Application Note

3D Hall-Effect Sensor for Knobs in Appliances

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ABSTRACT

Knobs are widely used in many scenarios as a way for humans to interact with machines. Detecting the rotation angle of the knob is required in most applications. Compared with traditional knobs, knobs using Hall-effect sensors have more advantages. TI 3D linear Hall-effect sensors such as the TMAG5273 and TMAG5170 can measure magnetic fields in three directions, and can calculate angles in any two axes using the on-board CORDIC calculator allowing the MCU to read the angle directly. In addition, a push-button knob design can provide more versatile functions.

Table of Contents

1 Problem with Mechanical Knobs and Rotary Encoders 2
2 Using 3D Hall Sensor for Angle Measurement 2
3 On-Axis and Off-Axis Test 3
3.1 On-Axis Test 3
3.2 Off-Axis Test 4
4 Push-Button Knob Function Test 5
5 Summary 8
6 References 9

List of Figures

Figure 1-1. Knobs Used in Appliances 2
Figure 2-1. On-Axis and Off-Axis Angle Measurement 2
Figure 2-2. 3D Linear Hall-Effect Sensor Axis 2
Figure 3-1. Configurations for Angle Sense With 3D Hall-Effect Sensors 3
Figure 3-2. 3D Linear Hall-Effect Sensor On-Axis Test 3
Figure 3-3. Angle Data and XY Axes Data Output 3
Figure 3-4. 3D Linear Hall-Effect Sensor On-Axis Output 4
Figure 3-5. Off-Axis Placement 4
Figure 3-6. Linear Hall-Effect Sensor Off-Axis Output 4
Figure 3-7. Magnet Angle and Hall Sensor 5
Figure 4-1. Push-Button Knob 5
Figure 4-2. Push-Button Function Data Output 6
Figure 4-3. Push-Button Function Software Flow Chart 7

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1 Problem with Mechanical Knobs and Rotary Encoders

There are many products in home appliances that use knobs, such as microwave ovens, water dispensers, air fryers, cook-tops and so on. Figure 1-1 showcases just a few examples of knobs on home appliances. At present, there are two mainstream knob designs: mechanical and rotary encoder. Mechanical knobs are bulky and unsightly, and these knobs wear out after long-term use, which affects their service life. The contact based rotary encoder knob is easily disturbed by the environment, such as water and dust. Contact based rotary encoder knobs are not practical in many scenarios. The price of these knobs can also be expensive. This document introduces a knob design based on the 3D Hall-effect sensor which can avoid the shortcomings of the above-mentioned designs. The 3D Hall-effect sensor has the advantages of small size, long life, low cost, and these sensors are not easily disturbed by the environment.

Figure 1-1. Knobs Used in Appliances

2 Using 3D Hall Sensor for Angle Measurement

TI offers several different types of Hall-effect sensors: switches, latches, single-axis linear, and 3D linear sensors. Linear Hall sensors output analog or digital signals, and when the strength of the external magnetic field changes, the output also changes. Unlike single-axis sensors, 3D linear sensors can use the magnetic field data from all three directions to calculate angle and magnitude. An integrated angle calculation engine (CORDIC) provides full 360° angular position information for both on-axis and off-axis angle measurement topologies, as seen in Figure 2-1. The angle calculation is performed using two user-selected magnetic axes. The three axes of sensitivity of a 3D linear Hall-effect sensor are defined as shown in Figure 2-2.

