Laboratory for Electrical Instrumentation and Embedded Systems
IMTEK – Department of Microsystems Engineering
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Lab Report M2

Magnetic Sensors

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1 Introduction

Magnetic sensors are used to measure magnetic fields, that convert the magnitude and variations of a magnetic field into electrical signals. The development of magnetic field sensors has always been the pursuit of mankind. Today, magnetic sensors are used in a wide range of applications, from commercial machinery to complex aerospace and military applications [1]. In recent times, magnetic sensors are designed for detection of position, angle, rotation as well magnetic field subject to Hall. In this module, magnetic sensor in Arduino Nicla ME is used to calculate earth's magnetic field and sensor performance is analyzed.

2 Theory

The earth's magnetic field resembles that of a simple bar magnet. This magnetic dipole has its field lines originating at a point near the south pole and terminating at a point near the north pole shown in Figure 1. These points are referred to as the magnetic poles [2]. These field lines vary in both strength and direction about the face of the earth. In North America the field lines point downward toward north at an angle roughly 70º into the earth's surface. This angle is called the magnetic angle of inclination (Ø) and is shown in Figure 2. The direction and strength of the earth's magnetic field (H_e) can be represented by the three axis values H_x, H_y, and H_z. The H_x and H_y information can be used to determine compass headings in reference to the magnetic poles [3]. Earth's total magnetic field intensity is given by the equation (1).

$$|H_e| = \sqrt{H_x^2 + H_y^2 + H_z^2} \text{ ---- } (1)$$

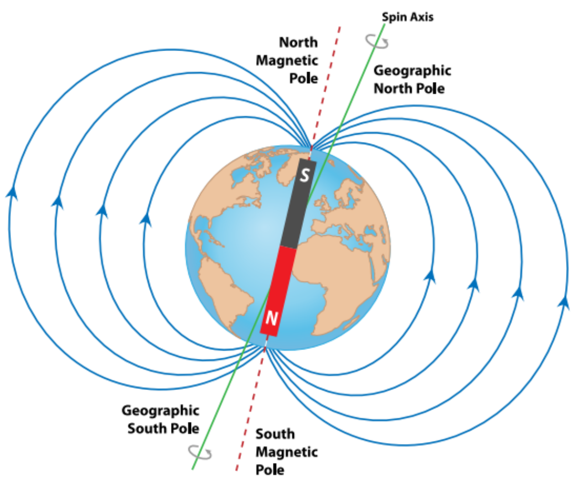

Figure 1: The earth's magnetic field forming the magnetic poles has an axis deviating slightly from the spin axis. The north magnetic pole (to which the north pole of a pivoted magnetic needle points) is a magnetic south pole [2].

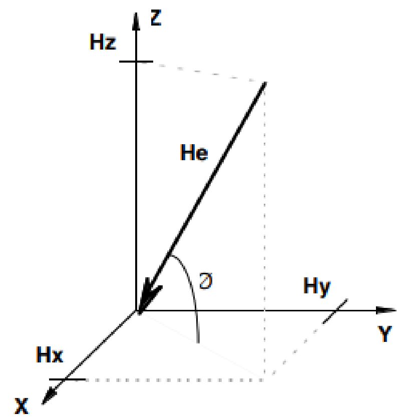

Figure 2: Earth's Field (H_e) in 3 Axis [3]

Magnetic compass is used for navigation and its magnetic needle is made of permanent magnet which is always aligned according to earth's magnetic field. A permanent magnet's magnetic field pulls on ferromagnetic materials such as iron and attracts or repels other magnets.

The International System (SI) unit of field intensity for magnetic fields is Tesla (T). Certain other non-SI units, like Gauss (G) are still occasionally used. The difference between Tesla and Gauss remains in the units used to define them. Thus, one Tesla equals 10000 Gauss (1T = 10000G), or one Gauss equals 0.0001 Tesla. Other units commonly used are micro Tesla (μT) and milli Gauss (mG). The magnetic field of one Tesla is quite strong.

The Earth's magnetic field is broken down into two main components: the horizontal component and the vertical component. The horizontal component is measured in the direction of the magnetic north and south, while the vertical component is measured in the direction of the magnetic up and down.

2.1 Magnetic Sensor

Magnetic sensors are devices that measure the magnetic field or magnetic flux in their surroundings. They are used in a wide range of applications, including navigation, industrial automation, consumer electronics, and scientific research.

Hall sensor is the most widely known magnetometer. Hall effect sensors are based on the Hall effect, which is the production of a voltage difference (Hall voltage) across an electrical conductor, transverse to the electric current and magnetic field. When the sensor is exposed to a magnetic field, it generates a measurable voltage difference that can be utilized to ascertain the intensity and orientation of the magnetic field. Hall effect sensors are commonly used for position sensing, current measurement, and proximity detection.

