A Low-Cost Geomagnetic Field Station

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Abstract

The geomagnetic field is the earth's natural defense that protects us from the cosmic rays coming in the solar wind. These energetic particles can damage our technology such as communication satellites, electric networks, hydroelectric and GPS navigation systems, especially in the South Atlantic Anomaly (SAMA). This work presents the design and implementation of a low-cost geomagnetic station to monitor the earth's magnetic field variations and their correlations with space weather. The station uses Commercial Off-The-Shelf electronic devices such as a Raspberry pi, high-precision analog-digital converters, and triaxial fluxgate sensors. The hardware system and the software allow the logging sensor’s data automatically. Preliminary results allowed us to measure variations correlated with Brazil's geomagnetic station in Medianeira.

Keywords:
Earth's magnetic field, magnetometer, FLUXGATE sensors, Space weather.

1. Introduction

The Earth's magnetic field is the object of study in various observatories and institutes around the world due to its influence on various phenomena such as earthquakes, solar storms, cosmic rays, and others. Magnetometer networks monitor the intensity of the Earth's magnetic field in real-time in different parts of the world, e.g., Intermagnet. In South America, we have the network of the Brazilian Space Weather Program (EMBRACEMag) (Denardinni et al., 2018).

Paraguay is located in the center of the so-called South Atlantic Magnetic Anomaly (SAMA) where the values of the terrestrial magnetic field decay to half of the values expected according to the dipole model. For this reason, it is important to monitor the behavior of the magnetic field through an automatic station that can record the magnetic field continuously.

Previous works like (Rosales and Vidal, 2016) in the Huancayo observatory study the diurnal variation of the magnetic field where the highest amplitude is recorded because it is in the area of the magnetic equator and below the Equatorial Electrojet. They also study the influence of the solar activity cycles in the diurnal variation and how this is observed with higher amplitudes in the measurement of the magnetic field in the three components X, Y, and Z . Franco, 2017 designed and implemented a geomagnetic station using low-cost hardware and software, with the use of a Raspberry Pi for data processing, analog-to-digital converter, FLC-100 fluxgate sensors. The software is based on C language, Python, and Javascript. Cortés and Medina, 2009 designed a hardware architecture based on the Lantronix WIPORT server system using an IEEE 802.11b protocol, 3-axis HMR2300 digital magnetic sensor, and Global Positioning System (GPS). The WIPORT system has a processor, memory, 802.11b transceiver and a pair of high-speed serial ports, an operating system, and an embedded web server.

In this work, we present the design and implementation of a geomagnetic station with an electronic system for processing the data captured by the magnetometer; the sensor will be installed below ground to maintain a constant temperature. The magnetometer circuit consists of FLUXGATE sensors that record the three main components, X(East), Y(North), and Z(Vertical) of the field, as well as frequency to voltage converters and a temperature sensor for monitoring the temperature. Other important parameters related are declination (D), inclination (I), horizontal intensity (H), and total intensity (F). The parameters describing the direction of the magnetic field are declination (D) and inclination (I). D and I are measured in units of degrees, positive east for D and positive down for I.

The paper is organized as follows, in section 2, we present the station architecture, section 3 describes the calibration used, and finally, section 4 shows preliminary results obtained and some comparisons with a Geomagnetic station.

2. Station Architecture

The geomagnetic station is divided into two main blocks:(1) The Magnetometer circuit; (2) the data processing. Figure 1 describes the architecture of the station and its components. It can be seen in Block 1 that the magnetometer circuit is responsible for measuring the magnetic field using the FluxGate sensors, using a frequency to voltage conversion, and temperature monitoring.

Block 2 shows the data processing has a Single Board Computer (a Raspberry Pi) with the RTC (Real Time Clock), GPS, and an ADC. A Voltage Regulator and another temperature sensor.

