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Discussions

Magnetogama : An Open Schematic Magnetometer

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Abstract. Magnetogama is an open schematic hand-assembled fluxgate magnetometer. Compared to other magnetometer, Magnetogama is superior in terms of its price and its ease of use. Practically Magnetogama can be used either in land or attached to unmanned aerial vehicle (UAV). Magnetogama was designed in order to give an open access to a cheap and accurate alternative of magnetometer sensor, therefore it can be used as standard design which is directly applicable to low budget company or education purposes. Schematic, code and several verification tests were presented ensuring its reproducibility. Magnetogama has been tested with two kind of tests, diurnal variation comparison with two nearest observatorium at Learmonth (LRM) and Kakadu (KDU).

1 Introduction

Magnetometer is a device which can record magnetic field at the specific location where the measurement is conducted. Several types of magnetometer present; such as proton precession magnetometer (PPM) (Serson, 1962; Tyagi et al., 1983), fluxgate magnetometer (Primdahl, 1979), superconducting quantum interference device (SQUID) (Drung et al., 1990; Fagaly, 2006; Cleuziou et al., 2006) and hall magnetometer (Peeters and Li, 1998). Fluxgate magnetometer has advantages over PPM since it measures magnetic field amplitude along with the direction and has a higher sampling rate. With the main purpose of measuring earth magnetic field, fluxgate magnetometer has sufficient accuracy in a compact form; SQUID magnetometer on the contrary needs liquid helium to operate, despite its very high accuracy.

Geophysicist needs a magnetometer which is portable with sufficient accuracy. PPM and fluxgate magnetometer are two type of magnetometer which meets those criteria. Commercially available magnetometer is usually already equipped with their own datalogger and acquisition system. Those magnetometers has been calibrated, tested and ready to be used in exploration scale with sufficient accuracy and stability. Unfortunately with all those benefits, the price is usually quite expensive. This aspect is disadvantageous for the one who start to learn geomagnetic method for educational purposes.

Magnetogama is a device which combines proprietary fluxgate magnetic sensor with widely available microcontroller and analog to digital converter (ADC). It has open schematic, algorithm and source code enabling everyone to build their own version of magnetometer. Magnetogama are easy-to-assemble and beneficial compared to the other complete proprietary magnetometer in terms of price and suitability either for general or unmanned aerial vehicle (UAV) magnetic survey. Magnetogama

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is designed to be as efficient and effective as possible. Beside its advantage on accurate reading, Magnetogama also has friendly, easy-to-use interface. Magnetic reading and location data can be stored automatically on non-volative memory.

2 Components

In order to properly function as complete magnetometer, there are at least six main components needed to be assembled. The components consist of magnetic sensor, microcontroller, analog to digital converter, data storage, positioning device, power supply and user input/output.

2.1 Fluxgate FGM3D/100 Sensor

Fluxgate magnetic sensor is the main component on this magnetometer. Choosing lightweight sensor with sufficient accuracy, low powered and less prone to error sensor is a keypoint in this consideration. FGM3D sensor from SENSYS GmbH (Figure 1) has several advantages including its waterproof (IP65 certification) and all-weather measurement condition. FGM3D fluxgate magnetometer sensor is three-axis sensor with core ring type equipped with feedback system. Receiving magnetic field as its input, this sensor output three channels analog signal. Each channel represent vector component from input magnetic field vector. This transfer function has sensitivity as small as 0.1 mV/nT with range from -10 to 10 V.

2.2 Microcontroller

Microcontroller is the main processor and hub of the whole system. All hardware are assembled and connected through this microcontroller. Software which manages acquisition are also installed on this microcontroller. Arduino platform is one of the most popular and easy to use programmable microcontroller. Utilizing programmable microcontroller ensures easy reproducibility. Arduino Mega 2560 R3 is the one used on this acquisition system. Arduino Mega 3560 R3 is development board with ATmega2560 microcontroller as its core. It is equipped with 54 digital I/O (input/output) pin, 16 ADC, 4 serial gate, 16 MHz crystal oscillator, USB gate, a power jack and reset button, therefore it has enough port to connect with other devices for this purposes. ATmega2560 has 8-bit architecture and capable to work up to 16 million execution in one second.

2.3 Analog to Digital Converter

Output signal from fluxgate sensor are in the form of analog signal. In order to be recorded, processed and displayed digitally an analog-digital converter is required. The output signal from sensor FGM3D is three differential analog signal, therefore an Analog to Digital Converter (ADC) which has at least three differential channel is needed. This keypoint factor requires ADC with sufficient bit resolution and differential channel support to be paired with FGM3D. ADC ADS1256 24-bit from Texas Instrument has been chosen for its high bit resolution, differential channel support and very low internal noise. It is known from the datasheet that there are 18 from 24 bit output from this ADC which are freed from internal noise.

2.4 Data Storage and Positioning

Data storage is an important factor on acquisition system to store output data from ADC to non-volatile memory, therefore no data lost will occur when the device is turned off. Getting and storing location data of the measured point in real world coordinate is also one of important aspect we need to consider. ITEAD GPS shield has all both capabilities regarding to storage and positioning system. It has one micro-SD slot and GPS receiver. Digital data from ADC and GPS is written by the shield which continuously parsing GPS data and communicating with microcontroller through serial connection into memory card.

2.5 Power

Compatible battery was chosen based on power consumption ensuring the time needed for acquisition. Another consideration is weight. Generally, battery is heavier than any other parts; luckily its capacity is usually proportional to its weight. Due to the plan to mount this acquisition system to UAV, the battery needed to be as light as possible. Lithium polymer battery is chosen to be used on this devices. The whole set of parts require two battery input, the first supplies FGM3D sensor and the second supplies microcontroller and any parts connected directly to microcontroller.