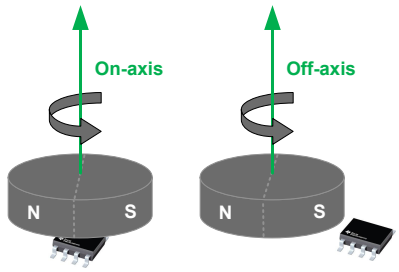

Figure 2-1. On-Axis and Off-Axis Angle Measurement

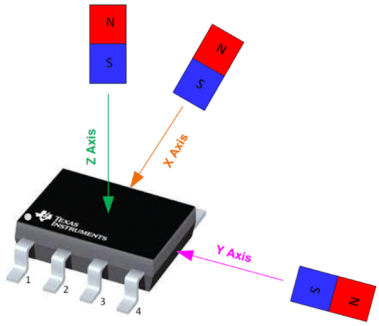

Figure 2-2. 3D Linear Hall-Effect Sensor Axis

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3 On-Axis and Off-Axis Test

As seen in Figure 3-1, by placing magnets in different positions, there are many ways to measure angles, such as in-plane, out-of-plane, on-axis test, and many others. Different placement methods have different requirements for the magnet. Users can choose the appropriate method according to various factors such as actual application scenarios, mechanical design, and installation position.

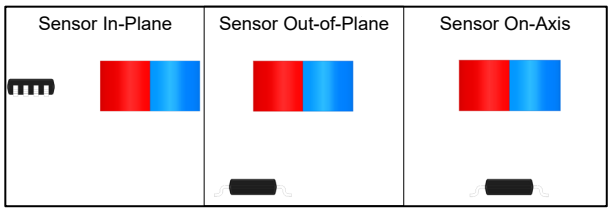

Figure 3-1. Configurations for Angle Sense With 3D Hall-Effect Sensors

3.1 On-Axis Test

Using the on-axis method, the magnet is placed directly above the sensor. As shown in Figure 3-2, the X and Y axes of the 3D Hall sensor are selected to determine the rotation angle of the magnet.

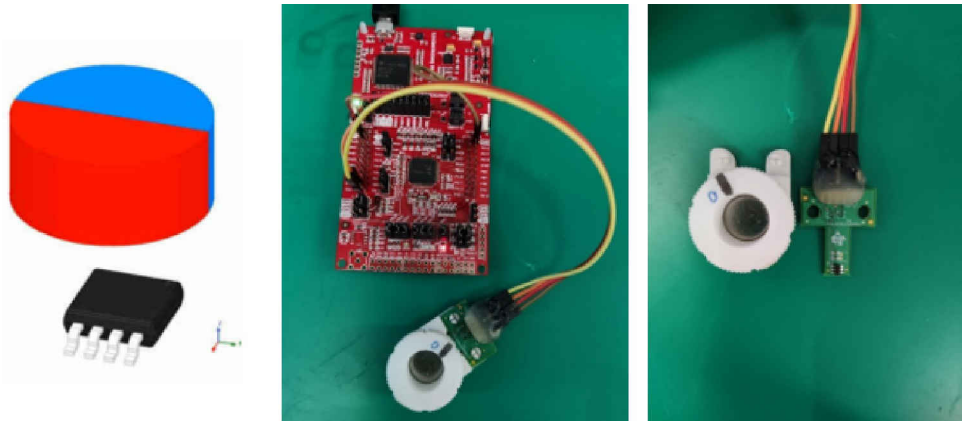

Figure 3-2. 3D Linear Hall-Effect Sensor On-Axis Test

The CORDIC engine of the TI 3D Hall sensors TMAG5273 and TMAG5170 calculates the angle seamlessly so the microcontroller can directly read the value of the register without processing the magnetic field data. Figure 3-3 shows the angle data and X and Y axes data in the actual test. Please note that the curve has a stepped shape due to manual turning of the knob.

