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Calibration of Magnetic Field Sensor Data Using Flight Results

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Abstract

It is important to decrease the angular velocity of the satellite to perform most of the missions. This study used active stabilization method in a 1U CubeSat. CubeSats have limited space, mass and power. For the active stabilization, low power magnetic torquers which were implemented in printed circuit boards (PCB) to save the volume were used. B dot algorithm was used to stabilize the satellite. Magnetic field data measured by the magnetometer is a key factor when it comes to B dot algorithm. This paper discusses about the flight results from the magnetometer and the variations seen in the results. Magnetometer results might be different from the expected, due to non- orthogonality errors, scaling factors, offsets etc. Mainly this papers presents about the magnetometer data calibration using on orbit results. This system was applied in BIRDS-3 satellite project where three CubeSats were deployed to the orbit on 17th June 2019 from International Space Station (ISS).

Keywords: Magnetic Field, CubeSat, Magnetometer, Attitude Stabilization, Flight results

Acronyms/Abbreviations

ISS: International Space Station
ADCS: Attitude Determination and Control System
MTQ: Magnetic Torquer
PCB: Printed Circuit Board
RAB: Rear Access Board
FAB: Front Access Board
WMM: World Magnetic Model

1. Introduction

This paper presents the on-orbit magnetometer data in the BIRDS-3 CubeSat project. This paper discusses about on-orbit magnetometer data, the issues found in the on orbit data and the proposed method of calibrating the on orbit data. BIRDS-3 is the third project under BIRDS program [1,2]. BIRDS-3 CubeSats were deployed to the orbit on 17th June 2019 from International Space Station (ISS). BIRDS-3 is a collection of three CubeSats belonging to Sri Lanka (Raavana-1), Nepal (NepaliSat-1) and Japan (Uguisu). BIRDS-3 CubeSats are being operated by the BIRDS ground station network [3]. Figure 1 shows the flight models of the BIRDS-3 CubeSats.

BIRDS-3 has four missions. They are Camera mission (CAM), LoRa Demonstration Mission (LDM), Attitude Determination and Control System (ADCS) and the Software Configurable Backplane mission (BPB). BIRDS-3 CubeSats have two mission boards named as Mission Board-1 and Mission Board-2. ADCS and CAM are installed in the Mission Board-2. LDM is installed in the Mission Board-1. Magnetometer is installed in the Mission Board-2.

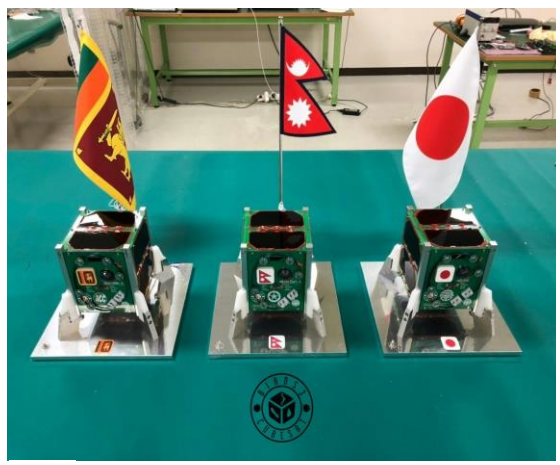


Fig. 1. Flight Model of BIRDS-3 CubeSats

Magnetometer is a common sensor that most of the satellites use. Mostly magnetometer data are used in Attitude Determination and Control Systems in the satellites. In BIRDS-3, magnetometer data are used in Attitude Determination and Control System. ADCS has magnetic torquers (MTQs) that are implemented in the Printed Circuit Boards (PCBs). These MTQs are controlled by the B dot algorithm. Magnetometer data are the key input to the B dot algorithm. But some magnetometers don't give the expected results due to errors such as non-orthogonality, offsets or scaling factor errors. Thermal stress or production faults can cause the non-orthogonalities that can be interpreted as angular deviations from quite orthogonal three-axis layout. These errors can be introduced as instrumental errors. Due to offsets and scaling factors, measured values from the magnetometer can be different from the datasheet. Also soft iron errors and hard iron errors can also cause the magnetometer readings. Soft iron errors can cause due to the reactions of the materials to the extrinsic fields. Hard iron errors can be defined as, in consequence of ferromagnetic materials or current-transmitting wires near the magnetometer.