The first power supply consist of two 4C 14.8V lithium polymer battery in serial configuration in order to supply positive and negative voltage required by FGM3D. Each of this battery has 1300 mAh capacity. The first power supply is connected to LM7812 and LM7912 as voltage regulator to stabilize input power on ± 12 Volt. The second power supply uses a bigger capacity of 2200 mAh 7.4V 2C lithium polymer battery to power microcontroller along with ADC, GPS and storage shield. No external voltage regulator is required for the second power supply since the internal 5V voltage regulator in Arduino Mega 2560 can be used for this purposes.

2.6 Display and input

Display on magnetogama is used to communicate between device and user. During the old days, simple dot matrix display which can only display numeric/character information is sufficient, but it is not intuitive enough toward the user. This magnetometer is designed not only to be simple but also as interactive as possible, therefore more complex LCD is used. LCD Nokia 5110 is used considering its simplicity and its ability to communicate with user with more complicated graphic or text. It has 84×48 pixel resolution utilizing PCD8544 controller which was also used on old Nokia 3310 LCD. This LCD is easy to use and suitable for simple project as presented on Wagh et al. (2014). User input is provided using 3×4 membrane keypad.

3 Schematic and Assembly

Microcontroller, magnetic sensor and all parts are assembled following block diagram and electronic schematic given on Figure 2 and 3 respectively. The assembled Magnetogama can be seen on Figure 4. It is important that additional external case is needed in order to protect the device and perform magnetic survey easily. Case were made from ABS plastic and acrylic as shown on Figure 5. With the included acrylic case, Magnetogama weights at 1 kg and has dimension of $116 \times 200 \times 65$ mm.

With given assembly setting and battery, it can last 10 hours 20 minutes on full acquisition time, which is sufficient for typical one day acquisition.

Those electronic components inside the case contain material that are prone to magnetic induction. As a consequence, it may affect the sensor reading and can not be neglected if located at a close distance from the sensor. Hence, the sensor is connected through 3 meters cable from the case to the sensor. It is important to set apart the sensor and the case at maximum distance allowed by the cable. Figure 6 shows relative influence of the assembled electronic components to sensor reading in various distance. The data points are fitted to exponential equation as shown with solid line. The magnetic signature of electronic component starts to have significant deviation at 260 cm. Therefore, the magnetic reading should not be affected at a minimum distance of 260 cm.

4 Remote Control

Magnetogama can be controlled locally via its membrane keypad or remotely using wireless serial interface. The wireless interface is switchable between Bluetooth and Radio. An android based device is used to control Magnetogama via Bluetooth interface. For Radio interface, a 915MHz radio receiver and transmitter is used to control Magnetogama via a special PC software developed in this research.

5 Verification

5.1 Comparison with standard magnetometer

The first step of calibration were performed by comparing continuous measurement recorded with Magnetogama with continuous data from standard magnetometer near the location of the test. Two standard magnetometer observatoriums located at Learmonth (LRM) and Kakadu (KDU), Australia were selected as comparison. The test were performed from UTC 12:00 February 8th 2016 to UTC 12:00 February 8th 2016. The test used 0.2 Hz sampling frequency resulting in 691200 points recorded for each components. FGM3D sensor was attached on non-magnetic tripod using acrylic mounting. The sensor orientation was then set up so that X-axis points to north, Y-axis to east and Z-axis downward.

Prior to direct comparison, noise reduction on tested Magnetogama were carried out. The noise reduction refer to international geomagnetic observatory organization (INTERMAGNET) technical reference manual. It is achieved by applying series of coefficients of a Gaussian filter to the data samples. Those series of coefficients listed on INTERMAGNET Technical Reference Manual. This digital filter also applied on both standard magnetometer. Figure 7 shows comparison between original and filtered Magnetogama magnetic field data record.

Figure 8 display a direct comparison between data recorded on Magnetogama (YOG) and two other reference stations (LRM and KDU). Due to longitude difference that causes difference in time and relative sun position, cross-correlation analysis were performed in order to estimate diurnal variation pattern. This cross-correlation analysis was aimed to determine signal delay from diurnal variation towards recorded data due to sun's relative position. Based on cross-correlation analysis, YOG-LRM has 41% correlation coefficient and YOG-KDU has 72%. This result is sufficient considering huge separation distance between those two stations. Therefore, local disturbance has the main effect on recording result.

5.2 Response test toward magnetic substance

Response test toward magnetic substance was performed by comparing Magnetogama with standard magnetometer. In this case, Proton Precession Magnetometer (PPM) from Geotron G5 was used as comparison. Magnetometers were located at x = 0 m, with some variation on y direction (0.5, 1, 1.5 and 2 m). Magnetic object (a motor scooter) was initially located at x = -10 m then moved 1 m for each measurement toward x direction until reaching x = 10 m (See Figure 9 for detailed illustration). Magnetization level due to magnetic object is inversely proportional with the square of its distance and reaching its maximum when magnetic substance was located at x = 0 m (Figure 10).

Figure 10 also depicts sensor's sensitivity. It is shown that Fluxgate FGM3D/100 is more sensitive than PPM Geotron G5 given by higher measured amplitude on Fluxgate FGM3D/100. Variation on magnetometer's position give us stable result with peak response when magnetic substance is located at x = 0 m. This result also gives insight about minimum distance threshold in which unwanted magnetic object will affect reading during real magnetic survey. Partial magnetic object as big as motor scooter do not show any obvious effect after 5 m distance. Unfortunately, vector calibration cannot be performed because PPM Geotron G5 is a scalar magnetometer, whereas Fluxgate FGM3D/100 is vector magnetometer. Therefore, for more precise utilization, calibration using another calibrated fluxgate magnetometer is needed.

6 Conclusions

Magnetogama is a hand assembled fluxgate magnetometer utilizing factory built-in Fluxgate FGM3D/100 sensor combined with Arduino Mega 2650 R3 microcontroller, ADC ADS1256 24-bit, data storage and GPS receiver shield. It is open schematic and easy to build even with minimum budget. It has sufficient accuracy to be used on exploration scale. For the purpose of UAV, Magnetogama is designed as lightweight as possible (1 kg) and can be carried by small UAV.

