Analysis of a calibration system for fluxgate magnetometers for use in geomagnetic observatories

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Abstract

Due to the cost and limitation of magnetic field insulation, it is difficult to produce stable and accurate reference fields for the calibration of a sensitive magnetometer. This study presents a comparative analysis of instrumental results with an instrument with world reference system (VSS – INTERMAGNET) in a continuous operation, to determine the quality of the data produced by a fluxgate magnetic sensor newly built in the Laboratory of Development of Magnetic Sensors of the National Observatory (LDSM / ON).

Introduction

The Magnetic Sensors Development Laboratory (LDSM / ON) has been developing fluxgate sensors since 1995. The LDSM has recently built a new magnetometer that will be able to meet the stringent precision requirements for use in geomagnetic observatories, according to the standard of the INTERMAGNET worldwide network.

Figure 1 – Magnetometer prototype developed by LDSM.

Due to the cost and limitation of magnetic field insulation, it is difficult to produce stable and accurate reference fields. We chose to carry out comparative tests on an instrument with world reference system (VSS – INTERMAGNET) in a continuous operation regime.

To achieve this demand, it is necessary to determine and control various instrument parameters, such as instrumental drift, thermal stability, noise, frequency response, among others. For this, a computational instrument control system was developed in the laboratory and used in the preliminary bench tests of a prototype.

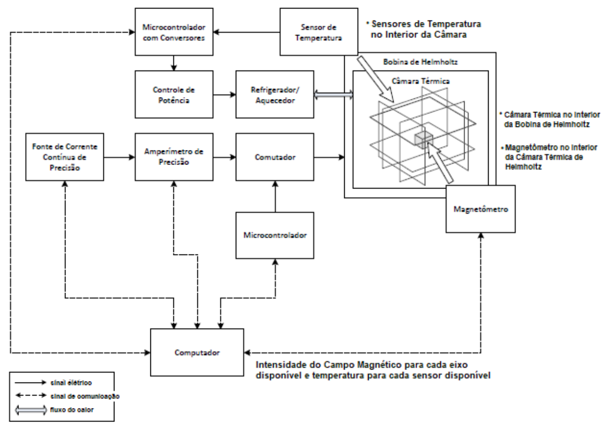

Figure 2 – Simplified diagram of the thermomagnetic characterization system for magnetometers (source: LDSM).

Figure 3 – Sensor in test on LDSM Helmholtz coil (source: LDSM).

Methodology

During the bench tests, it was observed that the parameters of the instrument follow a linear dependence with temperature. For this reason, the method used for the calibration of the magnetometer was the simple linear regression by the least squares, having as regression parameter the temperature.

Before the adjustment, a treatment is necessary in the raw data obtained by the device being tested. As it is a prototype, having limited immunity to electromagnetic interference, there may be spurious values in the measurements of the magnetic axes and in the temperature signal.

This treatment was performed in three stages:

1. Removal of spurious data;
2. Matching the sampling rate of the devices;
3. Moving average.

To perform the above processing, the programming language Python, version 3.6.5, was used with the Jupyter Notebook tool.

1. Removal of spurious data (outliers).

The geomagnetic data do not contain drastic variations in magnitude and even when magnetic disturbances occurs. The removal of the outliers is necessary because they are anomalous points that differ abruptly from their neighbors and can lead to an incorrect analysis.

We can visualize from a box diagram (Python tool – BoxPlot) the empirical distribution of the data in which we noticed some registered outliers. The LDSM magnetometer is a fluxgate device where we measure in three axes. Only one of the axes was used to proceed with the calibration, because when it is adjusted in one of them the rest is also calibrated.

We can see in figure 4, the outliers of component Z.

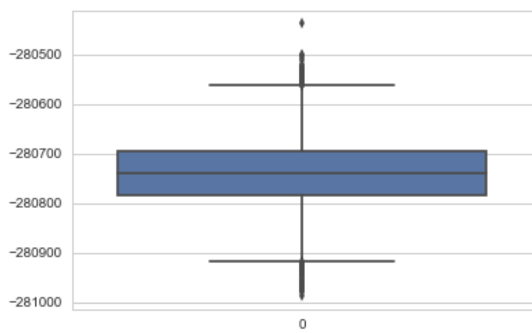

Figure 4 - BoxPlot with outliers outside the maximum and minimum limits of component Z.

The outliers were removed by the standard deviation method, where 95% of the data are located at 2 standard deviations from the mean. It was made for both the Z component and the temperature. To maintain continuity of the records, the spurious points were replaced by a simple interpolation of the adjacent data, keeping the same amount of measurements within the collected period.

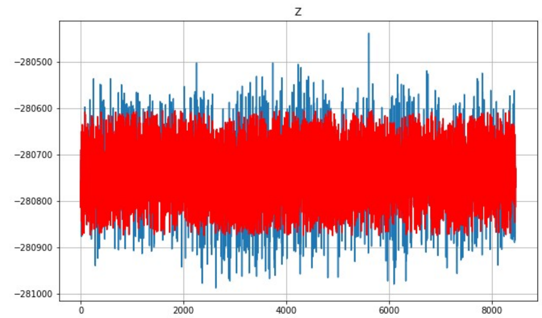

Figure 5 – Removal of the spurious of the component Z. In blue the raw data and in red the data without the spurious ones (5%).

