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Locating an old well in eastern Nebraska with a low-cost drone-based magnetic surveying system

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Abstract

We assembled a low-cost drone-based magnetic surveying system from a Scintrex ENVI PRO proton magnetometer and DJI Matrice 600 Pro drone. We used this system to locate an old exploration well in eastern Nebraska that is now out of sight in the middle of a cornfield. Because the well was drilled nearly five decades ago, before the advent of GPS, its coordinates are inaccurate. We used the magnetic signature of the well's casing to locate it. Our survey shows the pronounced magnetic anomaly approximately 35 m to the southwest of the well's database coordinates. The results of our survey show that our drone-based magnetic system provides a fast and efficient way to record magnetic data.

Introduction

There are millions of abandoned petroleum wells in the United States and around the world. If not sealed properly, these wells can act as conduits for contaminants, presenting a potential hazard to groundwater (e.g., Gass et al., 1977). These abandoned wells can allow the release of methane (e.g., Kang et al., 2016; Williams et al., 2021), so a proper audit of them is necessary. Repurposing abandoned wells for geothermal energy extraction is a way to convert these potential environmental hazards into useful infrastructure for practical green energy initiatives (e.g., Bu et al., 2012; Kurnia et al., 2020; Santos et al., 2022). However, many old petroleum wells were drilled before the advent of GPS, and their exact locations are inaccurate. This paper presents an example of locating an old exploration well in the middle of a cornfield in eastern Nebraska that is not evident at the surface. It is based on two research projects conducted by undergraduate students from the geophysics team at the University of Nebraska–Lincoln (UNL). The first project, by Erik Jacobson, involved assembling and testing the drone-based magnetic surveying system (Jacobson and Filina, 2019; Jacobson, 2020). The second project, by Sulaiman AlBadi, utilized this system to locate an old well in eastern Nebraska (AlBadi, 2021).

Drone-based magnetic surveying is becoming more popular for near-surface mapping (e.g., Quigley et al., 2022). It can be utilized in a wide range of projects including unexploded ordnance location (e.g., Mu et al., 2021), mining exploration (e.g., Malehmir et al., 2017; Cunningham et al., 2018), and environmental and hydrogeologic purposes (e.g., Jansen and Bell, 2019). A sharp rise in the use of drones in geophysical surveys (e.g., Lane and Stoll, 2017) prompted SEG to form a subcommittee that was tasked to put together a set of guidelines for geophysical drone-based surveys (Near-Surface Geophysics Inter-Society Committee on UAV Geophysics Guidelines, 2022). The first version of the drone-based magnetic guidelines was released in 2022.

Drone-based magnetic surveying system

Airborne magnetic surveys that use drones have many advantages such as low cost, low risk, low speed, and low flight elevations. This results in better target resolution with respect to other flying platforms such as aircrafts or helicopters. However, a drone-based system also has several disadvantages including limited flight time and distance, which both depend on the drone's battery capacity and weight of the magnetic system. The UNL geophysics team assembled a low-cost drone-based magnetic surveying system to conduct fast and efficient magnetic measurements. Our system (Figure 1) (Jacobson and Filina, 2019) includes an ENVI PRO magnetometer attached to a DJI Matrice 600 Pro drone. The proton magnetometer is a battery-powered, lightweight, and