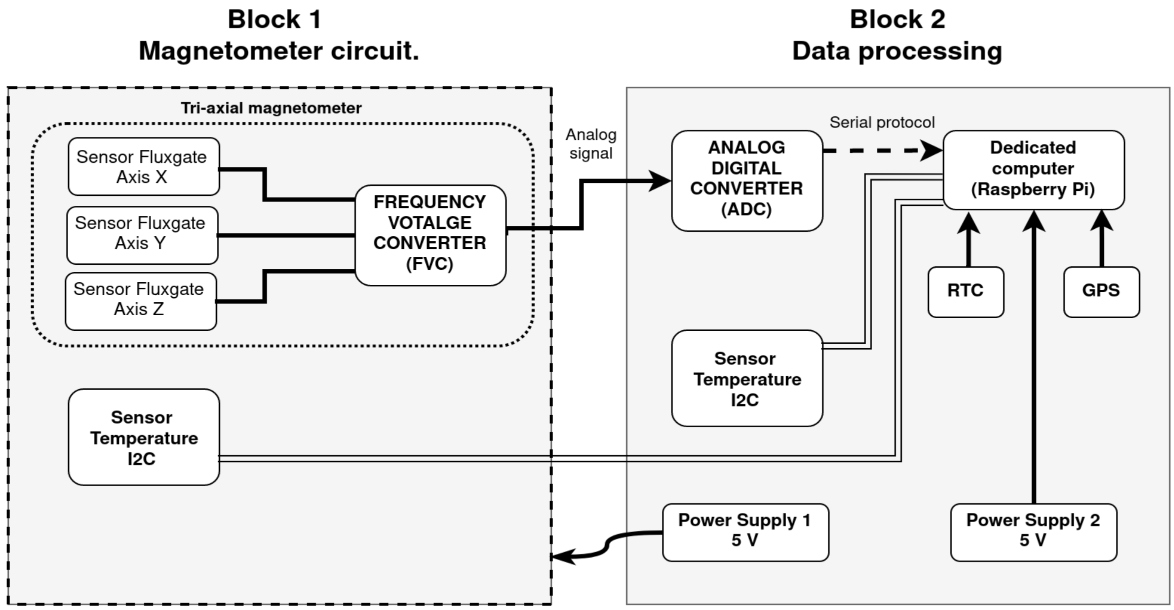

Figure 1: Block diagram of the proposed station.

2.1 Magnetometer circuit:

This block has three fluxgate sensors, three frequency to voltage converters, one temperature sensor, and the structure to keep all the components underground. The components are:

1. **FG-3+ fluxgate sensors** have high-sensitivity magnetic field sensors operating in the range of ±50 microtesla. The input voltage is 5 ± 0.5 V, and the supply current of 12 mA. The pickup frequency range of the sensor is ~50 kHz to ~120 kHz (Figure 2 (a)).
2. **Frequency to Voltage Converter:** it converts the input frequency coming from the magnetic sensor into voltage to transmit the signal through shielded laminated stranded pair cable (SSTP). The laboratory voltage range is ±3 V. Nominal current is 25mA (Figure 2 (b)).
3. **BMP180 temperature sensor:** used to monitor the temperature inside the PVC pipe placed under the floor. The input voltage range is 1.8V to 6V. The temperature range is -40 to +85 °C with an accuracy of ±1 °C (Figure 2 (d)).
4. **Support for the 3 axes:** the support for the magnetic sensors was designed in the form of a tower with three levels. It was designed and printed on a 3D printer. (Figure 2 (e))
5. **PVC pipe:** the printed support is placed inside the pipe to be able to introduce into the ground, as the temperature is maintained at ambient temperature below ground around ~20 to 30 °C, which was verified in the field (Figure 2 (c)).

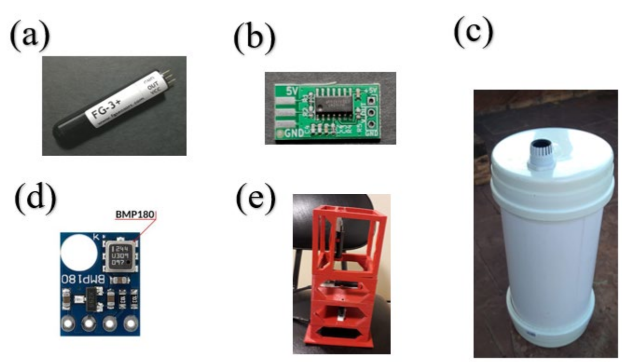

Figure 2: Components of the magnetometer circuit.

2.2 Data processing

To process the data captured by the magnetic sensors, a raspberry pi 4 and an Analog-to-Digital Converter (ADC) is used to digitize the analog values. A temperature sensor, a real-time clock (RTC), and a global positioning system (GPS) are also used. Figure 3 presents the components of this block.

