detect things such obstacles in their path, if there is cliff on the ground, or if they have experienced a collision with something.

From high-end to low-end vacuum robots, collision detection is a basic and necessary function because the floor contains many obstacles. Even though vacuum robot has many sensors to detect its environment, sometimes collision is inevitable. If a collision occurs, the robot must not continue to move forward but turn in another direction after judging where direction of the collision.

Collison detection is necessary so that the vacuum robot can adjust and survey which direction is available. The noise from collisions can be annoying, with the source of noise not only from robot striking another object but also from the robot's mechanical chassis.

2 Traditional Way of Collision Detection in Vacuum Robot

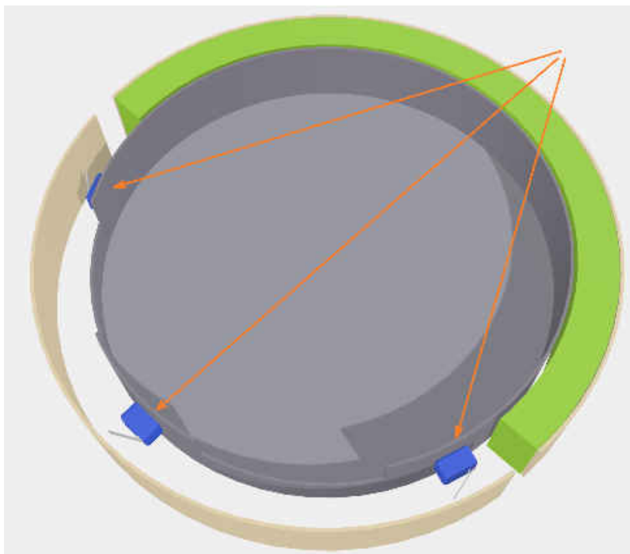

Figure 2-1. Switch on Vacuum Robot

The traditional way of detecting collisions is by using switches, mechanical switches or infrared receiver and transmitter pairs can be used as shown in Figure 2-1. To ensure that the switch signal is working reliably, the collision shell, which is part of the chassis, should compress deeply so that switch contacts may completely connect and release. As a result of the mentioned mechanical constraints, the collision noise in the event of a crash is inevitable.

In most instances, the mechanism is not simple as pictured above. These systems tend to be more complex and customized, which leads to a higher production cost. Another challenge a vacuum robot must overcome is harsh working environment. Cleaning products must operate appropriately in areas where various contaminants could be present. These contaminants include but are not limited to dust particles, oil, sewage, and even liquids such as juice or sauce. In order for the system to detect the direction of a collision, multiple switches or sensors are strategically placed to detect various directions. Using multiple sensors can lead to an increase in material and manufacturing cost.

3 Different Types of Hall-Effect Sensors

TI offers several different types of Hall-effect sensors: latches, switches, 1-axis linear, and 3D linear sensors. Linear sensors can provide detailed magnetic data since they represent the magnetic field strength using an analog voltage or a digital numeric representation. The voltage or numeric representation changes as the field experienced by the device's changes. Using these values, the distance can from the hall sensor to the magnet can be easily calculated. This makes linear Hall-effect sensors extremely useful for proximity sensing applications. Unlike single axis sensors, 3-axis or 3D linear sensors can use the magnetic field data from all 3 directions to calculate angle and magnitude. The three axis of sensitivity of a 3D linear Hall-effect sensor are defined as shown in Figure 3-1.

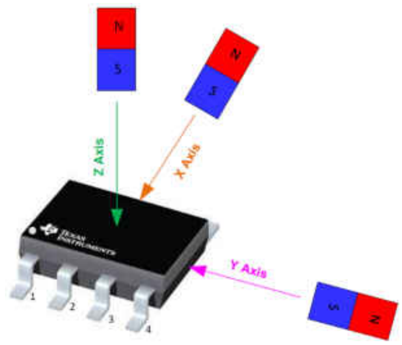

Figure 3-1. 3D Hall Sensor Axis

At the time of this article TI offers two types of 3D linear Hall sensors, one with an I2C interface the TMAG5273 and the other with a SPI interface the TMAG5170. Each of these 3D Hall sensors provides multiple magnetic range options that can benefit different use cases and different environments. For example, if the sensor is placed near a high-current cable, or besides running motors, a high magnetic field can be generated by these other devices. Using a different magnetic range option can yield a better SNR (signal-noise rate).