2. Attitude Determination and Control System

Stabilizing the CubeSat's attitude by the active control is the main objective of the ADCS mission. Main parts in the ADCS are shown in the following table 1.

Table 1. Parts in ADCS

System	Sensor/Method used
Sensors	Magnetometer
	Gyroscope
	GPS
Algorithm	B Dot
Actuator	Magnetic Torquer

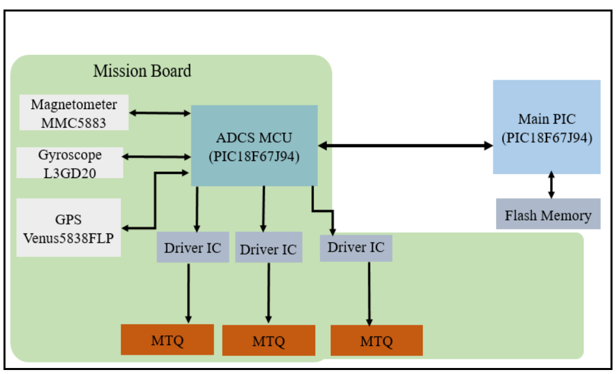


Fig. 2. Block Diagram of ADCS

The above figure 2 shows the block diagram of ADCS mission in BIRDS-3. ADCS MCU collects the data from the sensors and sends the data to Main PIC. Main PIC saves the data in the flash memory.

PIC18f67J94 is the microcontroller which is used in ADCS in BIRDS-3. The other components used in ADCS are as follows.

Table 2. Components used in ADCS

Component	Model name
Magnetometer	MMC5883MA
Gyroscope	L3GD20
GPS	Venus838flp
Driver IC	A3901

The magnetometer used in this study is a digital sensor. The range of the magnetic field that can measure using this sensor is ±8G. The current of the MTQs are controlled by the driver ICs. The following figure 3 shows the Mission Board-2 and the ADCS components.

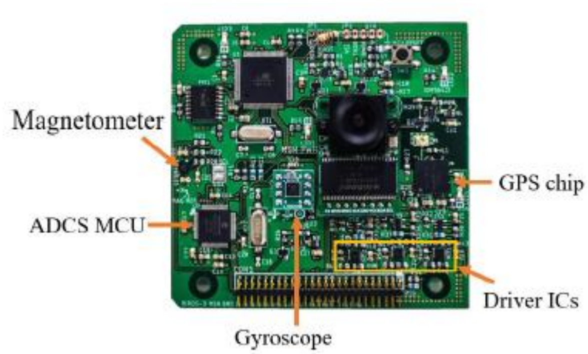


Fig. 3. Mission Board 2 with ADCS Components

MTQs are located in the –X, -Y and –Z sides of the CubeSat. –Y and –Z are solar panel boards while –X is the Rear Access Board (RAB). These PCBs has four layers. In each PCB, layer two and layer three are used for MTQs. Each MTQ has 100 turns. The following figure 4 shows the location of MTQs in the Cubesat.

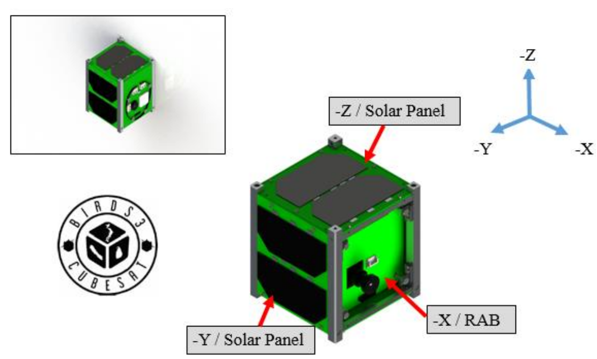


Fig. 4. Locations of the Magnetic Torquers

3. Calibration of the Magnetometer

In this section ground calibration results before deploying to the orbit and the on orbit variation will be discussed.