1. **Raspberry pi 4** is in charge of data processing and unifying all the data from the other devices by programming the operating system in Python (Figure 2 (a)).
2. **Analog-to-digital converter ADS1256** is responsible for the data from the magnetic sensor transferred in voltage to be digitized in the raspberry pi (Figure 2 (b)).
3. **Temperature sensor MCP9808:** used to monitor the temperature inside the case where the raspberry pi and other components are installed. The input voltage range is 2.7V to 5.5V. The temperature range is -40 °C to 125 °C (Figure 2 (d)).
4. **A real-time clock (RTC)** is responsible for keeping the exact time. It incorporates a battery that keeps accurate time when the device is turned off and interrupted. The voltage range is 2.3V to 5.5V (Figure 2 (e)).
5. **Global Positioning System (GPS):** it is responsible for locating the exact location of the geomagnetic station using latitude and longitude measurements (Figure 2 (c)).
6. **Power supply:** dedicated to the magnetic sensors and temperature sensors. The power supply provides 5V DC with 5A with all protection systems (Figure 2 (f))..

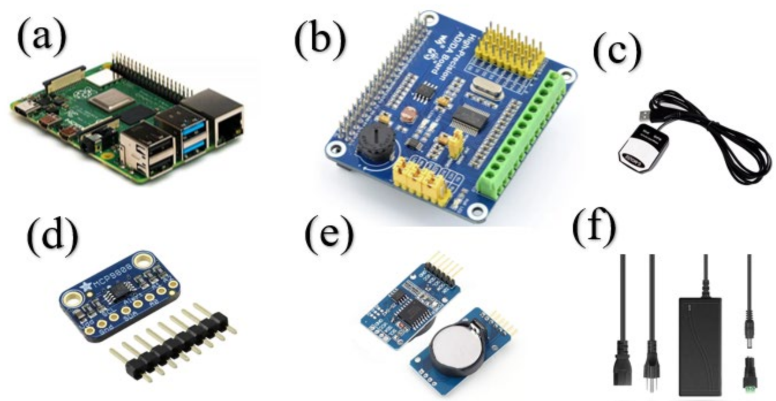

Figure 3: Main components of the data processing block.

2.3 Design of the roof and well of the geomagnetic station

The roof's design and the well's dimensions are made to place the magnetometer circuit and the data processing station inside them. Figure 4 (a), presents a 3D view of the geomagnetic station.

Figure 4: Geomagnetic station design.

Figure 4 (b) and (c) show the geomagnetic station installed without using steel on the structure. The magnetic sensors were installed underground 1.10 m from the surface to keep the temperature constant.

3. Sensor calibration

Calibration of the sensors was performed using a solenoid controlling the current employing a potentiometer. covered by a metal mu in the center of the solenoid. The mu-metal protects the sensor from external interference. The solenoid is powered by a precision 5V power supply where the solenoid current is regulated by a potentiometer from 0 to 80 mA in 10 mA steps. 1 of the sensors is inserted into the solenoid in a direction perpendicular to the magnetic north using a compass (see Figure 5 (a)).

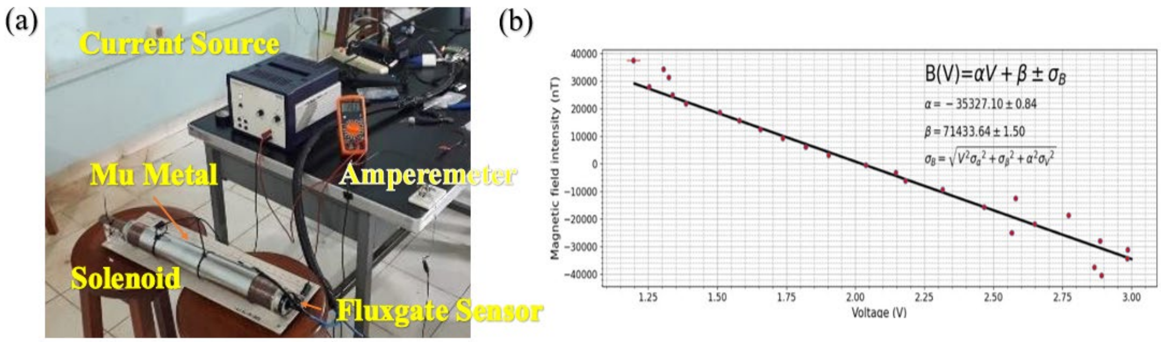

Figure 5: (a) Calibration of the sensor in the laboratory. (b) Shows the calibration results where a linear behavior of the sensor in relation to the magnetic field is observed.

3. Results and Discussion

Data has been collected from February 29 through April 12. Then the data had to be stopped to make some improvements to the equipment, putting it back into operation from June 29 to the present.

