*Application Note*

# ***Using 3D Linear Hall-effect Sensors for Joystick Button Press***

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**ABSTRACT**

This application note proposes a two-level magnetic flux change and latch detection method in Z-axis using 3D linear Hall-effect sensors to decrease possible X or Y offset during the button press action of a joystick . By using hardware interrupt and software slew rate or absolute value detection method, a fast response to the Z-axis pressing action can be achieved. Simultaneously, by latching the last X, Y conversion numbers, this method can significantly reduce the X and Y offsets. The average error in the axis most affected by mechanical errors can be reduced from 265% to 8.8%.

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# 1 Introduction

In joystick applications such as game controllers, remote controllers or gimbal camera, a sensor component or device is required to detect the movement of the joystick. The sensor converts the original mechanical displacement signals into electrical signals and communicates with the host MCU to update the sensing electrical signal. Using the information from the sensor, the MCU then provides the user control of the larger system.

Both the 5D switch or carbon film resistor joystick have been used as direct mechanical contact detection methods in joystick applications.

A 5D switch sets 5 mechanical triggers around the joystick. When the mechanical structure is pressed or triggered by the movement of the joystick, a continuous high-level signal is output from the switch to indicate the direction of movement. This method can only output high or low signal, cannot detect the tilt angle or movement speed to provide more precise detection.

Carbon film resistor joysticks change resistance for each axis relative to the movement of joystick. The carbon film has a good linear response, but this requires a larger mechanical package and regular use can result in resistance changes that cause joystick drift problems that limit the product life.

**Figure 1-1. Carbon Film Resistor Joystick and 5D Switch Joystick**

Recently, there has been increased interest in moving away from mechanical contact based designs to Hall-effect based designs which offer contact free position sensing and help resolve drift concerns that arise over the lifetime of the product. Depending on the joystick design, both standard 1D (single axis sensitivity) and 3D (x,y,z sensitivity) can be used for this purpose.

A 3D Hall-effect sensor integrates three Hall elements into one chip with a single plastic packaging, provides an ultra-small size and low cost while maintaining a good performance design. The size of TI newest generation 3D linear hall sensor TMAG3001 can achieve a packaging size of 0.83mm x 1.32mm.

Configuration of joysticks using Hall-effect sensors is explored in more detail in *Joystick and Lever Design With Hall-Effect Sensors*, application note.