The flip core element technology simplifies the design of magnetic sensors by employing a thin-film core made of an iron-nickel alloy. This core is typically assembled as a stack of multiple layers, each having a thickness in the range of a few tens of nanometers and containing a single magnetic domain. Periodic excitation prompts the magnetization to flip between saturation states. When an external magnetic field is applied simultaneously with the periodic excitation, a delay is observed at the receiving coil. This delay eases the time measurement process, offering a simpler approach compared to the detection method used in fluxgate sensors [2].

The Flip Core principle is characterized by decreased power consumption and reduced noise levels in comparison to a Hall sensor. It can measure the magnetic field with high precision and sensitivity. This technology finds extensive applications in aerospace and automotive settings, particularly in scenarios where the sensor's size and power consumption are crucial factors.

2.2 BMM150

BMM150 is a low power, low noisy, 3-axis digital geomagnetic sensor that perfectly matches the requirements of compass applications shown in figure 3. It provides absolute spatial orientation and motion vectors with high accuracy and dynamics. The BMM150 is well-suited for providing precise heading support to drones. When combined with an inertial measurement unit comprising a 3-axis accelerometer and a 3-axis gyroscope, it enhances accuracy [4].

Figure 3: BMM150 package [4]

The BMM150 incorporates two Flip Core elements for capturing the in-plane magnetic field components and one Hall sensor for the vertical component. Each Flip Core element and the Hall sensor are equipped with their respective circuits, all of which share the same ADC shown in block diagram figure 4 [2].

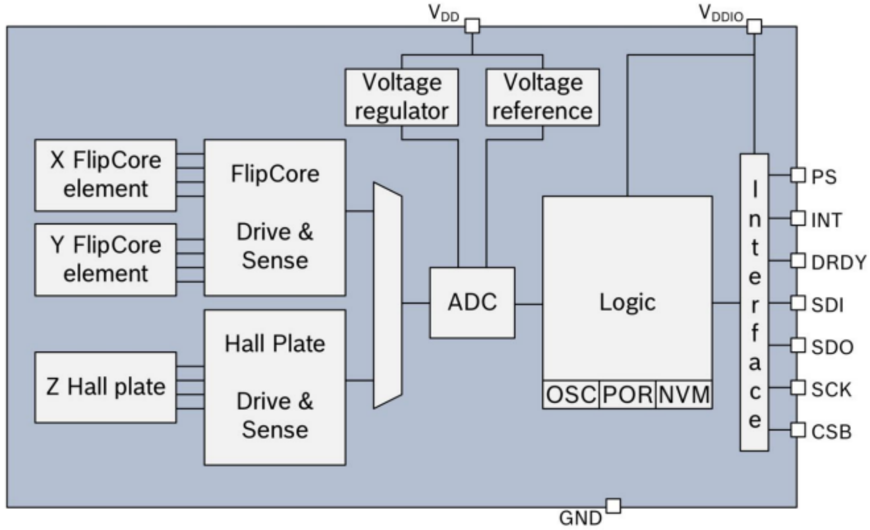

Figure 4: Block diagram of the BMM150 [2]

3 Methods

The Arduino Nicla Sense ME board is used in standalone mode, connected to laptop via USB and data is transmitted serially and data is acquired from all the sensors. The Arduino Nicla Sense ME board's integrated BMM150 magnetometer sensor is used in this module to calculate earth's magnetic field. This sensor is used in various experiments and data acquisition. The board is programmed using the Arduino IDE version 2.0 with the Arduino_BHY2 library version 1.5 (Bosch Sensortec).

Transmitted data from the Arduino Nicla ME is received and further processing and plotting is done by utilizing the pyserial library in Python. Arduino's built-in serial monitor is employed for basic data analysis and visualization. The Arduino program reads sensor using virtual sensor (SENSOR_ID_MAG_PASS) configured at a rate of 10Hz. The readings are taken for every 100ms and a total of 1000 values are documented.

In task 1, the sensor is kept in steady condition and the transmitted sensor readings are recorded using pyserial library in Python. The data is stored in NumPy array within a .npz file for further processing and plotting. Task 3 is similar to task 1 but carried out in an open environment.

In task 2, the sensor is first kept in steady state and 100 readings are recorded, then the sensor is flipped in both X and Y direction and again 100 readings are recorded. The data is then imported into a python script for calculation of mean before and after flipping and then the offset is calculated to process. The obtained offset is further used in Task 4 for calculating earth's horizontal, vertical, and total magnetic field for offset correction.

In task 5, the sensor is aligned to North direction with a straight street which is carried outdoor. The readings are taken then and B_y are measured and used to calculate the direction in degree.