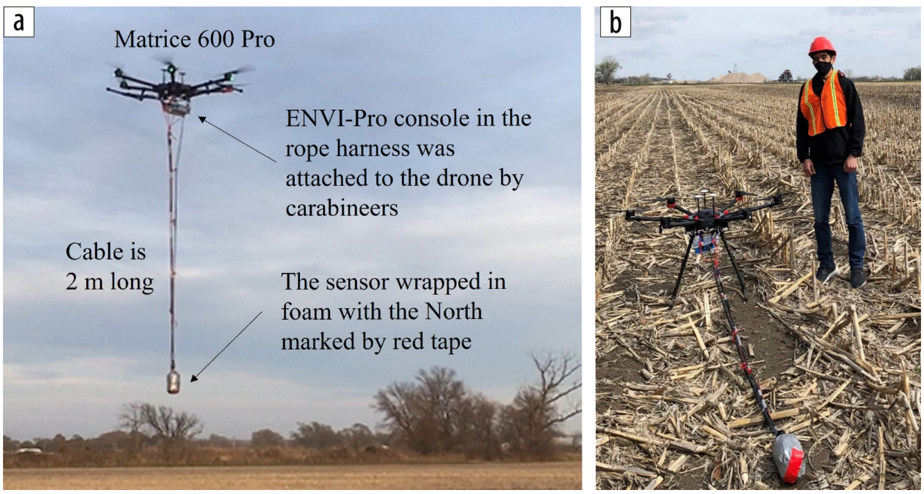

Figure 1. (a) The drone-based magnetic surveying system assembled by the UNL geophysics team. The total weight of the magnetic sensor and console is 3.4 kg. The DJI Matrice 600 Pro drone is capable of flying with this load for up to 20 minutes. Our tests allowed us to formulate the following optimal flight parameters: flight elevation is 7 m (the sensor is located 2 m beneath the drone), flying speed is 2 m/s, and magnetic field is sampled every 2 s. (b) The system is prepared for deployment. Sulaiman AlBadi serves as a scale.

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durable instrument that was introduced by Scintrex in 1994. It is capable of storing up to 188,000 data readings in internal memory. We used it in WALKMAG mode, which allows continuous data acquisition while using the device on the move. In addition to magnetic readings, the system records the noise level of the readings rated on a scale from 0 to greater than 10. Values from 0–1 correspond to low noise, 1–10 indicate moderate noise, and greater than 10 denote high noise data. Notably, the ENVI PRO sensor must be properly oriented during surveying, which must be done after take-off and before starting the survey.

Metallic parts and electromagnetic fields produced by the wires in the drone generate magnetic noise that is picked up by the magnetometer's sensor. This magnetic noise was carefully assessed and accounted for in the design of an aeromagnetic system (Figure 2). ENVI PRO noise measurements were recorded as the sensor was placed at different distances with respect to the drone, suggesting that the minimal clearance should be 66 cm. We used a 2 m long cable (Figure 1) to deploy the sensor beneath the drone, which is also necessary to protect the sensor during the drone's take-off and landing.

Our system takes advantage of low-cost components that were available to us. This sets our system apart from other commercial systems, such as MagArrow from Geometrics, which was designed specifically for drone operations and has built-in GPS trackers. In our case, we utilized the GPS units mounted on the drone itself. The magnetometer records time stamps along with magnetic readings. The drone records the time and geographic coordinates along with many other flight parameters such as elevation, heading, etc. We ensured that the time settings were synchronized between the magnetometer and the drone so we could use the time stamps to position our magnetic readings based on the drone's navigation data.

Once the system was assembled, we tested it during several flights at different speeds and elevations. Based on trial and error, we developed the following operational procedures:

1) The time settings should be synchronized between the drone and magnetic system before each flight to ensure proper data positioning.
2) The sensor should be placed outstretched and to the side of the drone before take-off (Figure 1b). For landing, the drone should be moved aside as soon as the sensor touches the ground so it is not damaged by the drone.
3) The ENVI PRO should be turned on before the drone is powered for the safety of the operator.
4) A 10 s pause is programmed into the flight's mission after each turn at each waypoint. This minimizes swaying of the sensor after abrupt movement.
5) A 2 m/s flight speed is optimal for magnetic data collection at a sampling interval of 2 s (one reading every 4 m). At these settings, the swinging of the sensor is minimal during flight, and the sensor is located nearly beneath the drone.
6) A 7 m flight altitude puts the sensor at a clearance of 5 m. This is high enough to avoid obstacles and low enough for accurate magnetic measurements. Because our survey was over a flat cornfield, this clearance was sufficient.