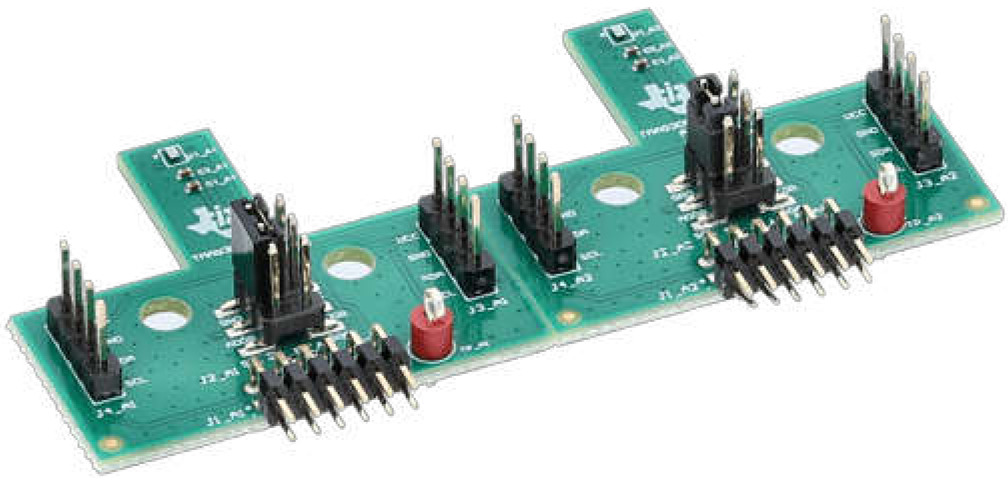

**Figure 1-2. TI TMAG3001 EVM**

A single 3D linear Hall-effect sensors can be used in joystick application to replace carbon film or 5D mechanical switch. The Hall-effect elements are arranged orthogonally to each other which allows for detection of the complete magnetic field as explained in Introduction to 3D Hall-effect sensors. Using angle calculations output by the TMAG3001 integrated CORDIC engine, the host MCU can determine the position of the joystick quickly. In addition to the ability to track the XY angle input, the use of a 3D Hall-effect sensor enables button press detection by capturing a step in magnitude of the magnetic field vector.

## 2 Z-Axis Pressing Offset Issue in 3D Linear Hall Sensor

In joystick applications, users often press the joystick in the Z-axis direction to engage the button press action. This press allows the user to indicates a single operation. For example, in a Gimbal camera, this action can enable the command to *start recording* or *take a photo*, and in a game controller, this action can also be considered as *confirm*. If during the pressing action, some offsets in the X and Y axes are created and sent to the MCU, this incorrect information can cause unexpected movements, such as shifting the center point of the screen in the Gimbal camera or incorrect menu commands.

### 2.1 Root Cause of X, Y Offsets in Z-axis Pressing Action

Figure 2-1 shows the designed for behavior during the pressing action of the Z-axis.

- No mechanical error between the center point of 3D linear Hall Sensor and joystick.
- The pressing action always keeps vertical angle

Please note that the Hall elements inside 3D linear Hall-effect sensor are not at the midpoint of TMAG3001. This requires a small offset from package center to properly align the device.

Through TI Magnetic Sense Simulator (TIMSS) simulations, the expected magnetic field can be modeled and used to perform calculations. If the magnet moves downwards, the magnetic flux in either the X and Y direction does not change and the magnetic flux in Z axis can increase exponentially. This model was then reproduced using the TMAG3001EVM and GUI, we can directly observe that the magnetic change is inversely proportional to $r^2$.

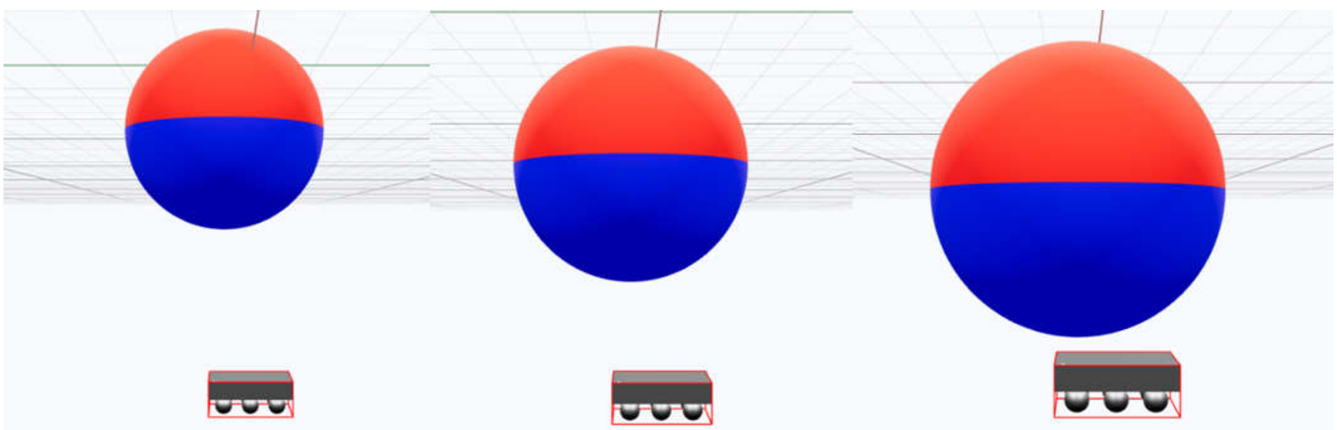

**Figure 2-1. TIMSS Simulation Model**

**Table 2-1. Simulation Results When Moving Magnet in Z-axis**

| Z_axis Displacement(mm) | Bx(mT) | By(mT) | Bz(mT) |
|---|---|---|---|
| 0 | 0 | 0 | 25.12599 |
| 0.25 | 0 | 0 | 29.55061 |
| 0.5 | 0 | 0 | 35.07820 |
| 0.75 | 0 | 0 | 42.07500 |
| 1 | 0 | 0 | 51.06340 |