7 Code Availability

The pseudocode below represents the general idea of the program inside microcontroller. Our source code for microcontroller and ADC can be accessed at https://github.com/adienakhmad/Magnetogama.

8 Data availability

Data which was used on this paper can be accessed at https://github.com/adienakhmad/Magnetogama.

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Figure 1. FGM3D Fluxgate magnetometer sensor

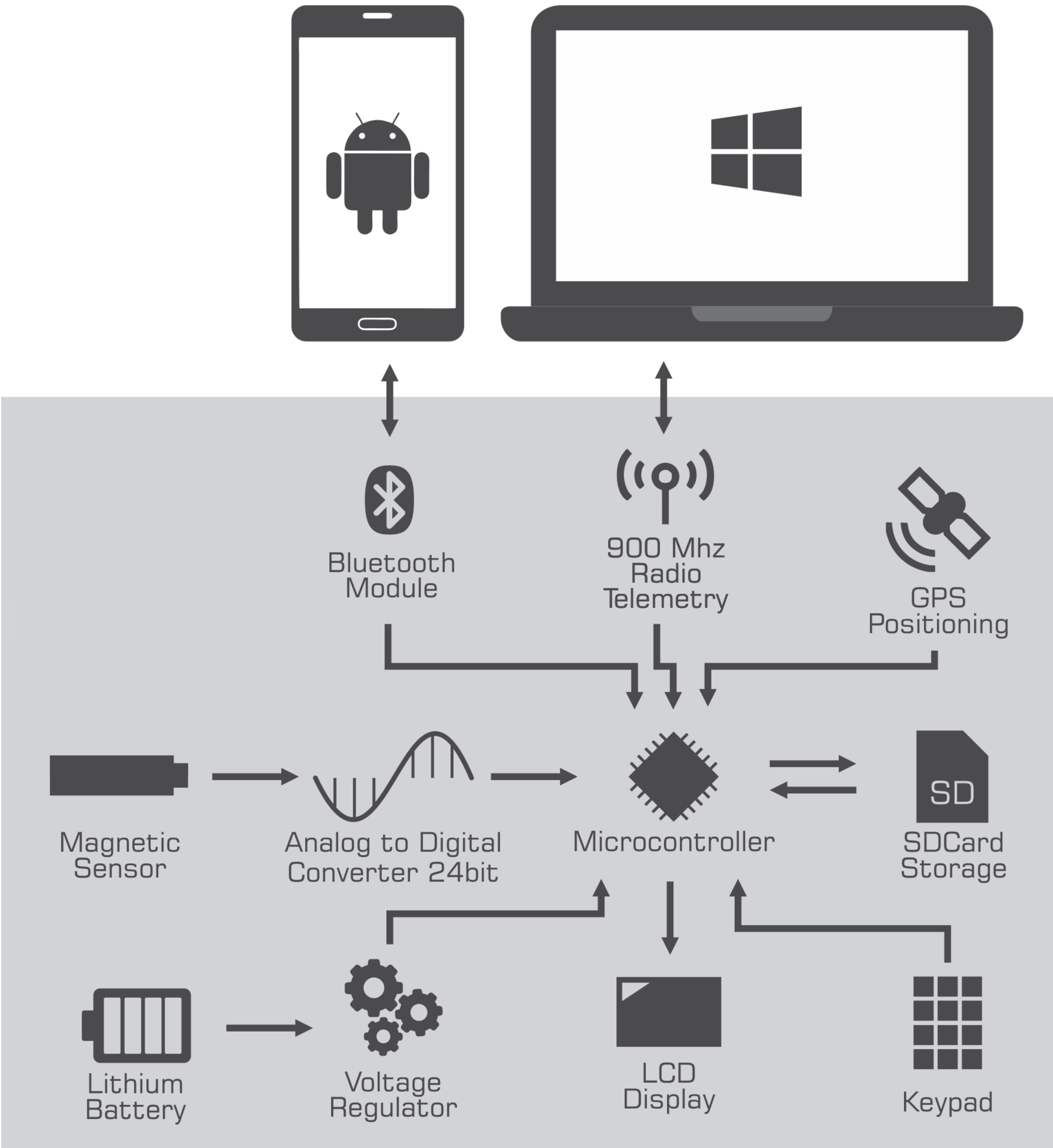

Figure 2. Magnetogama's block diagram.