3.1 Ground Calibration

As the magnetic field measured by the magnetometer was incorrect, the magnetometer was calibrated in the ground first. Magnetometer calibration was done using Helmholtz Coil at the test facility belongs to Kyushu University. The following figure 5 shows the test setup. Power supply and the laptop were kept outside the Helmholtz coil. Magnetometer readings were taken to the laptop using a serial cable. First we checked the initial values of the magnetometer. Initial value of X axis was 616.48mG, Y axis was -1004.71mG and Z axis was 879.64mG.

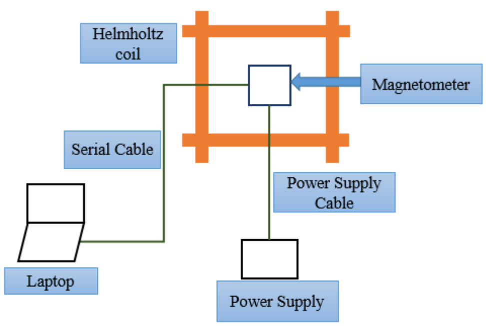


Fig. 5. Test Setup

Next, a known magnetic field values were created by the Helmholtz coil and checked the readings from the magnetometer. Sampling frequency of each graph is 1s. ±250mG and ±500mG was given to each axis to check the magnetometer readings. In each graph below, the readings when ±250mG was given are marked in black boxes.

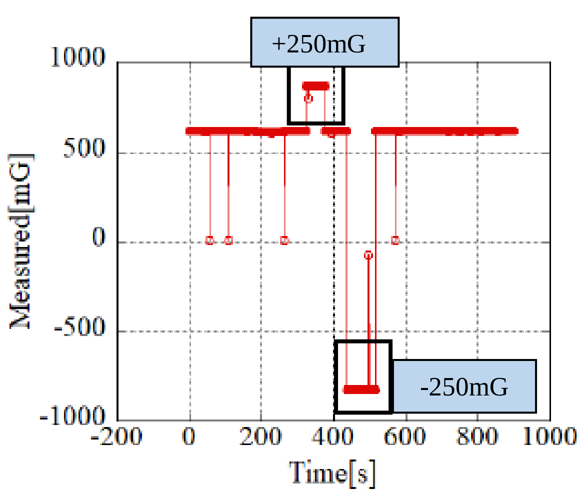
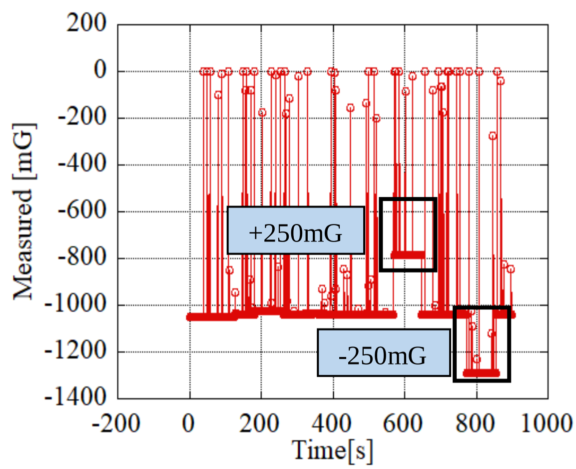


Fig. 6. X axis ±250mG readings

The above mentioned figure 6 shows the X axis values when the ±250mG was given by the Helmholtz coil. Initial value for X axis is around 616.48 mG. When the +250mG was given, magnetometer reading was around +860mG. When the -250mG was given to the X axis, the reading dropped down to the -800mG. Same experiment was repeated to all three axis of the magnetometer. Figure 7 shows the results of Y axis when ±250mG was given. As mentioned above the initial value of Y axis was -1004.71mG. When +250mG was given to the Y axis, the value reached up to around -800mG. Moreover, when -250mG was given value was reached to -1300mG.



. Fig. 7. Y axis ±250mG readings

The figure 8 shows the results of the magnetometer's Z axis after giving ±250mG. Initial value of Z axis was 879.64 m. When the +250mG was given the value was reached to around +1100mG. When the -250mG was given, value was reached to 600mG. We observed that each axis readings got some noise and that is the reason of the spikes in the graphs.