4 Results and Discussion

Task 1

The performance of magnetic sensor is addressed in task 1, specifically the comparison of flip core and hall effect technologies. Arduino Nicla Sense ME is placed on flat board under steady condition to record the readings for 1000 samples in intervals of 100 ms and plotted on a graph where no significant drift is observed as shown in figure 5. Multiple iterations of 1000 readings are captured on monitor to observe drift in the value and only minimal decimal drift is noticeable when the sensor is at rest. The magnetic flux of the sensor output is in µT.

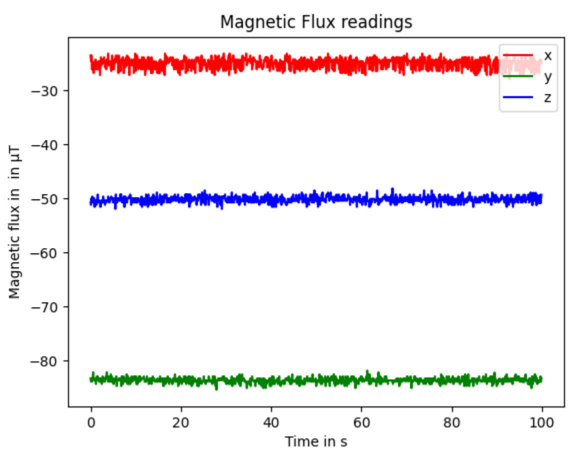

Figure 5: Magnetic Sensor readings for 1000 values

The mean and standard deviation is calculated and mean subtracted values are plotted to analyze the drift of the sensor over a number of samples in a stable condition. It is noted that the subtracted mean of all values is considerably small and falls within the acceptable tolerance range, indicating minimal noise levels.

The subtracted mean values vs frequency is represented through histograms shown below in (B_x - $\overline{B_x}$) in figure 6, (B_y - $\overline{B_y}$) in figure 7 and (B_z - $\overline{B_z}$) in figure 8. The histogram is plotted to show the deviation of the sensor readings from the mean value.

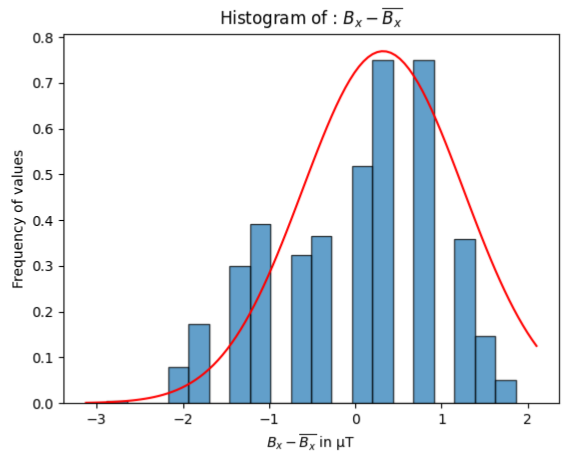

Figure 6: Histogram of B_x - $\overline{B_x}$

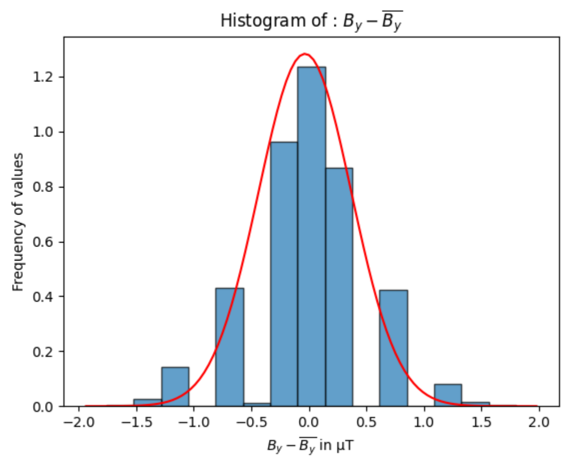

Figure 7: Histogram of B_y - $\overline{B_y}$

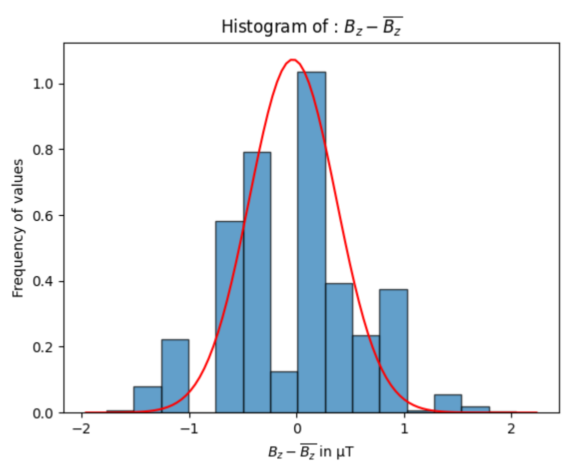

Figure 8: Histogram of B_z - $\overline{B_z}$

In the histogram of the mean subtracted data, most of the values lie around 0 in the mean subtracted histogram, which shows the samples don't drift much in the steady condition for X and Y with flip core technology but for Z, which relies on a hall sensor. The mean and standard deviation of all three directions, as measured, are presented in the below table 1.