In non-ideal situation, there are two main reasons either X or Y offsets can be observed from the sensor

- Mechanical error between joystick and 3D linear Hall sensor
- Manual press cannot be completely perpendicular to the sensor

The mechanical error indicates that the 3D linear Hall sensor can have a certain level of deviation compared to the reference value, as shown in Figure 2-2. While this is designed for to target the center of the sensing element, manufacturing tolerances during soldering and product assembly can inevitably cause some potential design errors.

More importantly, the joystick can tilt somewhat during the pressing action caused by imperfect user control. This mechanical error causes the sensor to no longer reside where the magnetic field vector is entirely contained within the Z-axis, and some component can be observed in either the X or Y axes. As a result, this is not uncommon to observe a small deviation with offset to either the X or Y axes.

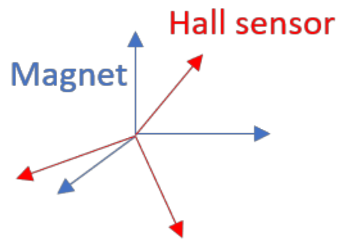


**Figure 2-2. Mechanical Error Between Magnet and Hall Sensor**

## 3 The Z-Axis Pressing Detection Method

As mentioned in Section 2 the mechanical error between the 3D linear Hall sensor and the joystick causes unwanted results on the X and Y axis during the Z-axis pressing process. For example, this can result in a step to the next menu option immediately prior to attempting to select a setting. This can result in unwanted operations form the MCU which adversely affect the user experience.

The functional goal is that the MCU can only detects the vertical button press with no operations are performed on the X and Y axes. This application note explores an algorithm for fast pressing detection method in the Z-axis while minimizing any influence in the X and Y axes.

### 3.1 General Introduction of Proposed Method

In general, this detection method uses a hardware threshold interrupt and software slew rate or absolute value detection to reduce the influence caused by the Z-axis pressing action in the X and Y axes. Figure 3-1 shows the magnetic flux change in the Z-axis during the Z-axis pressing process. The magnetic flux change along the Z-axis is similar to an exponential function. In order to detect the pressing action as soon as possible, this method applies two-level magnetic field detection.

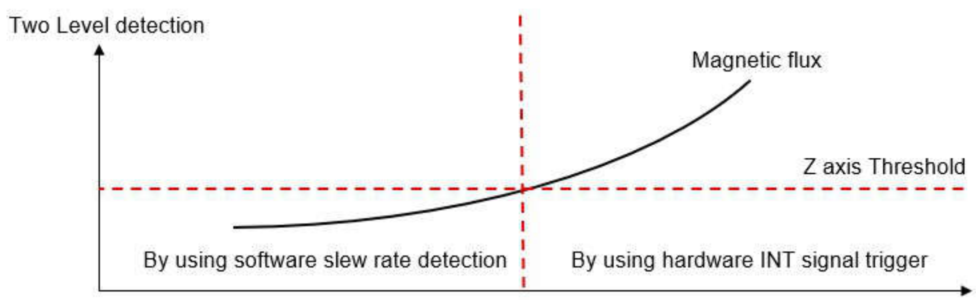


**Figure 3-1. The Magnetic Flux Change in Z-axis Pressing Action**

### 3.2 Software Slew Rate Detection

At the beginning of pressing action, the Hall-effect sensor continuously monitors the magnetic field and sends this to the MCU. Once the MCU detects that the magnetic flux difference between two or more samples is larger than the pre-set value, the MCU can set a flag to indicates that the Z-axis has already been pressed. This first level of pressing detection is achieved by the software.