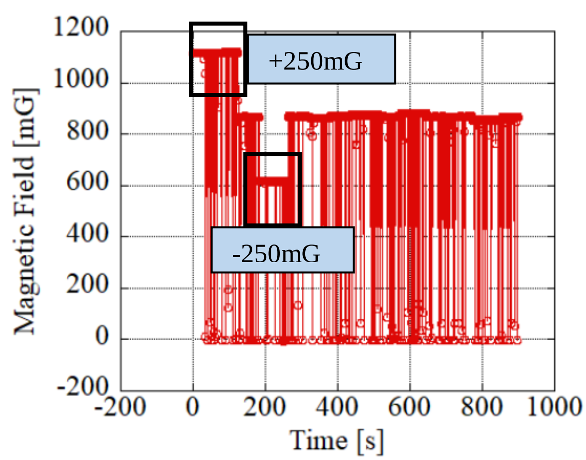


Fig. 8. Z axis ±250mG readings

To find the error in the magnetometer, we increased and decreased the magnetic field gradually. The figure 9, 10 and 11 shows the results of each axis when the magnetic field was gradually increasing and decreasing. The readings start from the initials value of the each axis. Sampling frequency of each graph is 1s. We found a sudden drop in the reading when we were doing this test.

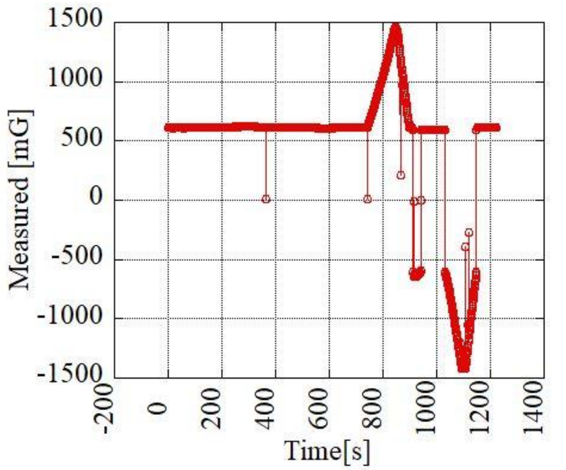


Fig. 9. X axis gradually increasing and decreasing

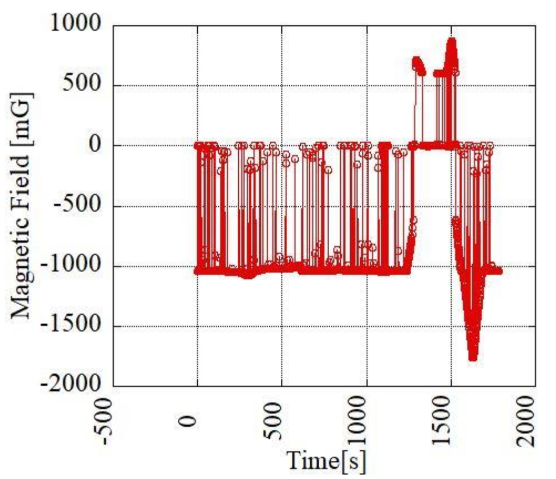


Fig. 10. Y axis gradually increasing and decreasing

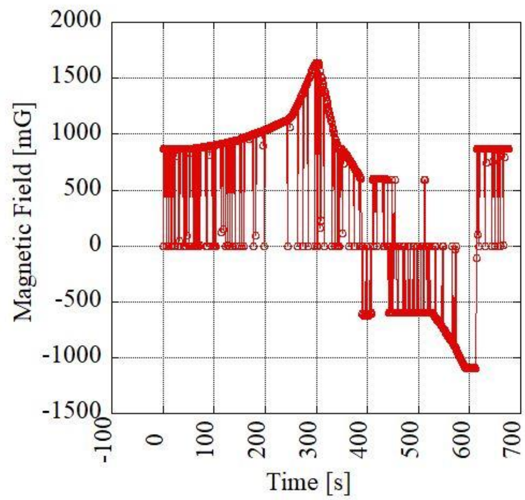


Fig. 11. Z axis gradually increasing and decreasing

After finding the error in the magnetometer, the code was corrected. Again we increased and decreased the magnetic field gradually to check whether there are more errors.