Figure 6 shows the values obtained with our detector located in Isla Bogado 25°17'47.5"S 57°29'21.5"W for the horizontal component H and the vertical Z for March 30 and 31. Figure 7 shows the magnetic field values obtained by the Medianeira station in Brazil, which is the closest station to our location. Comparing both measurements, it can be seen that they behave in a similar way, indicating that we can trust the variation observed by our detectors if we use the Medianeira station as a reference.

It can be seen that the horizontal and vertical values started to deviate from normal around 11:00 local time (-4 GMT) in Paraguay, exactly at the regime change observed in Medianeira. The absolute values of the field still need calibration to be done by taking the magnetometer close to EmbraceMag station.

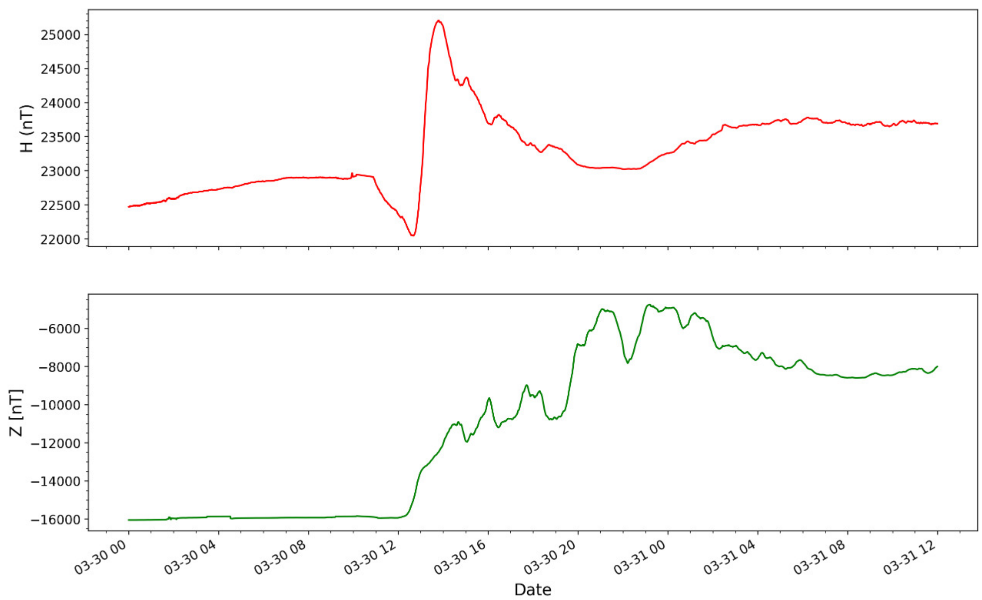

Figure 6: Data collected with the Isla Bogado station on March 30 and 31.

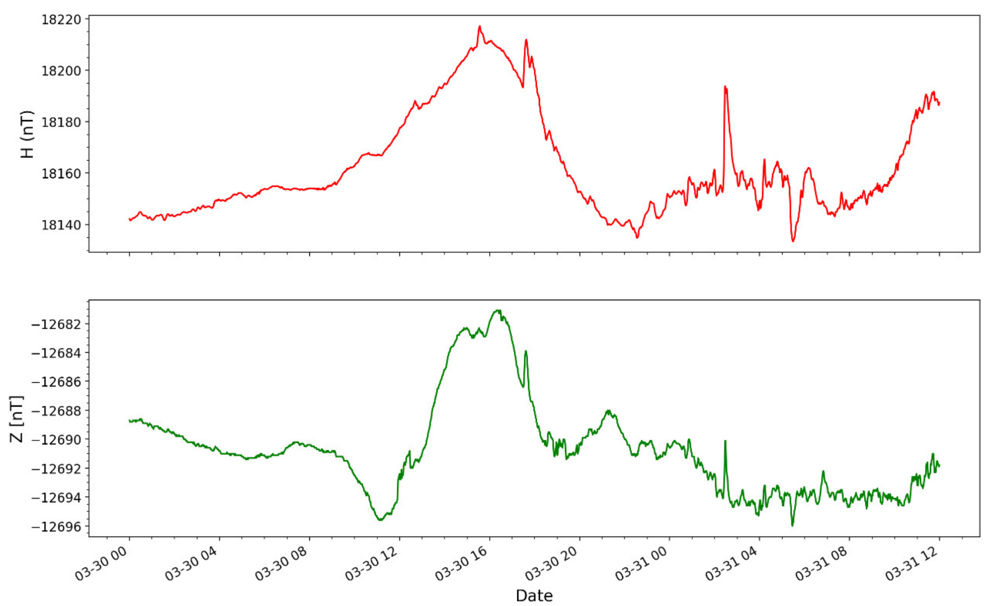

Figure 7: Data obtained with the Medianeira station on March 30 and 31.