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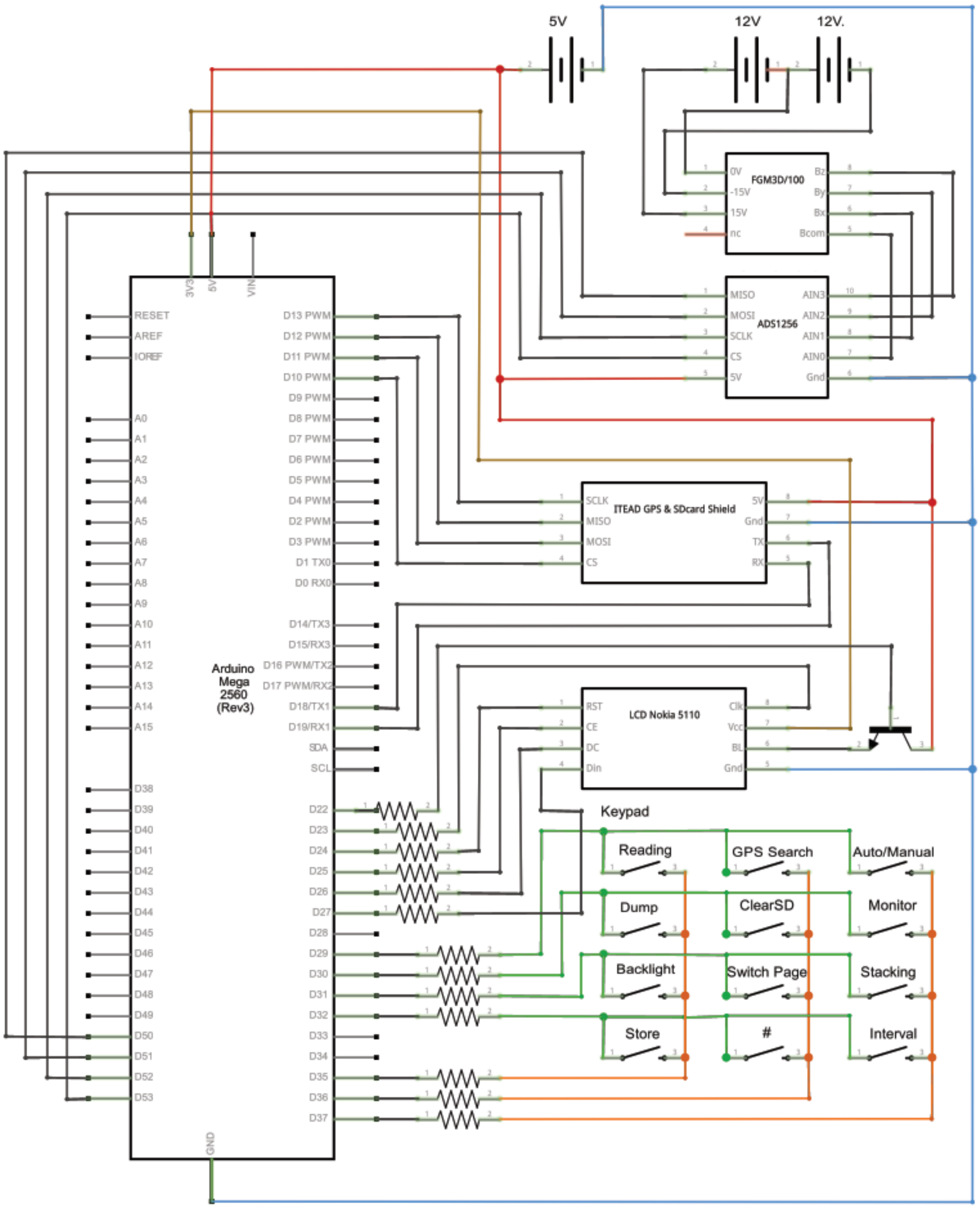

Figure 3. Magnetogama's schematic.

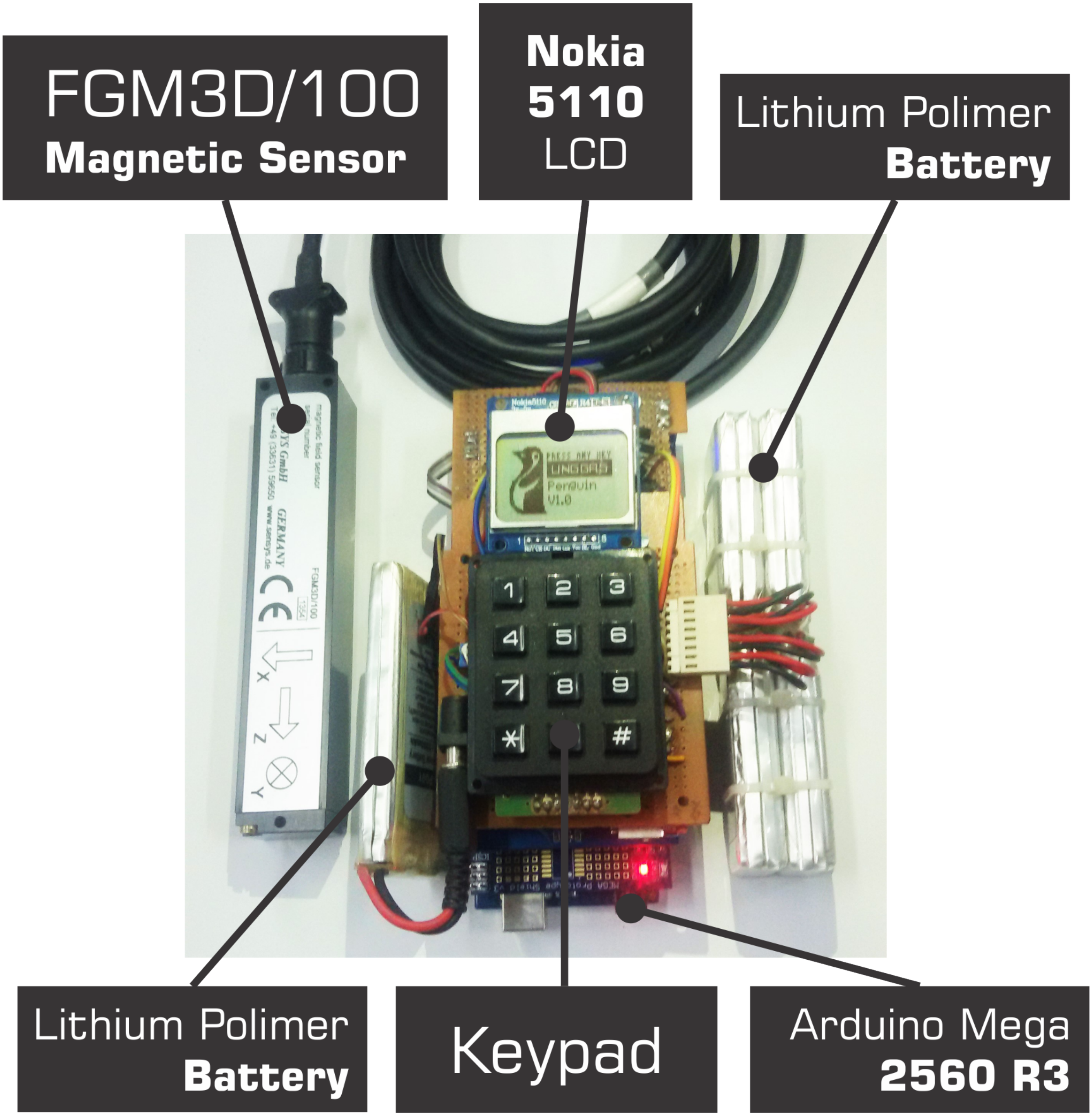

Figure 4. Assembled acquisition tools consist of magnetic sensor FGM3D/100, Arduino Mega 2560 R3, keypad, lithium polymer battery and Nokia 5110 LCD.