The threshold of the software can be manually adjusted by the user to fit different systems. For example, different magnets in the joystick and different distances between the joystick and 3D Hall sensor can cause different amplitude responses in the 3D linear Hall sensor. The setting value can be defined by simulation or experimental results. Figure 3-2 shows the simplified software detection function.

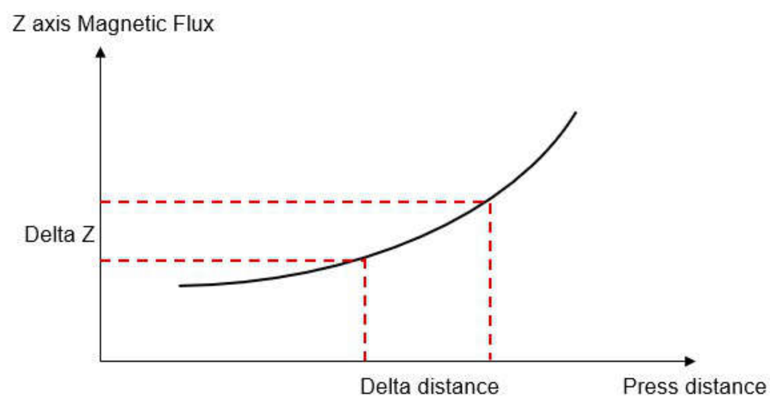


**Figure 3-2. Software Detection Method**

## 3.3 Hardware Threshold Detection and Interrupt

If the users presses slowly, the amplitude difference between two or more conversion results might not exceed the setting software threshold. In this situation, a second-level hardware detection is required to make sure that the pressing action is detected quickly. By setting a magnetic flux threshold in the TMAG3001 register, once the magnetic flux amplitude in the Z-axis exceeds the hardware threshold. The Hall-effect sensor creates an interrupt signal using the INT pin to be captured by the GPIO of the MCU. If desired, this threshold crossing can also be transmitted through I2C communication to indicate that the magnetic threshold has been exceeded. Figure 3-3 shows the simplified hardware interrupt function.