Compared with mechanical or IR switches, Hall-effect sensor are more reliable, and they are minimally affected by environment changes like temperature, humidity, dust, or water.

4 Using 3D Hall Sensor for Detecting Collision Angle in Vacuum Robot

If the system is correlating the motion of magnet with the motion of bumper, when the bumper collides with an object then the collision angle can be extrapolated by using a 3D Hall-effect sensor. As shown in Figure 4-1, a magnet is mounted on a frame that is connected to the bumper. When bumper moves, the magnet movement follows due to the connected frame. Although the magnet and hall sensor are placed on the central axis in image, the magnet and Hall sensor can be placed anywhere on the frame because the motion at any point on the frame would be the same.

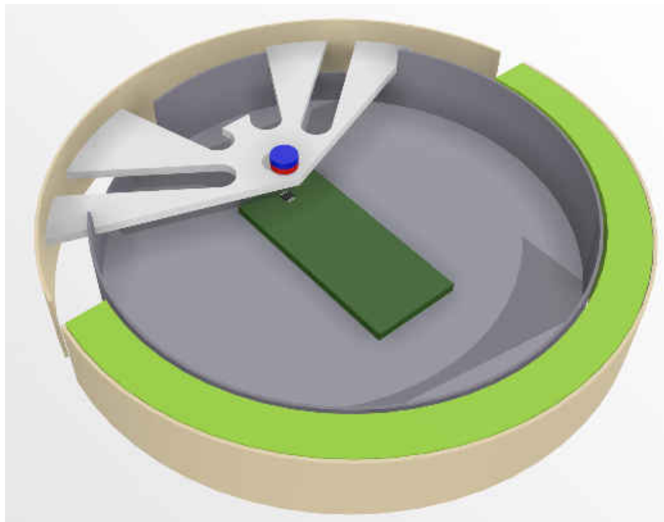

Figure 4-1. Structure of Mounted Hall Sensor and Magnet

When a collision occurs from 0º~180º, the magnets position over the hall sensor would follow a similar path in 3D space path as shown in yellow trace on Figure 4-2. If a 3D linear hall sensor, like TMAG5170, is placed under magnet Figure 4-3 shows the waveform collected by this event. Note that the waveform shape is depended on hall sensor, mounting setup, direction, and the magnets direction.