Next, we measured the values for the calibration of the magnetometer. This is the last step in the magnetometer calibration process. During this test one magnetic field value was given for 60 seconds and the coil was switched off for 60 seconds. The generated magnetic fields were, from -600mG to +600mG (±200mG, ±400mG, ±600mG). The average of 60 data points was taken in each value. The following figures 12, 13 and 14 shows the magnetometer reading results of X, Y and Z after the calibration. This calibration was done to the ground back up magnetometer.

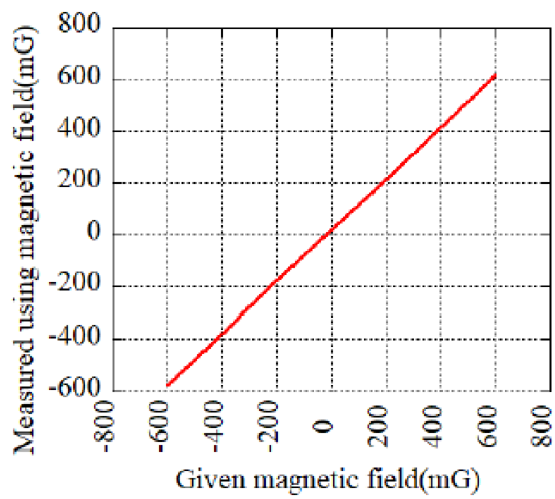


Fig. 12. X axis Calibration results

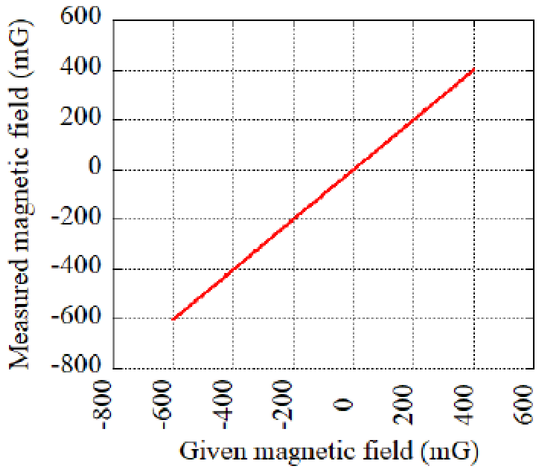


Fig. 13. Y axis Calibration results

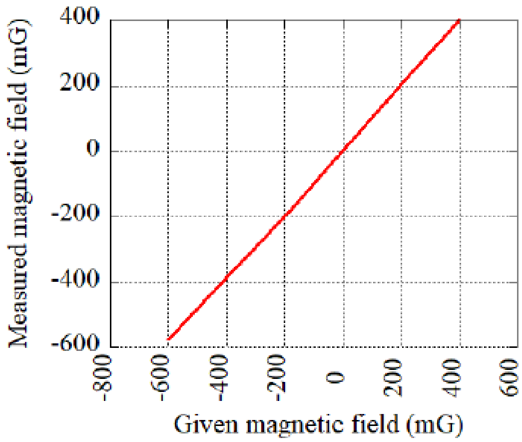


Fig. 14. Z axis Calibration results

Accuracy of each axis can be calculated using the following equation.

$$\text{Accuracy} = \frac{(\text{Given[nT]} - \text{Measured[nT]})}{\text{Given[nT]}} * 100\% \qquad (1)$$

Accuracy of X axis is 1.20%, accuracy of Y axis is 0.40 % and accuracy of Z axis is 1.40%.

3.2 On-Orbit data and Calibration method

After BIRDS-3 CubeSats were deployed to the orbit high sampling mission was started after 16 seconds. High sampling is a mission to collect the sensor data from ADCS and FAB (Front Access Board) in every five seconds. ADCS data includes the gyroscope, magnetometer and GPS data. The following figure 15 shows the magnetometer data which were collected by all three CubeSats after the deployment from ISS. The zero of the time axis corresponds to the 16 seconds after the deployment from ISS.