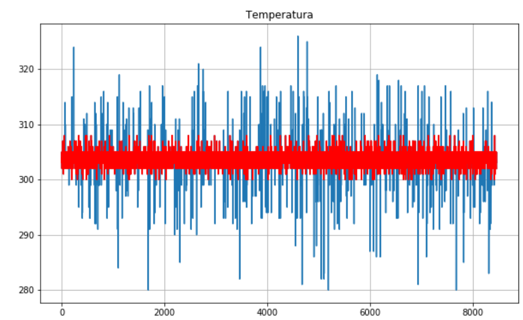

Figure 6 – Removal of temperature spurious. In blue the raw data and in red the data without the spurious ones (5%).

2. Sampling rate matching of the devices.

The LDSM magnetometer performs about 3 measurements per second. The INTERMAGNET magnetometer records 1 measurement per second. To compare them, we need to make its sampling rate equal, by interpolating the data.

Table 1 – Example of LDSM magnetometer data with about 3 measurements per second.

	DAY	HOUR	X	Y	Z	TEMPERATURA	Sem Espurio Z	Sem Espurio TEMP
0	2017-08-28	00:54:01	423136	1216	-280757	305	-280757.0	305.0
1	2017-08-28	00:54:02	423143	1170	-280814	302	-280814.0	302.0
2	2017-08-28	00:54:02	423024	1235	-280689	305	-280689.0	305.0
3	2017-08-28	00:54:03	423128	1131	-280814	304	-280814.0	304.0
4	2017-08-28	00:54:03	423268	1011	-280731	303	-280731.0	303.0
5	2017-08-28	00:54:04	423124	1194	-280711	304	-280711.0	304.0
6	2017-08-28	00:54:04	423142	1289	-280753	303	-280753.0	303.0
7	2017-08-28	00:54:04	423158	1117	-280810	304	-280810.0	304.0
8	2017-08-28	00:54:05	423166	1104	-280738	305	-280738.0	305.0
9	2017-08-28	00:54:05	423112	1158	-280780	303	-280780.0	303.0
10	2017-08-28	00:54:06	423091	1213	-280650	305	-280650.0	305.0

Table 2 – Example of the LDSM magnetometer data with the same INTERMAGNET sample rate.

	index	DAY	HOUR	X	Y	Z	TEMPERATURA	Sem Espurio Z	Sem Espurio TEMP	Media Z	Media TEMP
0	0	2017-08-28	00:54:01	423136	1216	-280757	305	-280757.0	305.0	-280757.0	305.0
1	1	2017-08-28	00:54:02	423143	1170	-280814	302	-280814.0	302.0	-280752.0	304.0
2	3	2017-08-28	00:54:03	423128	1131	-280814	304	-280814.0	304.0	-280772.0	304.0
3	5	2017-08-28	00:54:04	423124	1194	-280711	304	-280711.0	304.0	-280758.0	304.0
4	8	2017-08-28	00:54:05	423166	1104	-280738	305	-280738.0	305.0	-280759.0	304.0
5	10	2017-08-28	00:54:06	423091	1213	-280650	305	-280650.0	305.0	-280747.0	304.0
6	12	2017-08-28	00:54:07	423136	1166	-280710	303	-280710.0	303.0	-280734.0	304.0
7	15	2017-08-28	00:54:08	423163	1208	-280809	304	-280809.0	304.0	-280756.0	304.0
8	17	2017-08-28	00:54:09	423166	1214	-280801	307	-280801.0	307.0	-280768.0	306.0
9	19	2017-08-28	00:54:10	423115	1238	-280687	303	-280687.0	303.0	-280747.0	303.0
10	22	2017-08-28	00:54:11	423088	1254	-280668	305	-280668.0	305.0	-280705.0	305.0

3. Moving average

The moving average is a data smoothing technique acting as a low-pass filter. It was implemented with a window of 300 points for the Z component and 300 points for temperature data.

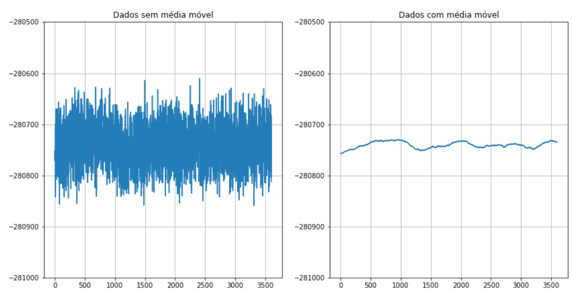

Figure 7 – Moving average of the Z component. On the left are the data without the moving average and on the right are the smoothed data.