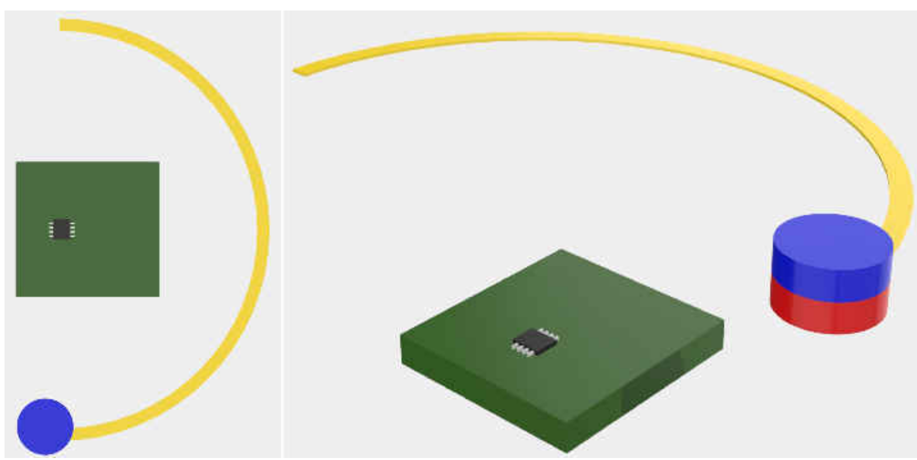

Figure 4-2. Magnet Position Trace After Collision

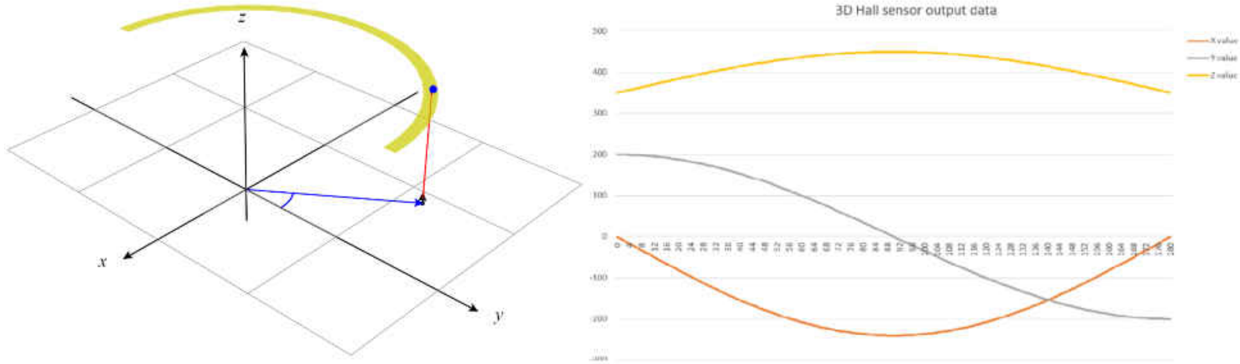

Figure 4-3. Angle Calculation and Output Data Waveform of Hall Sensor

The bumper is connected with main structure of vacuum robot via a spring. As shown in Figure 4-4, the spring is indicated by the red cylinder under the magnet frame. The spring function is used to return the magnet back into its resting position after a collision occurs. Besides the spring, the chassis should have another structure that helps support the magnetic frame.

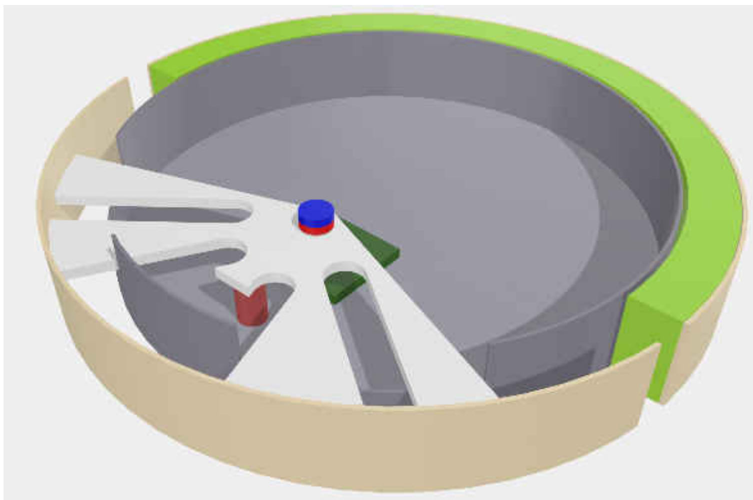

Figure 4-4. Spring Installation

5 Analysis of Error Sources

- Error in installation position and direction error of Hall sensor board. For example, the Hall sensor is not directly under magnet and its axis does not coincidence with the bumper's central axis. The installation error can cause the magnets movement trace to behave as shown in Figure 5-1. In this instance the measured angle should have been 0° through approximately180° but due to the shift the result was 5° through approximately 195° and a bigger shift could result in -15° through approximately 195°.