4. Conclusion

The low-cost geomagnetic station will allow us to start monitoring the impact of solar activity in our country. First measurements indicated that we could observe a huge change in both components of the magnetic field, exactly at the same time as the closest station of the EMBRACEMag. Although the values of the magnetic field must be calibrated in a more conventional way, the data showed that we can measure sudden changes in both directions of the magnetic field.

References

Franco, F., Estgeomag: Integrando soluções de hardware, software e internet das coisas na medição de grandezas geomagnéticas, *Final Degree Work, Universidade Federal do Espírito Santo, Centro Tecnológico*, 2017.

Medina, A., Background of the study of the terrestrial magnetic field in Colombia, *Scientia et Technica*, no. 50, pp 181-186, 2012.

Cortés, A. and Medina, F., Design of a computer assisted magnetometer, Master's thesis, *Universidad Tecnológica de Pereira, Pereira*, 2009.

Beggan, C. and Marple, S., Building a Raspberry Pi school magnetometer network in the UK, *Geoscience Comunication,* 1, 25-34, 2018.

Denardini, C. M., Chen, S. S., Resende, L. C. A., Moro, J., Bilibio, A. V., Fagundes, P. R., et al., The embrace magnetometer network for South America: Network description and its qualification, *Radio Science,* 53, 288-302, 2018.

Kurita, J. ;Ortiz, Derlis; Moreira, L.; Moreira, J.; Stalder, D. H.; Vega, B. CanSat Pico-satellite Building Workshop as an Effective Tool for STEAM Education, A Case Study. https://www.asee.org/public/conferences/172/papers/31648/view

Rosales, D. and Vidal, E., Variación diurna estacional del campo geomagnético registrado en el observatorio de Huancayo, *Latinmag Letters,* Vol. 6, A16, 1-6, 2016.

Mochales, T. and Valcárcel, M., Visualizing and interpreting magnetic parameters by means of digital tools, *Enseñanza de las ciencias de la tierra,* 2016.

Biographies

Christian Paniagua is an electronic engineering student at the Faculty of Engineering of the UNA in the process of writing his thesis. Since, March 2020, was awarded by the BECAL-IDIOMAS scholarships to study English at the Paraguayan American Cultural Center. In 2020 was Vice President of the IEEE Robotics and Automation Society. Currently working in the area of telecommunications. His areas of interest are information technology (IT), databases, process automation, and instrumentation.

Diego H. Stalder received the BS degree in Electronic Engineering (2010) from the Engineering Faculty of Asuncion National University (FIUNA), the Master (2013) and the PhD degree (2017) in Applied Computing from the National Institute for Space Research, Brazil. Since 2019, is a full time researcher at FIUNA, Paraguay. His research interests include time series analysis, deep learning models, biometric signal processing and instrumentation.

Jorge Molina is a Doctor from the Brazilian Center for Physical Research (CBPF), he did his doctoral thesis in the Fermilab DZero experiment, with postdoctoral studies at the State University of Rio de Janeiro (UERJ) and the CIEMAT Madrid, from where he collaborated with the CMS experiment of CERN. Since 2009 he has been at FIUNA, where he was director of the Mechanics and Energy Laboratory until 2015. He is currently Director of Research at FIUNA, and continues to collaborate with the Fermilab Laboratories, with Unicamp at Campinas and represents Paraguay in the LAGO and LAS4FRI collaborations.

Gustavo Menesse, graduate in Environmental Engineering (2016) from the Agronomic Science Faculty (FCA) and also received a science bachelor in physics (2020) from the Exact and Natural Sciences Faculty (FaCEN), both from Asuncion National University (UNA). Currently pursuing a Master in physics applied to medicine and biology (FAMB) at University of São Paulo (USP). Has experience in low-cost instrumentation for environmental monitoring.

Tomas Rolón received the BS degree in physics (1974) from Science Institute, actually Exact and Natural Sciences Faculty of Asuncion National University (FaCEN), the BS degree Electronic Engineering (1979) from the Electronic Engineering Institute (IIE), actually Engineering Faculty of Asuncion National University (FIUNA), the Master in Physics and Physical technologies (2010) and the PhD degree (2013) in Physics from the Zaragoza University, Spain. His research interests include the areas of nuclear, particles and electromagnetics fields, and their instrumentations.