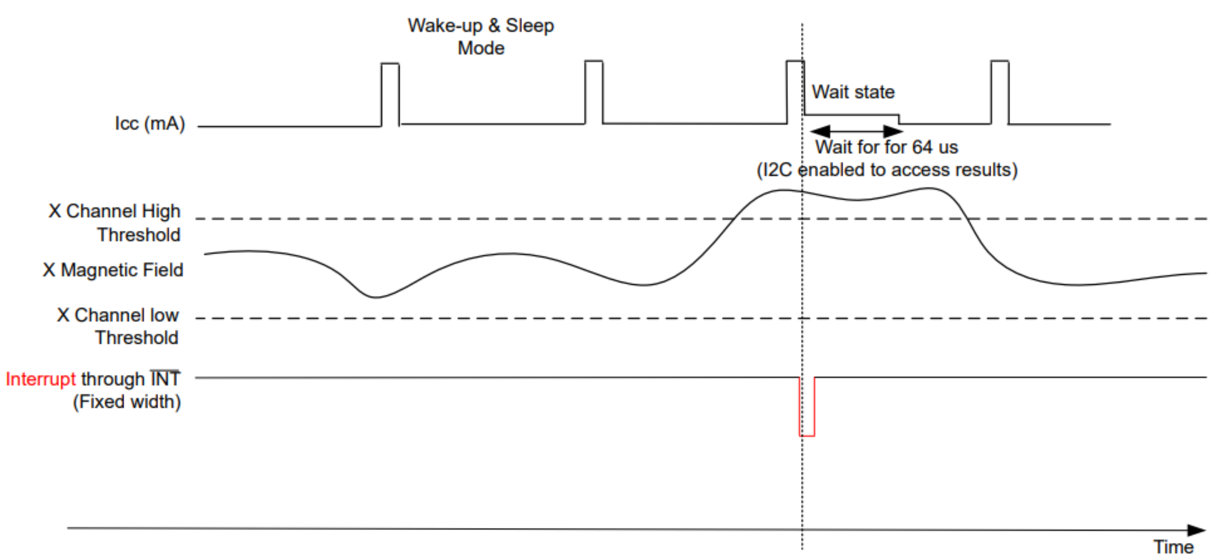


**Figure 3-3. Hardware Detection Method**

## 3.4 Latching Method

Once the software or hardware threshold has been triggered, TMAG3001 creates an output flag as an indicator. In practical applications, once the joystick has been pressed, the system does not require any X and Y information as long as the Z-axis press is maintained. Until the button press is released, any new X or Y output data from the Hall-effect sensor can ignored while focusing solely on the Z-axis conversion result.

In this example, The MAG_CH_EN function in the register of the TI Hall sensor was used to enable only the conversion of the Z-axis during the press event. This allows the 3D linear Hall sensor to update only the Z-axis information to the MCU. Since each additional axis conversion adds to the total conversation time for the sensor, sampling only on Z during this time can improve the system response time to restore X and Y tracking.

To make sure of robust tracking of the X and Y positions prior to the button press, an array is used to create a buffer to save the X and Y information immediately when the program enters the interrupt function. The number in the buffer was used as the X and Y conversion numbers to further decrease the offset value.

### 3.4.1 Implementation of Two-Level Detection Method

The detailed implementation of two-level detection method is specified in the following, taking TMAG3001 as an example.

1. Obtain the magnetic flux change in Z axis by pressing the joystick
   This step is used to set a correct threshold for hardware detection and a designed for step for software detection.
2. Set a corresponding threshold on Z axis by using THR_Config_3 register in TMAG3001 or Z_THR_Confing in TMAG5173.
   Larger thresholds require more pressing distance in the Z axis which also allows for larger offset in X and Y. A lower threshold means a reduced pressing distance in Z-axis, but this can cause a false trigger if set to low.
3. Set the interrupt signal in INT pin by writing 1h to INT_CONFIG_1 4-2 bits.
   The INT pin sends a signal to MCU to indicate that the magnetic flux has already crossed the threshold.
4. During normal operation the 3D linear Hall-effect sensor works in continuous sample or trigger sample mode based on user setting. The MCU calculates the slew rate or absolute change value based on the conversion number to determine whether the threshold is exceeded.
5. Once the hardware threshold or the slew rate exceeds the setting value the device enters iterrupt or latch mode. The previous X and Y axis are recorded into an array immediately and then MAG_CH_EN to 4h is set to 4H(Only convert Z-axis magnetic flux). After the interrupt is cleared, the main function returns to normal working mode and sets MAG_CH_EN to 7h(enable all three-axis conversions).

Figure 3-4 shows the flowchart of detailed implementation of proposed detection method.