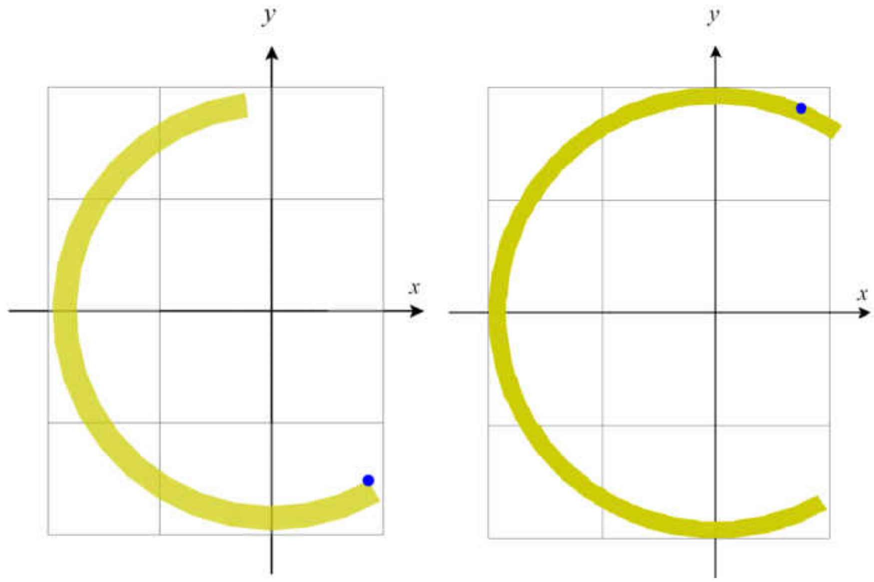

Figure 5-1. Magnet Position Trace Due to Installation Error

- The bottom of the magnet is not parallel to Hall sensors package. This slight offset will also generate an angle between the magnet and the sensor IC generating an error as seen in Figure 5-1. This shift magnet can also cause the waveform of output data to no be as smooth and symmetrical like the data shown in Figure 4-3. Figure 5-2 shows measured data when the magnet is not parallel to the Hall sensor.

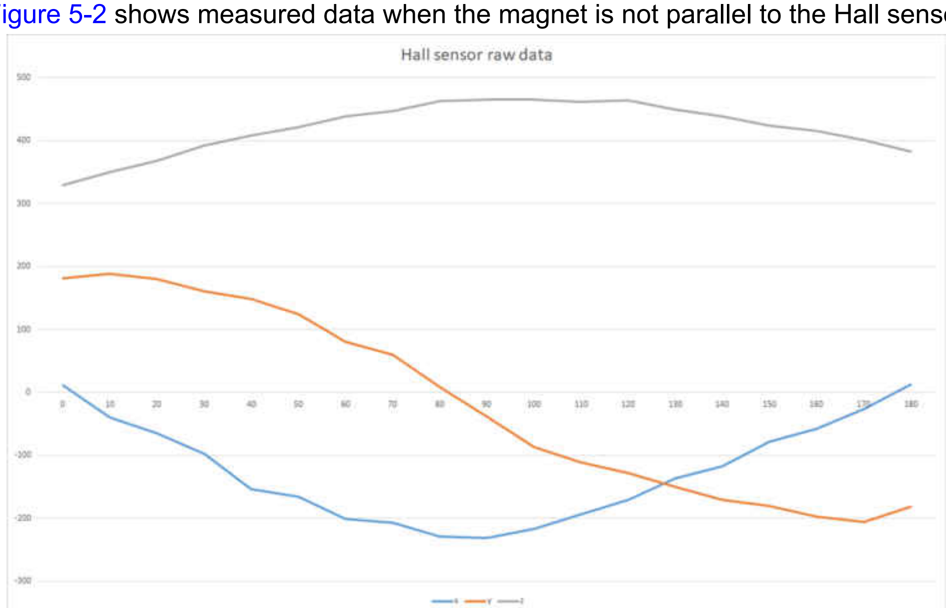

Figure 5-2. Hall Sensor Output Raw Data From 0° Through Approximately 180° of Collision

- Low SNR, the sensors SNR depends on the distance between magnet and sensor, the magnets strength, and the Hall sensors range setting. The TMAG5170 offers two different sensitivities each with three configurable range settings. These options range from ±25 to ±300 mT.
- Uneven lateral deformation of spring.

