Journal of Mineral Resources Engineering, 9(1): 25-40, (2024)

Imam Khomeini International University
Vol. 9, No. 1, Spring 2024

نشریه مهندسی منابع معدنی
Journal of Mineral Resources Engineering
(JMRE)

Research Paper

The Fast and Low-Cost Magnetometry with Micro Electro Mechanical Systems Sensor

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Received: 07 Feb. 2023 **Accepted: 04 Oct. 2023**

Abstract: With the extraction of surface minerals and the depletion of their reserves, the exploration of deeper deposits has become a pressing consideration. Among the geophysical techniques available for such exploration, magnetometry stands out. Proton magnetometers, the prevailing instruments in terrestrial magnetometry, are characterized by their high cost, high weight, and large size. Moreover, their low sampling rate necessitates prolonged and consequently costly field operations. However, the advancement of Micro Electro Mechanical System (MEMS) sensors, which are both lightweight and cost-effective and possess high sampling rates and satisfactory sensitivity, has garnered significant interest. In this research, one such MEMS sensor was deployed and employed in the examination of a small iron deposit located in Western Iran. Then, the findings from these measurements were compared to those obtained using a proton magnetometer. The comparison reveals a substantial difference in efficiency. Magnetometry with MEMS sensors over the selected deposit took approximately 8.5 hours, whereas the survey with the proton magnetometer on the same profiles spanned around 44 hours. In addition to the time savings, the application of MEMS sensors led to a remarkable reduction in operating costs, by up to fivefold. On the other hand, due to the small size of this magnetometer, by placing it in a handbag or backpack of the operator, it is possible to carry out the magnetometer survey without any problem of dealing with the opponents and to prevent the postponement of the field magnetometer operation.

Keywords: Sensor, Magnetometry, MEMS, Proton.

How to cite this article
Shahsavani, H. (2024). *"The fast and low-cost magnetometry with Micro Electro Mechanical Systems sensor"*. Journal of Mineral Resources Engineering, 9(1): 25-40.
DOI: 10.30479/JMRE.2023.18390.1626

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INTRODUCTION

In recent times, the exploration of subsurface mineral deposits has become imperative due to the depletion of surface reserves. Magnetometry, a branch of geophysics, has a rich history dating back to ancient Chinese use of Earth's magnetic properties for metal deposit exploration [1,2]. Proton magnetometers, introduced in 1965, revolutionized magnetometry and continue to be widely used [3]. Various magnetometer types have emerged, including cesium vapour, rubidium, potassium, and fluxgate magnetometers, each with unique attributes [4-7]. Additionally, the development of Micro-Electro-Mechanical System (MEMS) sensors has gained attention in geophysics [8-10]. These sensors, which have evolved for navigation, offer smaller size, lower cost, and increased precision, making them viable alternatives [11]. MEMS magnetometer sensors can be categorized into micro-fluxgate, Hall-effect, and resistive types [9]. Despite some limitations, they hold promise in various applications [12-15]. While MEMS sensors have lower sensitivity compared to proton magnetometers, their ability to detect economic reserves, which generates more than 200 nT change on the Earth's magnetic field [16], justifies their use. Moreover, MEMS sensors can significantly reduce the cost and the time of magnetometry surveys. Their compact size allows for discreet transportation, ensuring sensitivity in field operations. This study involved setting up a precise Hall-effect-based MEMS magnetometer. Measurements were conducted on an iron reserve simultaneously with a proton magnetometer to evaluate the MEMS sensor's performance.

METHODS

Magnetic field measurements were conducted within the specified limits using a micro-electro-mechanical (MEMS) sensor. The sensor, as illustrated in Figure 1, is identified as the MLX 90393 model manufactured by SparkX. It can communicate with a microcontroller through both I2C and SPI communication protocols. In this study, the relevant sensor has been enclosed within a customized housing. For the sake of lightweight design, the housing material is selected as balsa wood. The entire assembly, including the housing and its contents, weighs only 150 grams.

The variations in the Earth's magnetic field strength over a metallic ore deposit range from 200 to several thousand nanoteslas. Therefore, a sensitivity of 160 nanoteslas is entirely acceptable for the detection of an economic metallic ore deposit, and an accuracy of ±0.1 nanoteslas in magnetic field measurements, especially for the exploration of magnetite, is sufficient.

The study area encompasses a rectangular shape, approximately 1800 meters in length and 800 meters in width, oriented in the northwest-southeast direction. Figure 2 on Google Earth illustrates the designated study area. Within this study area, 27 profiles, ranging from 138 meters to 1000 meters in length, have been proposed. These profiles have been designed in a north-south direction. As depicted in Figure 2, the profile lines cover the study area in a diagonal manner. These profiles have been planned using open-source software called "Mission Planner," which guides drones. The total length of the proposed profiles is approximately 30 kilometres. A spacing of 50 meters has been selected between the acquisition profiles, which appears suitable for the initial exploration phase.

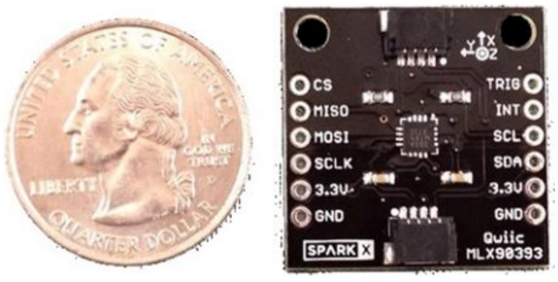

Figure 1. A micro-electro-mechanical sensor

Figure 2. Proposed Profile Paths for the Survey Using Magnetometers [17]

The length of each of the surveyed profiles, along with the acquisition time for each profile, has been summarized in Table 1.