Direction	Mean (μT)	Standard Deviation (μT)
X	-25.051	0.938
Y	-83.615	0.488
Z	-50.169	0.583

Table 1: Summary of the mean and standard deviation of 1000 values of magnetic sensor

Task 2

In Task 2 the Nicla Sense ME board is placed on flat board under steady condition and 100 readings are recorded. Then the sensor is flipped around 180º around X and Y in X-Y plane and again 100 readings are recorded to calculate offset of X and Y. To calculate the offset of Z, the sensor readings are recorded in steady state in Z plane and again flipped. The mean of 100 values before and after flipping are recorded in table 2, table 3 and the calculated offset of all three directions are recorded in table 4. The offset is later used for correction in further experiments.

Direction	Mean (μT)
X	-4.86
Y	-36.53
Z	-91.34

Table 2: The mean of 100 values before flipping

Direction	Mean (μT)
X	-66.46
Y	-77.28
Z	-15.78

Table 3: The mean of 100 values after flipping

Direction	Offset (μT)
X	-20.69
Y	-71.87
Z	-53.56

Table 4: Offset for correction

The offset values are slightly deviating from the standard values given in the BMM150 magnetometer datasheet [5]. The deviation in the values may be because the values given in the datasheet is for the temperature 25℃ which was not the same while conducting the experiment and there might be influence of nearby metals and improper alignment of sensor.

Task 3

Task 3 is similar to task 1 but is conducted in an outdoor environment avoiding metals and other parameters which might influence the sensors readings to calculate the earth's magnetic field shown in table 5. It is observed that the earth's magnetic field calculated in an outdoor environment is much weaker than the earth's magnetic field calculated with other influences like metals etc. The mean and standard deviation for 1000 values is calculated.

Direction	Magnetic intensity (μT)
X	0.72 ± 0.50
Y	20.39 ± 0.61
Z	-45.09 ± 0.72

Table 5: Magnetic intensity of all three axis

Task 4

A comparison between the anticipated and computed values of B_{hor}, B_{vert} *and* B_{total} are recorded in table 6 below. It is seen that there is a deviation from the expected value [6]. It may be because of misalignment of the sensor or due to the influence of surrounding metals on magnetic field.

Values	B_{hor} (μT)	B_{vert} (μT)	B_{total} (μT)
Expected	21.24	43.52	48.43
Calculated	20.41	45.09	49.49

Table 6: Comparison of expected and calculated values of B_{hor}, B_{vert} and B_{total}

Task 5

The experiment is carried out by placing the sensor in the north direction which is shown from the satellite image of Google Earth Pro. The sensor deviation of 2.02° is observed but the expected deviation at the location of experiment is 3.24° according to national centers for environmental information [6]. A small difference between expected deviation and calculated deviation is observed and it might be due to magnetic heading accuracy which is $\pm 2.5°$ according to the BMM150 magnetometer datasheet [5].

5 Summary

The sensor readings indicate precision and lower noise levels in the X and Y directions, utilizing Bosch's flip core technology compared to the Z direction, which relies on a hall sensor. A slight variation in readings observed outdoors shows that the Earth's magnetic field is weak compared to local magnetic fields influenced by metals nearby.

The results demonstrate that B_{hor}, B_{ver}, and B_{total} values closely align with the expected values, with only minor deviations noted. Additionally, a slight magnetic deviation of 2.02° was observed at the experimental location.

References

[1] https://www.ablic.com/en/semicon/products/sensor/magnetism-sensor-ic/intro3/ (Accessed – 10 Jan 2024)

[2] J. Kieninger, S. J. Rupitsch, Sensors Lab Course. University Freiburg. Winter term 2023/24 (Accessed – 10 Jan 2024)

[3]https://aerospace.honeywell.com/content/dam/aerobt/en/documents/learn/products/sensors/application-notes/AN203_Compass_Heading_Using_Magnetometers.pdf (Accessed – 10 Jan 2024)

[4] https://www.bosch-sensortec.com/products/motion-sensors/magnetometers/bmm150/ (Accessed – 11 Jan 2024)

[5] https://www.mouser.com/datasheet/2/783/BST_BMM150_DS001-1509615.pdf (Accessed – 12 Jan 2024)

[6] https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml (Accessed – 12 Jan 2024)