- Impact of robot movement speed, direction and spring strength and surface material.

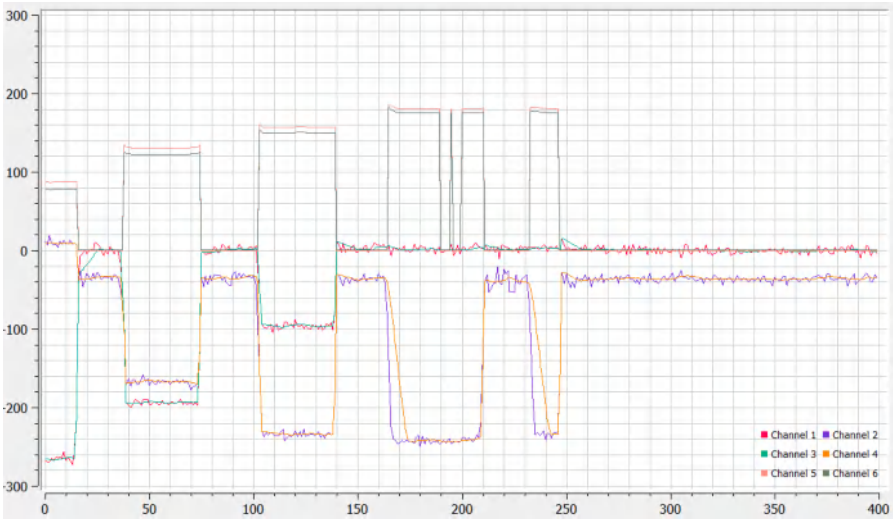

Figure 5-3. Raw and Filtered Data Wave of Hall Sensor

For most general mechanical errors in mass production, after using statistical curve-fit calculation of full-scale data. The measurement error can be reduced in the R&D designing phase to ensure accuracy needed by the system. A second order curve-fit equation mostly reduces error and helps meet error requirements. Source data of equation should be raw angle data of X and Y axis, instead of using raw magnetic data of the X and Y axis. The raw arctangent angle should be calculated first because collision depth will be related to curve-fit angle if directly using raw X and Y magnetic data.

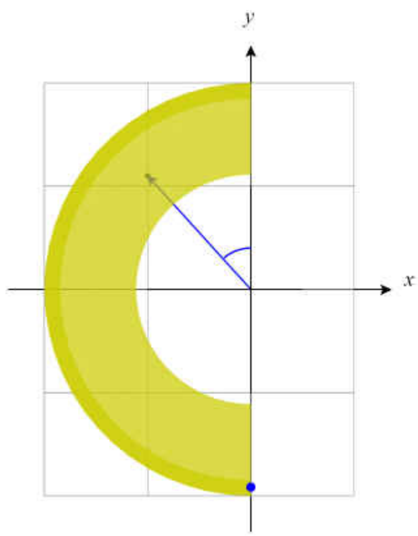

Figure 5-4. Magnet Position Trace After Adding Threshold

Setting a data threshold to set a calculation point. This helps by filtering noise generated by the moving robot. The magnet point trace after collision is shown on Figure 5-4.

The error caused by robot moving can be mainly attributed to the robots' speed, moving direction, spring strength, and material of bumper surface. Due to the impact's direction, since it is not toward the central portion of the bumper arc, this collision can cause a relatively large error between measuring angle and real collision angle when using the Hall sensor output data. As shown in Figure 5-5, an equation can help by compensating for the robot speed and direction raw angle data.