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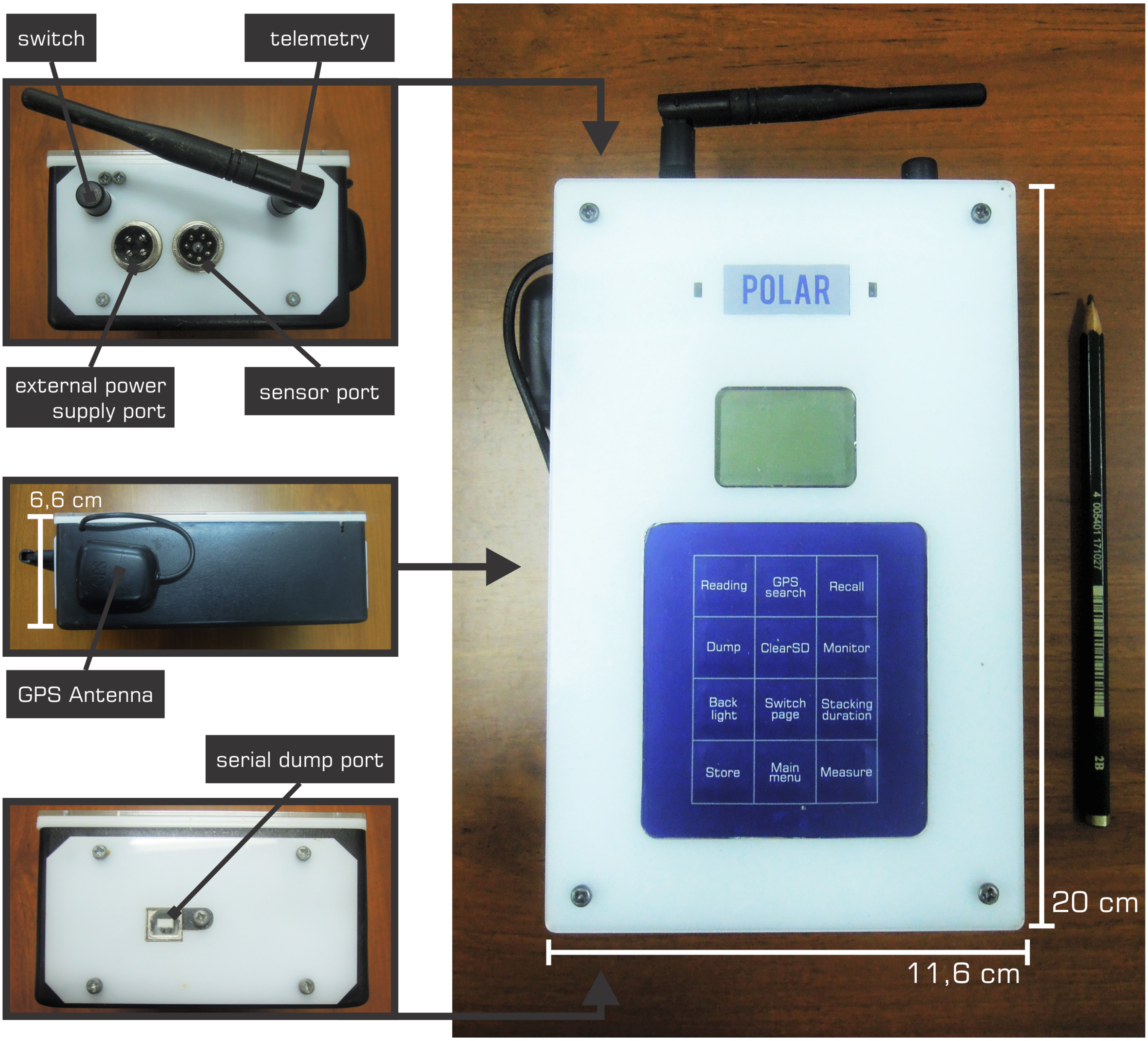

Figure 5. Magnetogama assembled using external plastic case and acrylic cover.