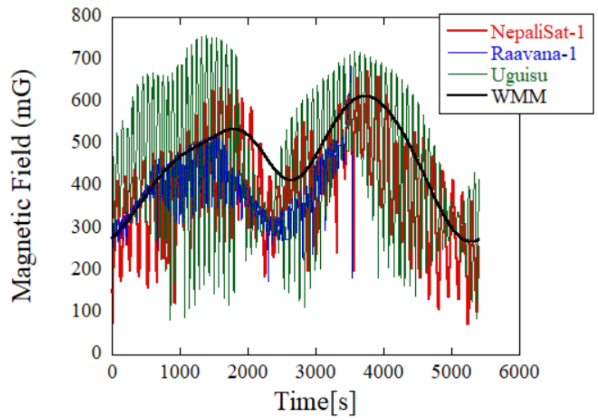


Fig. 15. On Orbit Magnetometer data

The measured magnetometer data are compared with the WMM (World Magnetic Model). In the above picture it shows the difference between the on-orbit measured data and the data created by WMM. There is a heavy variation in the on orbit magnetometer data in all three CubeSats. It is required to correct the error created by the magnetometer data.

Magnetic torquer in Uguisu was switched on. But due to the incorrect magnetometer data, MTQ was not successful. The following figure 16 shows the kinetic energy difference in the beginning of the mission and the end of the mission. As mentioned above B dot algorithm was used to control the magnetic torquers. Magnetic field values are the key input for the B dot algorithm.

$$M = -K\,\dot{B} \qquad (2)$$

M is the magnetic Moment, B is the magnetic field and K is the positive scalar.

$$\dot{B} = \frac{B_1 - B_0}{\Delta T} \qquad (3)$$

B_1 and B_0 are magnetic field flux density values measured at a given sampling rate. T is the time. If the magnetic field values are incorrect, the current flows to the MTQ will be incorrect too.

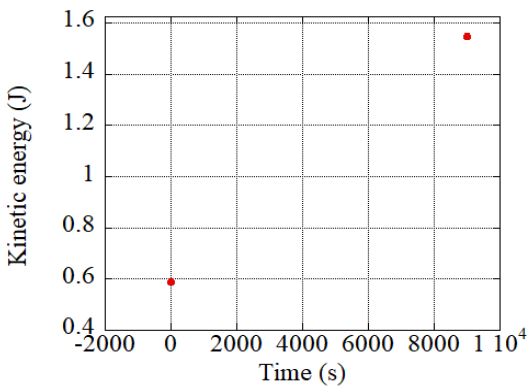


Fig. 16. Kinetic energy difference

The proposed method to correct the data is by genetic algorithm.

Genetic algorithms can provide good solutions following the natural selection and reproduction. Genetic algorithm gives finest solution for a given problem. The following variables are considered in this study. B_x, B_y, B_z as the real magnetic field data and B_x', B_y', B_z' as the measured magnetic field data by the magnetometer. Offsets are represented by x, y and z and a, b, c are the scaling factors. The below equations shows the relationship between real magnetic field data, measured magnetic field data, scaling factors and offsets.

$$\acute{B_x} = aB_x + x \quad (4)$$

$$\acute{B_y} = bB_y + y \quad (5)$$

$$\acute{B_z} = cB_z + z \quad (6)$$

The fitness function that is used in this study to find the unknowns, is given below. In the fitness function "y" is the error between the measured magnetometer values and the real magnetic field. WMM data are considered as the real magnetic field values in this study.

$$y = (B_x - \acute{B_x})^2 + (B_y - \acute{B_y})^2 + (B_z - \acute{B_z})^2 \quad (7)$$

Finding the best match for above variables are still being done.

5. Conclusions

This paper discussed about BIRDS-3 Attitude Determination and Control System, On-Orbit Magnetometer Data and Proposed Calibration method. BIRDS-3 is a project where three CubeSats were built and deployed to the orbit on 17th June 2019 from International Space Station. These CubeSats will be operated until End of Life (EOL)

Main Objective of ADCS is to stabilize the Cubesats using low power magnetic torquers. The magnetometer was calibrated in a ground test facility. The paper shows the calibration results of the ground back up magnetometer. The on orbit magnetometer results shows some variation in all the CubeSats. The On Orbit data were compared with the World Magnetic Model data. Genetic Algorithm will be used to correct the error in on-orbit magnetic field data. The results after applying the algorithm will be reported in future.

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