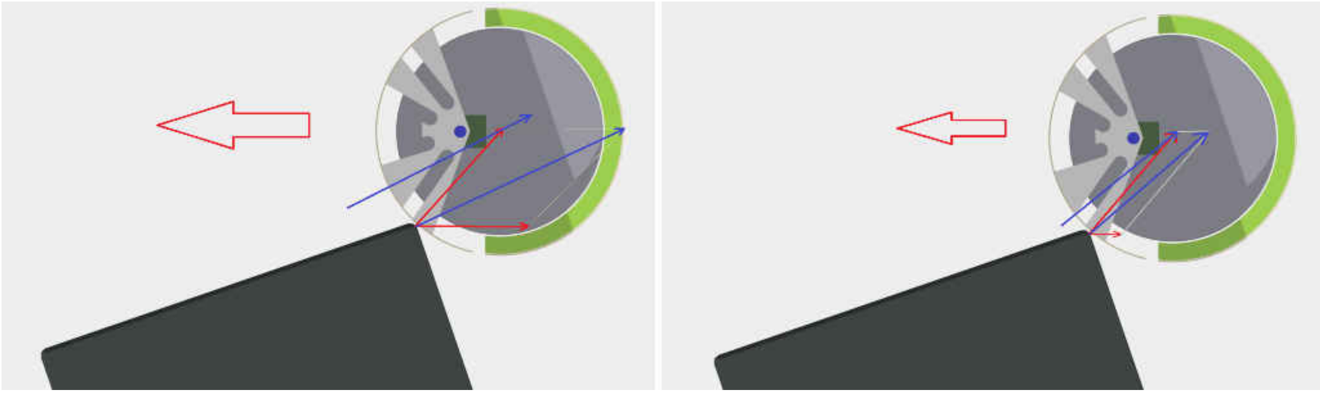

Figure 5-5. Collision Force When Robot Moving

6 Functional Demo Test

The demo was created using TMAG5170UEVM and TI M0+EVM board. The mechanical implementations are shown in Figure 6-1.