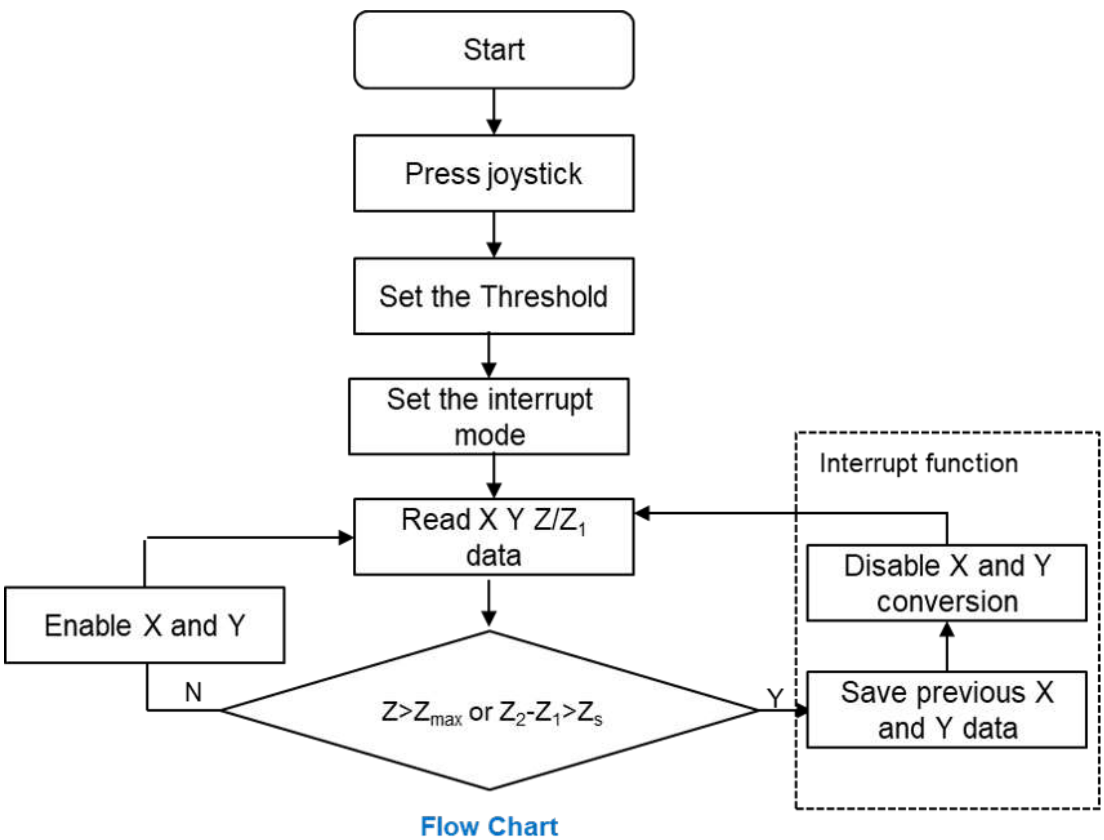


**Figure 3-4. Flow Chart of Proposed Method**

## 3.5 Test Result

To test the performance of proposed method, a test environment has been implemented by using customer's end products and the customized joystick as the basic platform. TMAG3001EVM is directly connected to the joystick and the TI-SCB board. TI-SCB board was connected to XDS110 to communicate with host computer. The software environment uses TI CCS. To protect customer information, the picture of customer information is not shown here.

Regarding the code, this application note first used the TMAG3001 Example Code, then adds modified and relevant code into the code to achieve the proposed method.

The aim of proposed algorithm is to decrease the X and Y offsets when users press the joystick. To verify the performance of algorithm, the aim is to compare the offset value after press action with and without algorithm

1. Tilt joystick without press, record the maximum and minimum value of X and Y axis
2. Tilt joystick with press, record the maximum and minimum values of X and Y axis.
3. Add proposed two-level detection method into the code
4. Tilt joystick with press, record the maximum and minimum values of X and Y axis.
5. Read the buffer data in the latch array

Step 1 and 2 is used to prove the mechanical error. Through comparison between step 2 and 5, the performance of proposed method can be verified.

Figure 3-5 and Figure 3-6 shows the results of step 1 and 2, respectively. As shown in these figures the minimum value decreased from -0.4mT to -4.5mT after pressing the thumbstick. This indicates there are significant mechanical errors between the joystick and TMAG3001. Furthermore, this means that the device rolls along the X-axis.