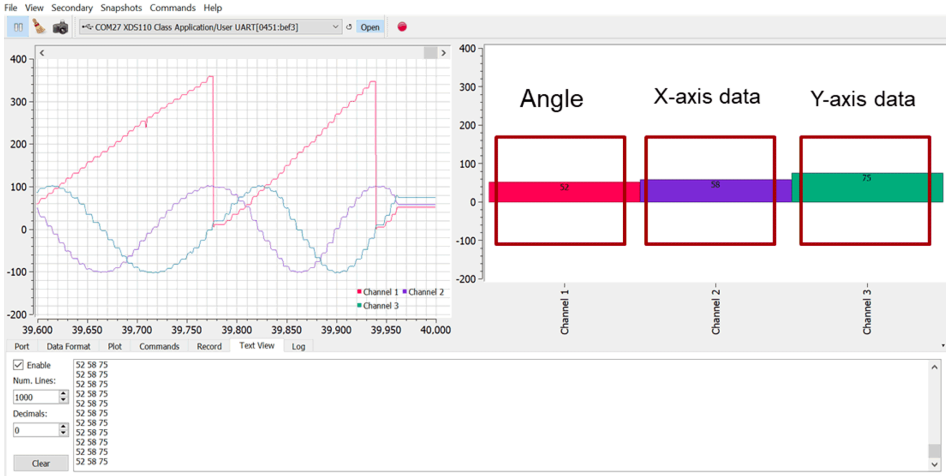

Figure 3-3. Angle Data and XY Axes Data Output

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When the magnet rotates, the X and Y axes of the magnetic field change in a sinusoidal mode. See Figure 3-4.

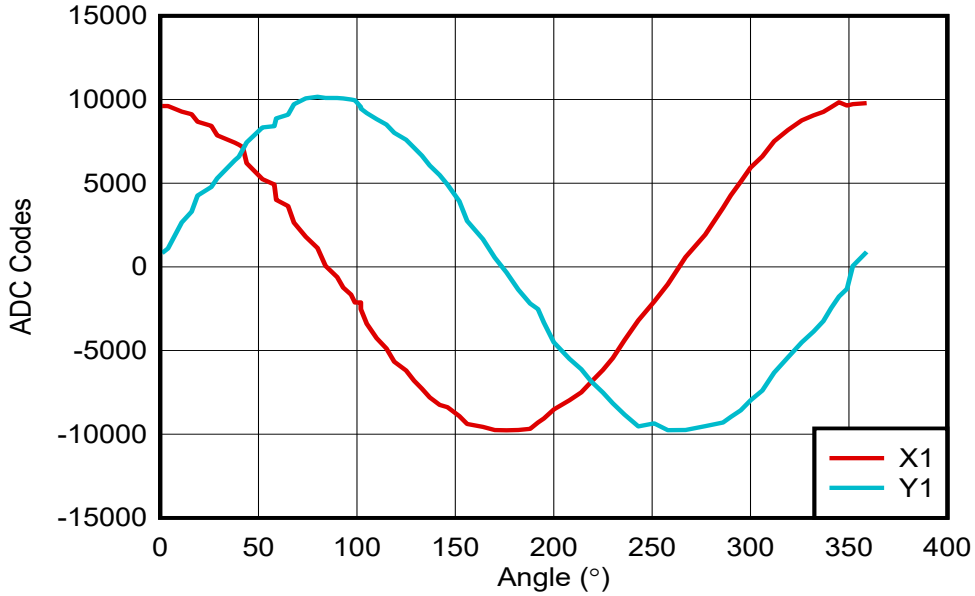

Figure 3-4. 3D Linear Hall-Effect Sensor On-Axis Output

3.2 Off-Axis Test

In the off-axis method, the magnet is not placed directly above the sensor, which can be any other position within reasonable proximity of the magnet. The placement is shown in Figure 3-5.

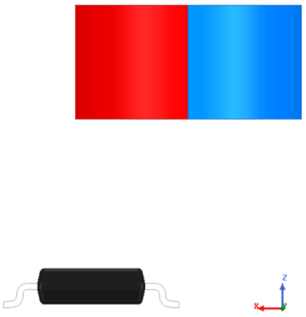

Figure 3-5. Off-Axis Placement

The output and angle changes of the X and Y axes are shown in Figure 3-6:

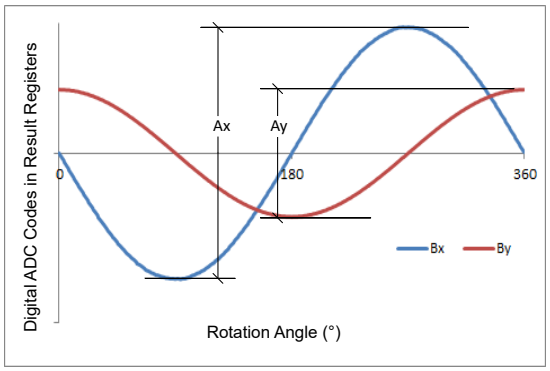

Figure 3-6. Linear Hall-Effect Sensor Off-Axis Output

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Considering the installation of knobs and magnets in use, out-of-plane measurement method is common; take the cook-top knob as an example, as shown in Figure 3-7. The Hall sensor is under the knob, and the magnet is inside the knob.

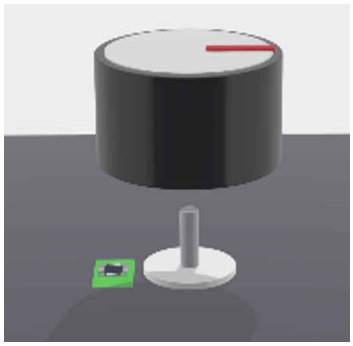

Figure 3-7. Magnet Angle and Hall Sensor

4 Push-Button Knob Function Test

In some application scenarios, detecting the knob angle is not the only need, sometimes users also need to add push-button functionality. Take the on-axis test as an example to demonstrate how to use the 3D Hall-effect sensor to realize the push-button function.

In on-axis test, the magnetic field strength of the z-axis is basically unchanged, so determining whether the knob is pressed or not can only be judged by detecting the change of the magnetic field of the X and Y axes. However, when the knob is rotated, the magnetic field of the X and Y axes are also changing, which can prove difficult for the user to distinguish whether the change is caused by pressing the knob or rotating the knob. However, in use scenarios, the X and Y axes change caused by rotation is still somewhat different from pressing, which can be judged by considering the following two points:

1. Absolute magnetic field strength: When the knob is pressed and rotated, their absolute magnetic field strength is different. We can set the magnetic field threshold to judge whether to press or rotate. However, this is related to the installation of the actual magnet, and cannot be regarded as a sufficient and necessary condition.
2. The sudden change of the magnetic field per unit time: Compared with normal rotation, when the knob is pressed, the sudden change of the magnetic field in the X and Y axes is larger.

Here we use a knob that can be pushed, as shown in Figure 4-1shows how to use a knob that can be pushed and placement of the 3D Hall sensor under the knob.

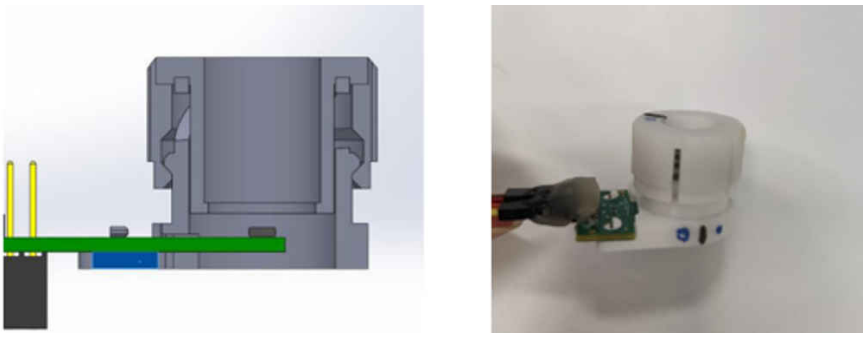

Figure 4-1. Push-Button Knob

Use the above knob to perform push button test and no push button test, and get the X and Y axes magnetic field data as shown in Figure 4-2. Users manually rotate the knob and use UART to receive data. Since the amount of data is not large, the curve is not very smooth.