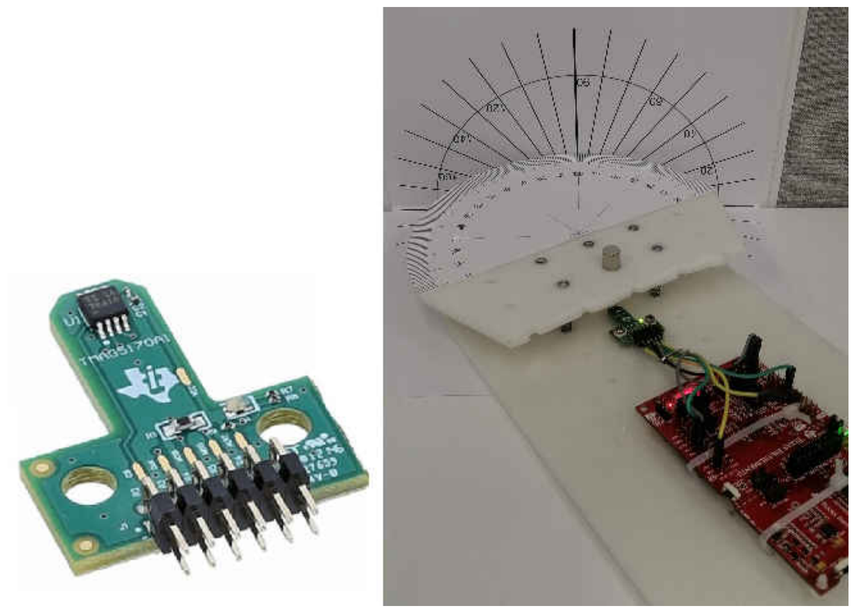

Figure 6-1. TMAG5170EVM Board and Robot Collision Angle Detecting Demo

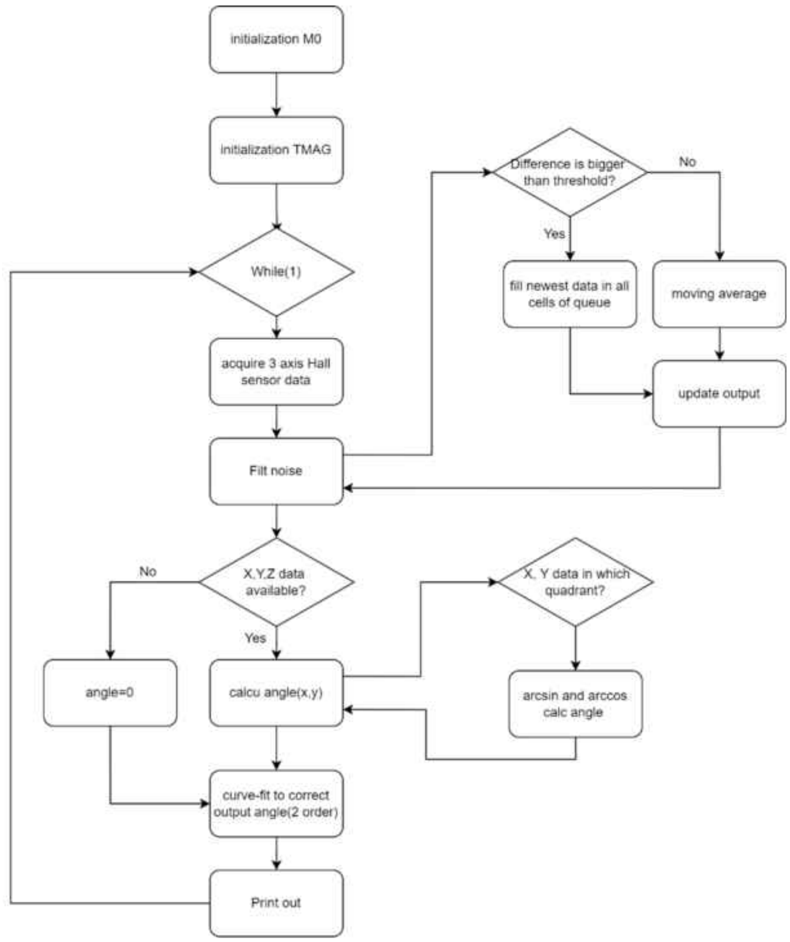

Figure 6-2. Firmware Flowchart

2nd curve fit chart and error comparison

After implementing a 2nd curve-fit equation, the measuring error was reduced to ±3° from a max -11°.

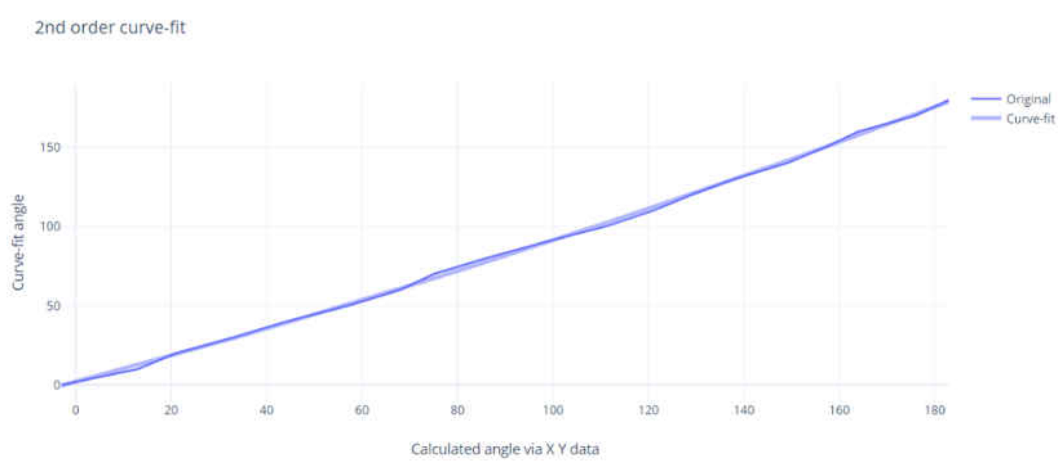

Figure 6-3. Curve-Fit Chart

Figure 6-4. Error of Hall Sensor Output in Demo