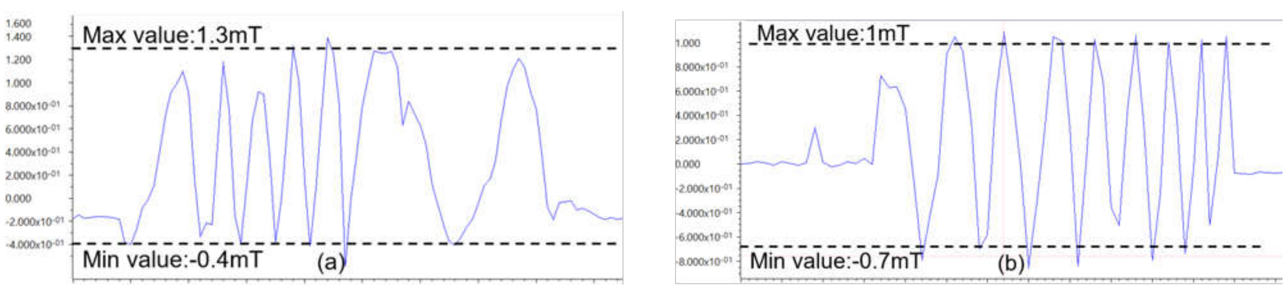


**Figure 3-5. Y and X Axis Performance Without Pressing**

From the perspective of offset caused by the pressing action, -4.5mT can be considered the largest offset without any operation.

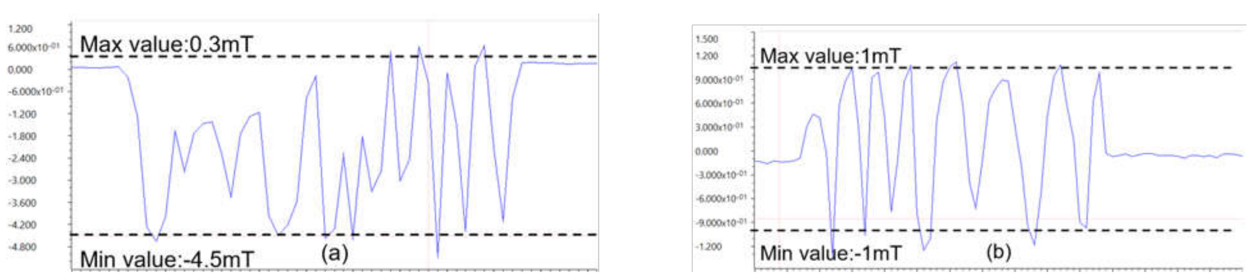


**Figure 3-6. Y and X Axis Performance With Pressing**

In step 3,4 and 5, because the refresh speed in dual-time function in CCS is relatively slow, The conversion number is read in the buffer array as shown in Figure 3-7. The value in the figure refer to the last Y axis conversion value before the trigger.