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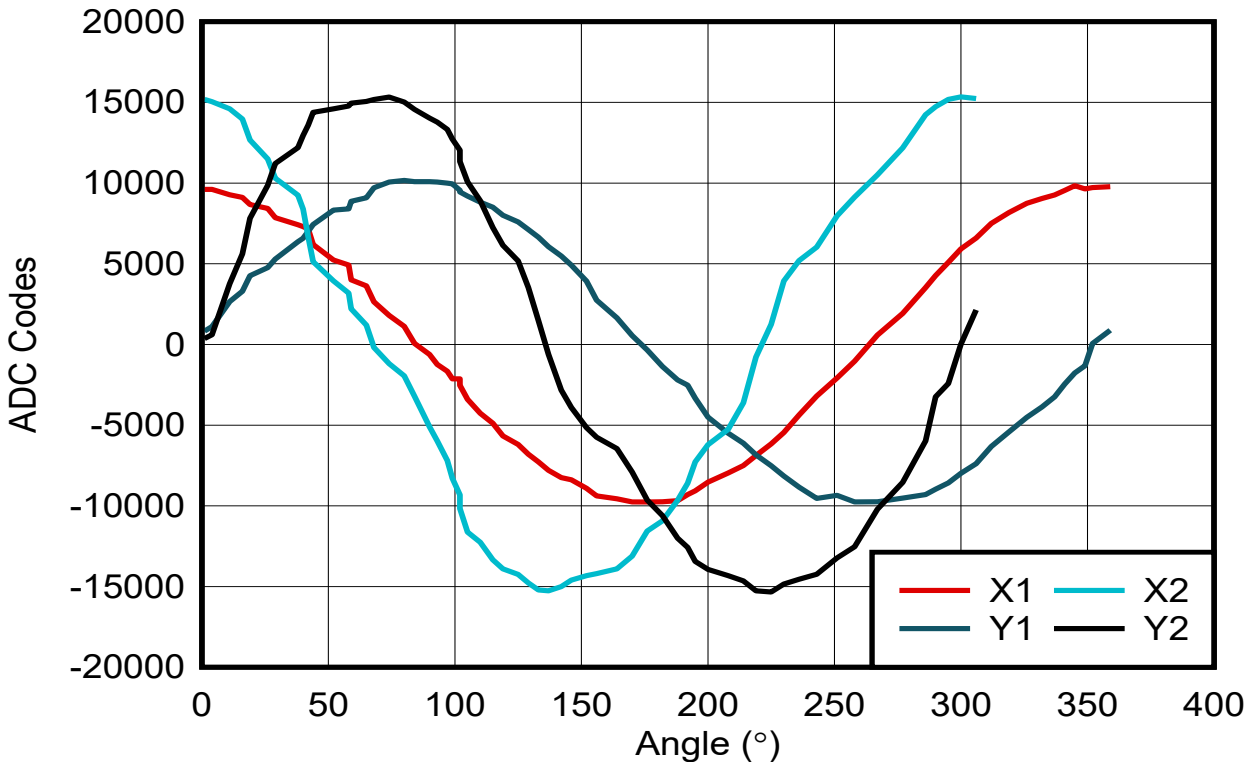

Figure 4-2. Push-Button Function Data Output

From the figure, we can come to the following conclusions:

1. No matter whether the knob is pressed or not, the trend of X and Y magnetic field changes is the same, which means that the obtained angle is also the same.
2. When the knob is pressed, the magnetic field strength of the X and Y axes is greater than when the knob is not pressed.
3. Press the button at any time, the sudden change of the magnetic field strength is pronounced.

The flow chart of the software implementation is showed as Figure 4-3:

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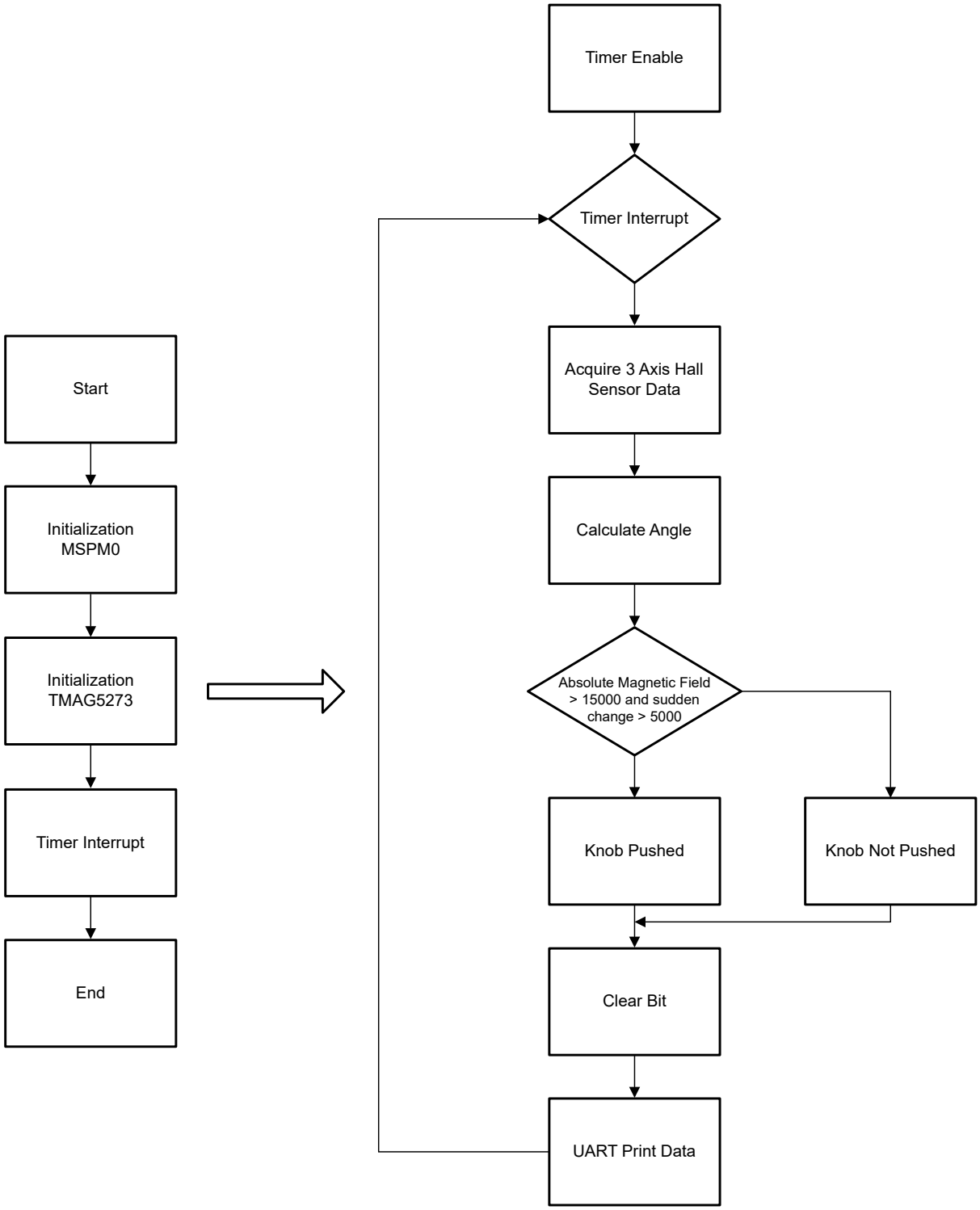

Figure 4-3. Push-Button Function Software Flow Chart

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5 Summary

TI 3D linear Hall-effect sensors such as the TMAG5273 and TMAG5170 can measure magnetic fields in three directions. These sensors can also calculate angles in any two axes using the on-board CORDIC calculator allowing the MCU to read the angle directly, save MCU resource and easy for customer to use.

Different measurement methods have different requirements for the placement of sensors and magnets. Customers can choose the appropriate measurement method according to their own application scenarios. Usually, in home appliances, the preferable method is to use TMAG5273 3D Hall effect sensors because of low cost, and the sensor's detection angle accuracy can reach 1° without considering the mechanical error, which can meet most home appliance scenarios.

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6 References

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