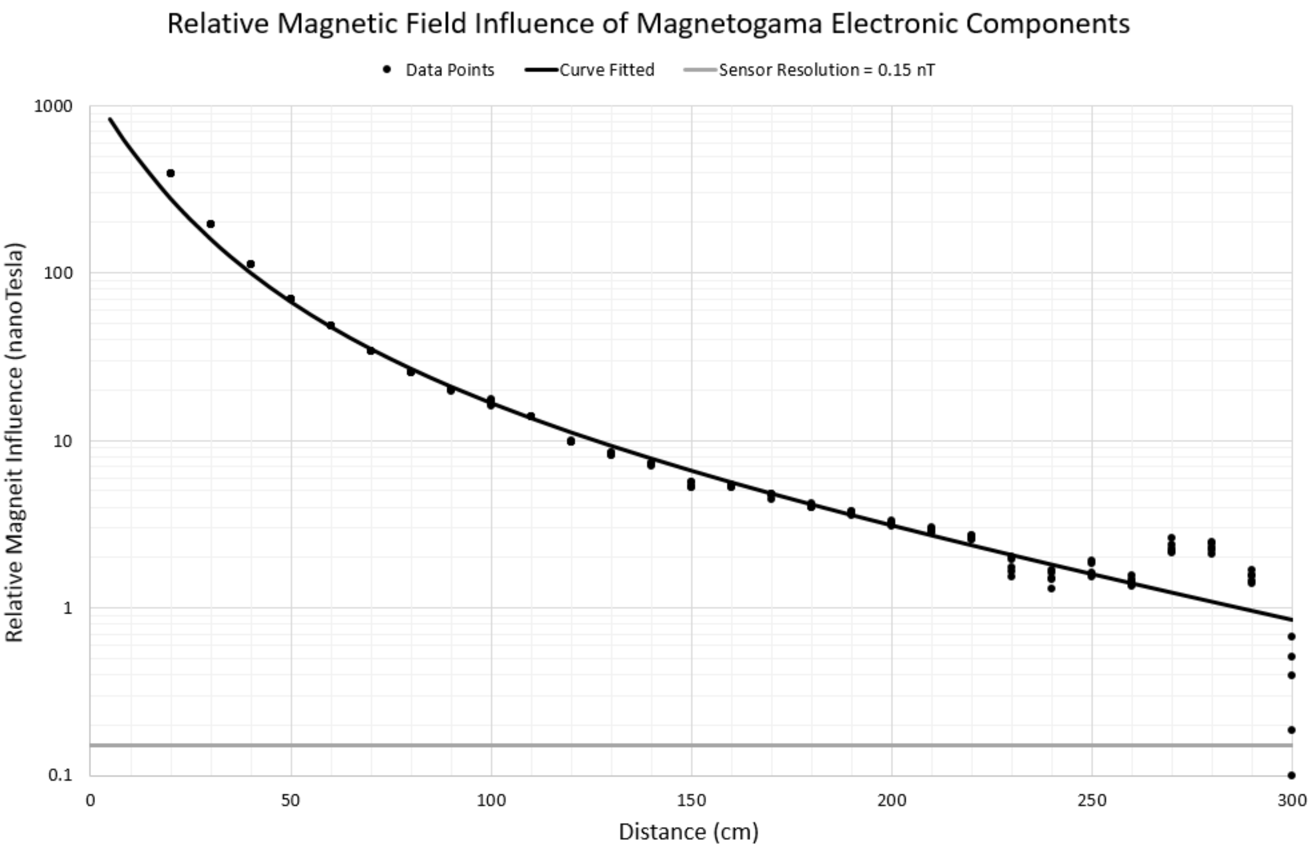

Figure 6. Relative magnetic field influence of magnetogama to sensor reading over various distances.

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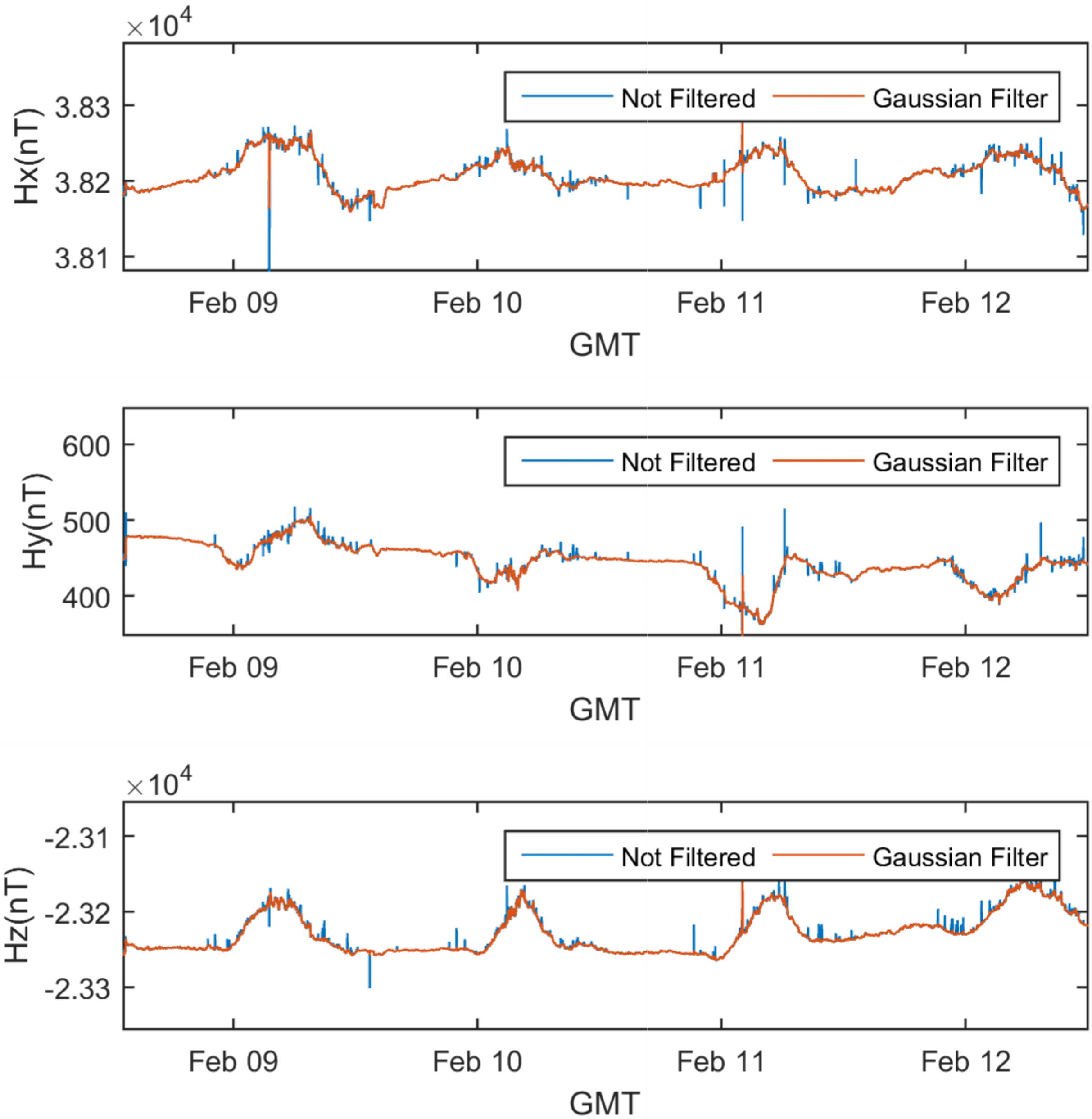

Figure 7. Comparison between original and filtered Magnetogama (YOG) magnetic field record on each component.