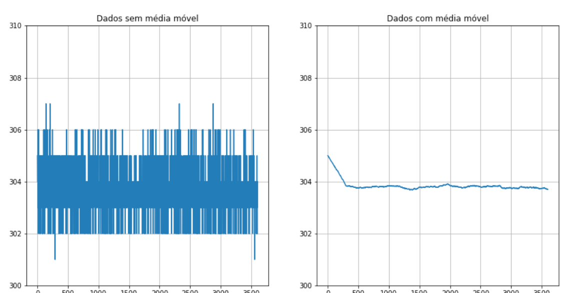

Figure 8 – Moving average of temperature. On the left are the data without the moving average and on the right are the data smoothed.

After the treatment of the raw data, the method of the least squares was applied obtaining the coefficients for the correction of zero, scale and thermal variation by the equation below:

$$F = a \cdot V + b.\ (t - t_0) + c \cdot Z + d \cdot (t - t_0)$$

Where F is the reference field in nT, V is the gross value read in the sensor, t is the current temperature, t0 is the calibration temperature and [a, b, c, d] are adjustment parameters.

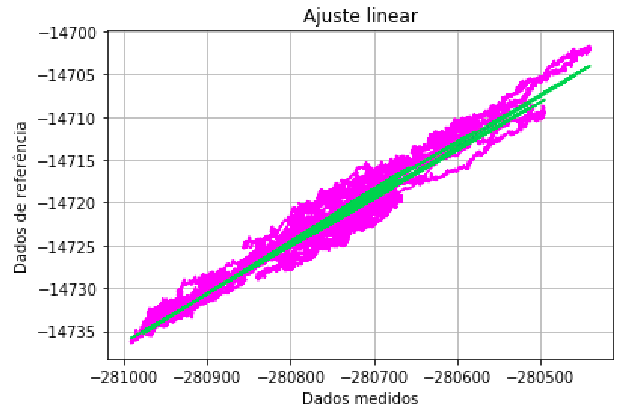

Figure **9** – Graph figure of the linear adjustment. In pink the data without adjustment and in green the data with the adjustment.

Results

Even applying coefficients obtained from a variation of only a few degrees of temperature and with an excursion of less than 100 nT, mean differences of a mere 1 nT were obtained, confirming the tests previously performed in the LDSM bench.

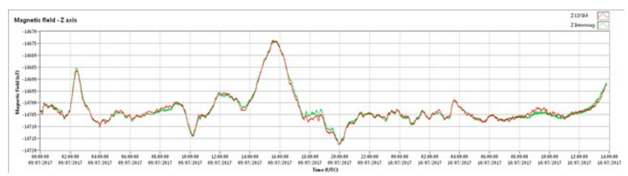

Figure 10 – Comparative results after adjusting the sensor under test.

Due to restrictions of instrument installation in the Vassouras observatory, the results are still preliminary, but promising. The first magnetograms obtained by the calibrated instrument and the reference instrument are practically identical within a few nanoTeslas, evidencing the viability of the proposed calibration method.

Final considerations

As a perspective for the continuation of this project, a new instrument is in the final stage of construction. This will be installed next to the original prototype, producing a new set of data for analysis. The new instrument will be built with more refined materials and circuits, which should produce results that are more precise if the proposed calibration system proves to be completely effective.

Acknowledgments

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References

PRIMDAHL F., The fluxgate magnetometer, J. Phys. E: Sci. Instrum. 12 241, 1979.

ACUÑA M H, Space-based magnetometers, Rev. Sci. Instrum. 73 3717, 2002.

Cabral G.G., Sistema De Teste e Calibração Ativa para Magnetometros de Núcleo Saturado, Master's Dissertation – in preparation, Observatório Nacional 2019.

CAMPBELL W.H., Introduction to Geomagnetic Fields, Cambridge University Press. USA. 2003.

JANKOWSKI J., SUCKSDORFF, C., Guide for Magnetic Measurements and Observatory Practice, 1 ed. Warsaw, NOAA / IAGA, 1996.

BELYAYEV S. and IVCHENKO N., Digital fluxgate magnetometer: design notes, Measurement Science and Technology, Volume 26, Number 12, 2015.

TUMANSKI S., Handbook of Magnetic Measurements. CRC Press. USA. 2011.

RIPKA P., Magnetic Sensors and Magnetometers. ARTECH HOUSE. USA. 2000.

MUSMANN G. and AFANASSIEV Y., Fluxgate Magnetometers for Space Research. Germany. 2010.

KOREPANOV, V. & MARUSENKOV, A., Flux-Gate Magnetometers Design Peculiarities. Surv Geophys. 33: 1059. 2012.

TAYLOR J.R., An Introduction to Error Analysis the study of uncertainties in physical measurements. University Science Books. USA. 1996.

OTAVIANO A. M. HELENE , VITO R. VANIN. Tratamento Estatístico de Dados em Física Experimental. Ed. Blucher. 1991.

BEVINGTON P.R. ROBINSON D.K., Data Reduction and Error Analysis for the Physical Science. McGraw-Hill Education. 2002.

URROZ G.E., Regression Analysis with SCILAB. 2001.

INTERMAGNET, Technical Reference Manual, Version 4.6. 2012.

REEVE W.D., Geomagnetism Tutorial. USA, 2015.

JANKOWSKI J. and SUCKSDORFF C., Guide for Magnetic Measurements and Observatory Pratice. Varsóvia. 1996.