As mentioned in Table 1, the survey duration for 27 profiles is approximately eight and a half hours. The total length of the profiles is 23211 meters, and the number of collected samples is 1134450. The spacing between samples along the profiles ranges from 1.5 to 3.6 centimetres. It's worth noting that this small spacing between samples is made possible due to the high sampling rate of the sensor, allowing for measurements along the profiles to be nearly continuous compared to proton magnetometers.

Table 1. Information about data survey along each profile

Profile number	Start time (GMT)	End time (GMT)	Survey duration	Number of samples	Sample spacing (cm)	Profile length (m)
1	06:29:40	06:34:09	00:04:29	10001	1.5	141
2	06:35:56	06:39:59	00:04:03	9001	2	247
…	…	…	…	…	…	…
26	11:56:27	12:09:25	00:11:38	28901	2	600
27	12:12:07	12:22:05	00:9:58	23001	2.6	600
Total	08:26:27	1134450	-	23211	-	-

FINDINGS AND ARGUMENT

The first step in data processing after inputting the data into the Oasis Montaj software is the removal of spikes or anomalies from the data. Following this stage, the data is prepared for grid generation. In this phase, the total magnetic intensity (TMI) is computed using the Oasis Montaj software. Figure 3 illustrates the map of TMI within the study area.

The results obtained from the previous measurements with the proton magnetometer in this area are shown in Figure 4.

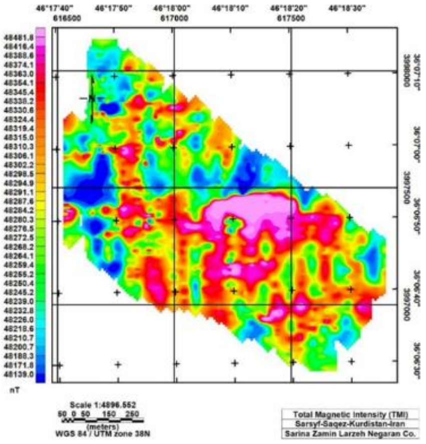

Figure 3. Map of the total magnetic intensity (TMI) derived from the survey in the SarSef-Saqqez region, obtained using the sensor

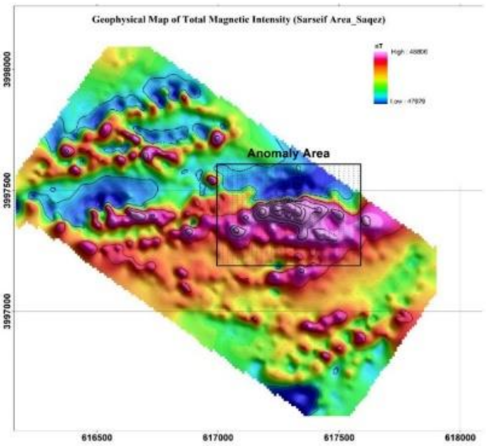

Figure 4. Map of the total magnetic intensity (TMI) of the Earth in the SarSef-Saqqez region using the proton magnetometer

This map has also been generated using the Oasis Montaj software. As expected, the TMI map obtained from the magnetometer sensor data closely aligns with the obtained TMI map from the proton magnetometer. Especially, the main dipole resulting from the main anomaly, with its centre located at coordinates 617250 E and 3997499 N, is well detected by the sensor measurements. Smaller dipoles in the southern part of the main anomaly are also well captured by the sensor. In the western part of the map of TMI obtained from the magnetometer sensor, smaller anomalies resulting from minor anomalies are not clearly visible. It is likely that by addressing the leveling errors, these minor anomalies in the western section will become more apparent. However, it appears highly probable that these anomalies in this region are not associated with an economic deposit. The data collected using the proton magnetometer in Table 2 have been compared with the measurements made using the sensor.

Table 2. Comparison of data acquisition with MEMS sensor and proton magnetometer

Magnetometer type	Number of samples	Distance between samples (meters)	Duration of survey (hours)	Survey cost (unitless)
Proton magnetometer (scalar)	2085	10	45	1000
MEMS sensor (vector)	113445	3.0	5.8	200

The numbers in Table 2 actually represent the advantages of using a MEMS sensor in magnetic data acquisition. The spacing between samples in data acquisition with the MEMS sensor is such that this type of acquisition can be considered continuous. More importantly, the time required for field operations is significantly reduced in the case of data acquisition with the MEMS sensor, roughly one-fourth of the time needed for proton magnetometer-based acquisition. Additionally, the cost of data acquisition using the MEMS sensor is approximately one-fifth of the cost of proton magnetometer-based acquisition. Furthermore, since the MEMS sensor is of vector type, it allows for extracting additional information such as the direction of the Earth's magnetic field.

CONCLUSIONS

The deployment of micro-electromechanical system (MEMS) sensors in magnetometry is in its early stages, and their sensitivity is not as high as traditional magnetometers. However, considering the need for low-cost and rapid geophysical methods in mineral exploration, the potential use of MEMS sensors is being explored. In this study, one of the most precise and low-error micro-electromechanical sensors has been chosen. Data were then collected over a metallic deposit using this sensor. These acquisitions were compared to a magnetic survey using a proton magnetometer. This comparison demonstrates that the MEMS sensor effectively detects the two poles resulting from the main anomaly present in the study area. Moreover, by addressing leveling errors, it is likely that smaller anomalies in the study area will become visible. Additionally, this research shows that using MEMS sensors can reduce the time and the cost of magnetic field survey operations by approximately one-fourth and one-fifth, respectively, compared to conventional methods. This is while the data collected with the MEMS sensor is nearly continuous. Furthermore, the small size of the MEMS sensor allows it to be deployed inconspicuously in the desired area without drawing the attention of potential opponents of magnetic survey operations.

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