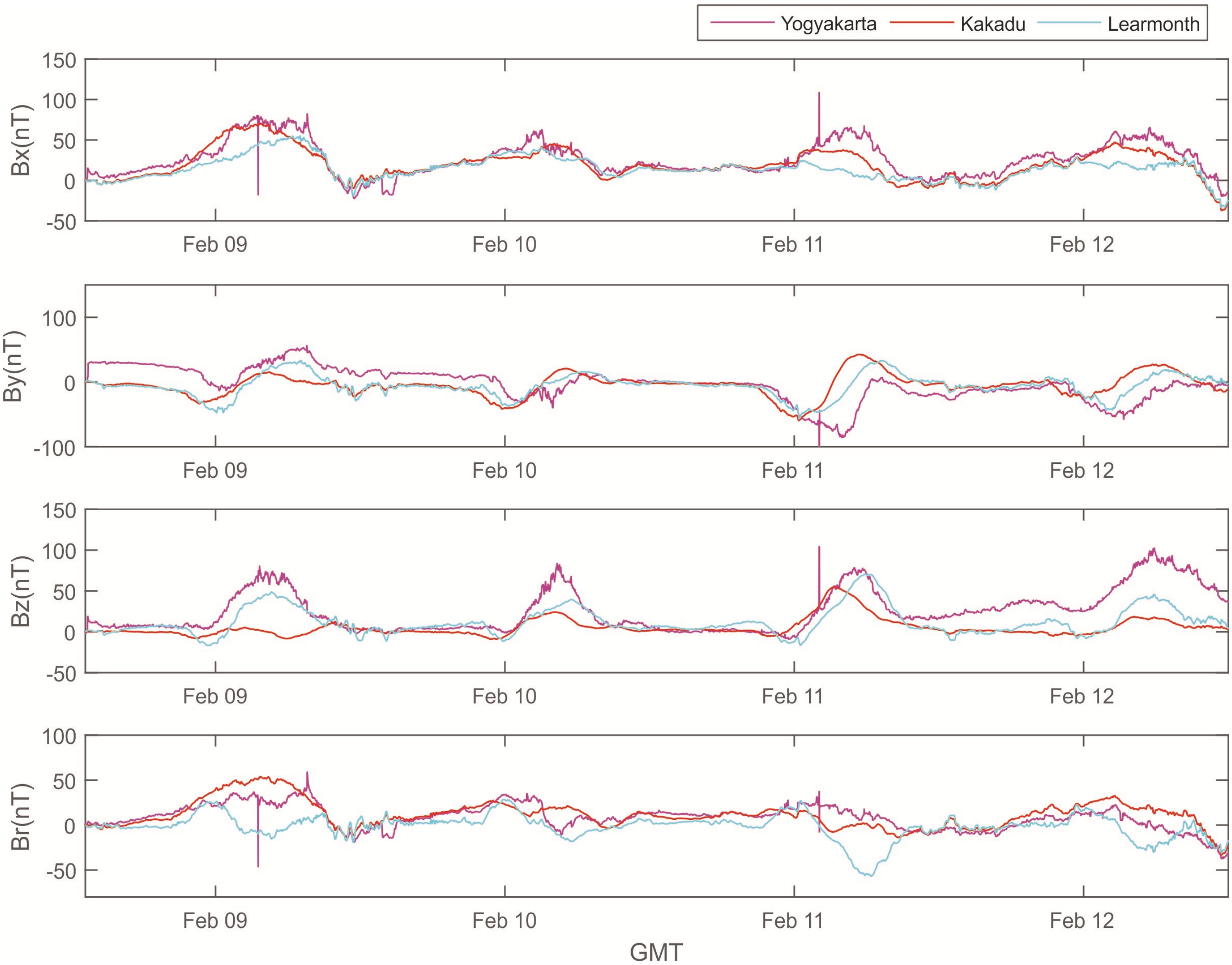

Figure 8. Comparison between magnetogama (YOG) and magnetometer on Learmonth (LRM) and Kakadu (KDU) observatorium.

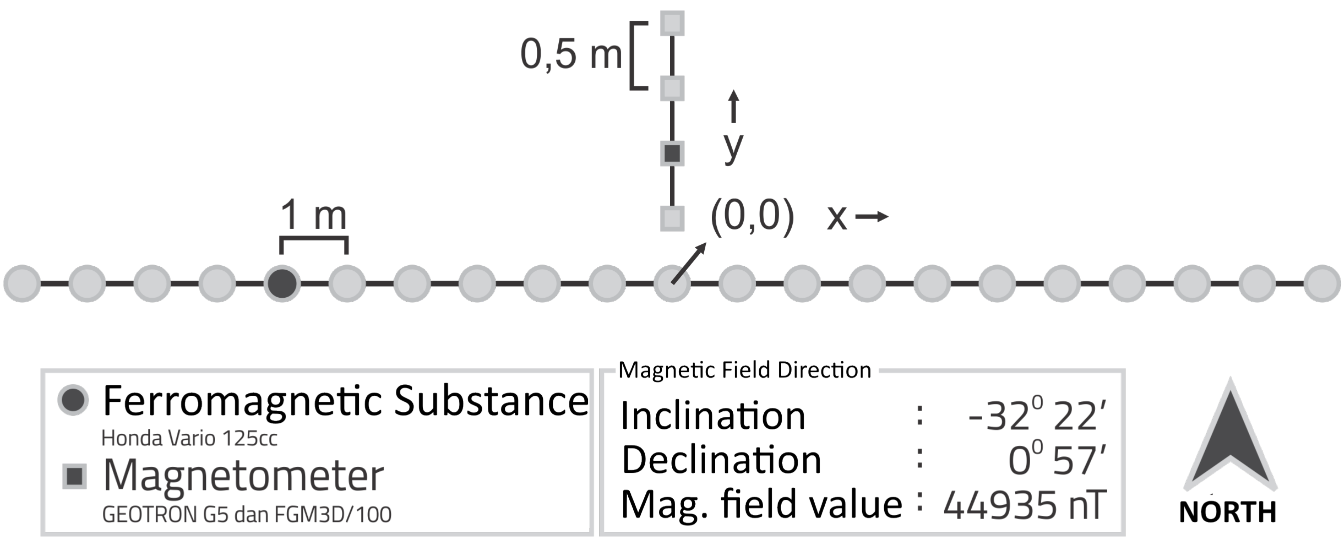

Figure 9. Sketch on magnetogama's test toward magnetic substance.