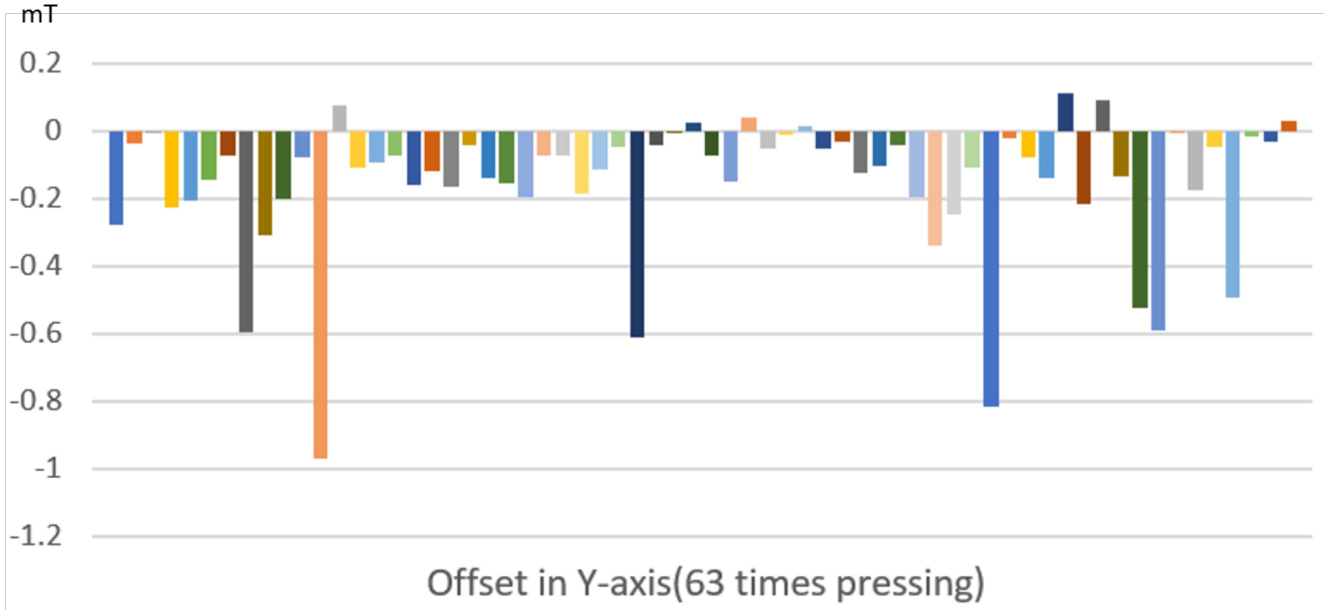


**Figure 3-7. Offset Results in Y Axis**

Using the detection range without press as the reference value to calculate the average error with and without algorithm, the results are shown in the following calculation. Since Y-axis is affected by the mechanical error most and has the most offset, this is used as the reference value during the calculation, the average error of Y-axis without algorithm is 4.5/1.7mT, which is 265%. After implementing the algorithm, the average error in the array is -0.158mT, therefore the average error is 0.158/1.7mT, which is 8.8%.

Through this two-level detection method, the average error is decreased from 265% to 8.8%, which provided an effective and easy-implement algorithm to better utilize TI 3D linear hall sensor.

# 4 Summary

Implementing a two-level magnetic flux change detection algorithm to detect button press events for 3D linear Hall-effect sensors reduces potential in X and Y axis output caused by unintentional user input. Experimentally this approach was found to reduce the total error percentage from 265% to 8.8%. This improvement stabilizes the tracking of joystick position and improves the quality of operation for the end user.

TI has a mature product series or 3D linear Hall-effect sensor. Please refer to Table 4-1 for more performance and package information.

**Table 4-1. TI 3D Hall-Effect Sensors**

| Device | Description |
|---|---|
| TMAG5170 | Commercial grade 3D linear Hall-effect sensor with SPI and integrated CORDIC at 1/4 degree resolution. |
| TMAG5170-Q1 | Automotive grade 3D linear Hall-effect sensor with SPI and integrated CORDIC at 1/4 degree resolution |
| TMAG5170D-Q1 | Dual-die automotive grade 3D linear Hall-effect sensors with SPI and integrated CORDIC at 1/4 degree resolution |
| TMAG5173-Q1 | Automotive grade 3D linear Hall-effect sensor with I2C and integrated CORDIC at 1/16 degree resolution |
| TMAG5273 | Commercial grade 3D linear Hall-effect sensor with I2C and integrated CORDIC at 1/4 degree resolution |
| TMAG3001 | Commercial grade 3D linear Hall-effect sensor with I2C integrated CORDIC at 1/16 degree resolution and wake up detection |

# 5 References


- Texas Instruments, *TMAG5173-Q1 High-Precision 3D Hall-Effect Sensor With I2C Interface*, data sheet.
- Texas Instruments, *Joystick and Lever Design With Hall-Effect Sensors*, user's guide.
- Texas Instruments, *Absolute Angle Measurements for Rotational Motion Using Hall-Effect Sensors*, application brief.
- Texas Instruments, *TMAG3001 Low-Power 3D Linear and Angle Hall-Effect Sensor With I2C Interface and Wake Up Detection in WCSP*, data sheet.

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