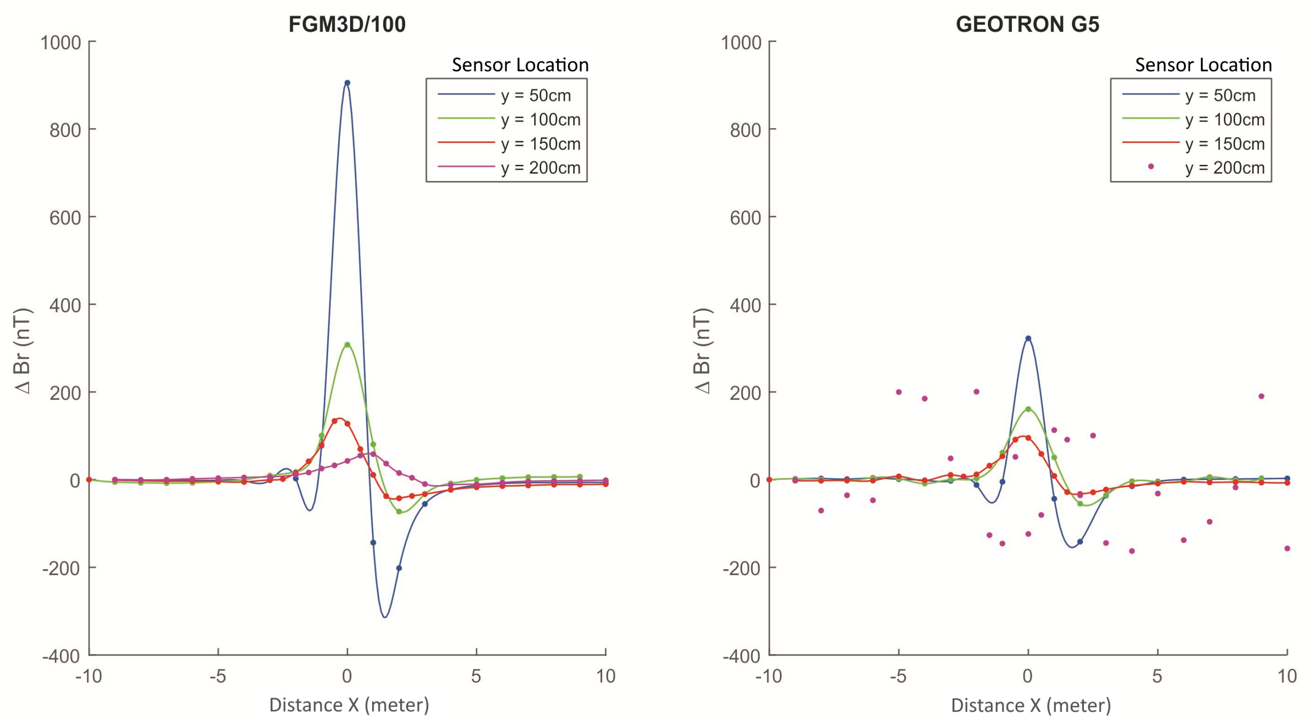

Figure 10. Magnetic field response comparison between FGM3D/100 and PPM Geotron G5.

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Appendix A: Algorithm

A1 Microcontroller

Algorithm 1 General Algorithm on Microcontroller

```
t0 ← time (millisecond) since device start
dt ← time interval between measurement
loop
    gpsfix ← gps fix data
    listen for keypad press
    if keypad is pressed then
        key ← the key pressed on keypad
        process function attached to key
    end if
    listen for serial command
    if command is received then
        cmd ← the received command
        process function attached to command
    end if
    t1 ← time now since device start
    if t1 − t0 ≥ dt then
        x, y, z ← magnetic reading from ADC
        lat, lon, elev, time ← position data parsed from gpsfix
        write x, y, z, lat, lon, elev, time to storage
        send x, y, z, lat, lon, elev, time to remote
        t0 ← time now since device start
    end if
end loop
```

A2 Analog to Digital Converter (ADC)

Author contributions. Wahyudi, Nurul Khakhim and Tri Kuntoro are research project leader who provide idea and guidance, including quality check on our apparatus. Afif Rakhman, Anas Seto Handaru and Adien Akhmad Mufaqih designed and test Magnetogama. Theodosius Marwan Irnaka and all the others help writing the manuscript.

Algorithm 2 Algorithm on ADS1256 A/D Conversion

for all differential channel connected to FGM3D **do**
  $ch \leftarrow$ current channel
  set multiplexer register to ch
  wait for conversion to finish
  $hb, mb, lb \leftarrow$ three 8-bytes raw ADC code {high, mid, and low byte}
  $vali24 \leftarrow (hb << 16) + (mb << 8) + lb$ {combine into integer 24-bit value by byte shifting}
  $valf32 \leftarrow$ convert $codei24$ into 32-bit floating point
  $vref \leftarrow$ voltage reference
  $pga \leftarrow$ programmable gain amplifier
  $voltage \leftarrow (codef32/\mathtt{0x7FFFFF}) \times ((2 * vref)/pga)$ {conversion from raw code to voltage}
  $fac \leftarrow$ conversion factor from V to nT
  $magval \leftarrow voltage \times fac$
  return $magval$
end for

Competing interests. There is no competing interest.

Disclaimer. Magnetogama is an open schematic apparatus, therefore the copyright of the product belong to the authors.

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