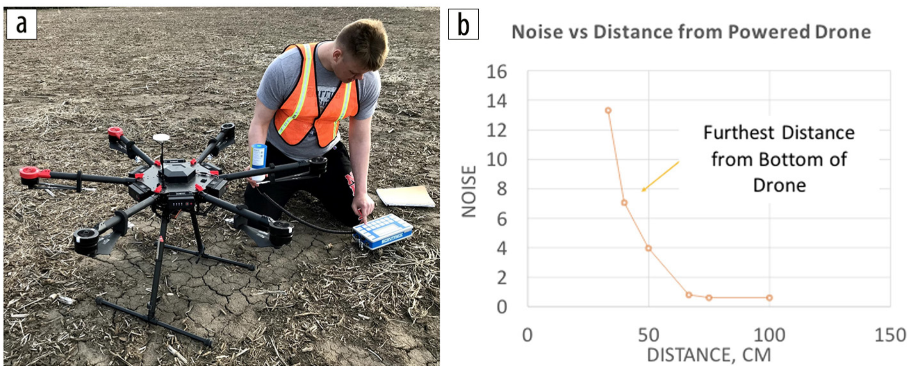

Figure 2. (a) Erik Jacobson measures magnetic noise at different distances from the drone. (b) Noise is a unitless value recorded by the magnetometer in response to outside electromagnetic interference. The noise is minimized at 66 cm. The distance from the ground to the mounting frame is pointed out in this figure as the farthest distance from the bottom of the drone.

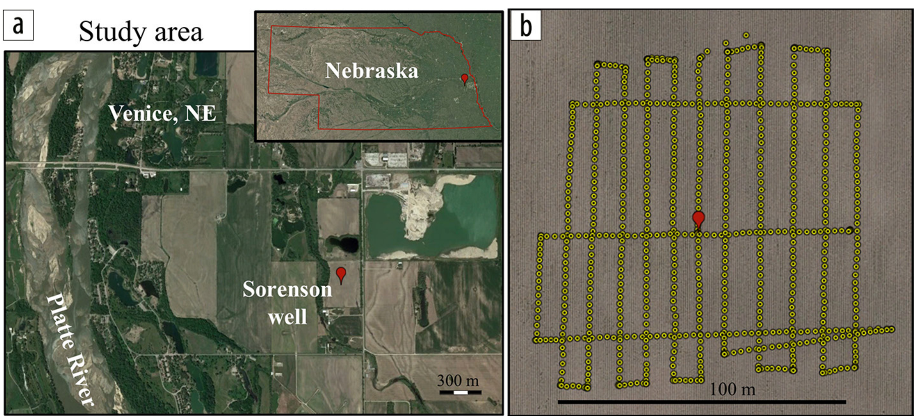

Figure 3. (a) The study area is located in eastern Nebraska over the Sorenson well, which was drilled in 1974 for petroleum exploration. The well was cased with metal pipes, resulting in a strong magnetic anomaly. (b) The 20-minute-long drone-based magnetic survey was performed over the well in early 2021. Yellow circles show the locations of magnetic readings.

Locating an old well in eastern Nebraska

The survey presented in this paper was conducted over an old well known as Sorenson Harry C that had been drilled for petroleum exploration in eastern Nebraska (Figure 3). According to the Nebraska Oil and Gas Conservation Commission (NOGCC), drilling of the well began 22 September 1974 but no hydrocarbons were found. At that time, GPS was not available to precisely locate the drill site. Therefore, we expected that the published coordinates of the well were inaccurate. The objective of our survey

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was to determine the exact location. A strong magnetic signature over the well was expected because the well is cased with metal tubes. Our survey included one flight (Figure 3b) centered over the well coordinates provided by NOGCC (41°13′28.73″ N, 96°19′57.26″ W) (shown by white circles in Figure 4). Figure 4a shows a magnetic anomaly after the ambient magnetic field for that location was removed. The value 53,042 nT was obtained for a day of the survey via an online calculator provided by the British Geological Survey. A magnetic map after applying reduction-to-the-pole (RTP) using the inclination of 68.2° and declination of 2.6° is shown in Figure 4b. RTP removes skewness of the recorded magnetic anomaly due to the nonverticality of an ambient magnetic field, so we applied this transformation to better locate the well. The magnetic anomaly suggests that the well is approximately 35 m southwest of its published NOGCC location (red circle in Figure 4b). We interpret that the well is located in the center of the pronounced magnetic anomaly. The updated well coordinates are 41°13′28.16″N, 96°19′58.58″W. In addition, the magnetic data in Figure 4b suggest that the well is not exactly vertical because the magnetic anomaly shows some deviation from the circular pattern that is expected for a vertical well. Based on the RTP magnetic signature (Figure 4b), we concluded that the wellbore is slightly tilted to the northeast. We plan to ground truth the inferred location of the well during a future ground-penetrating radar survey.

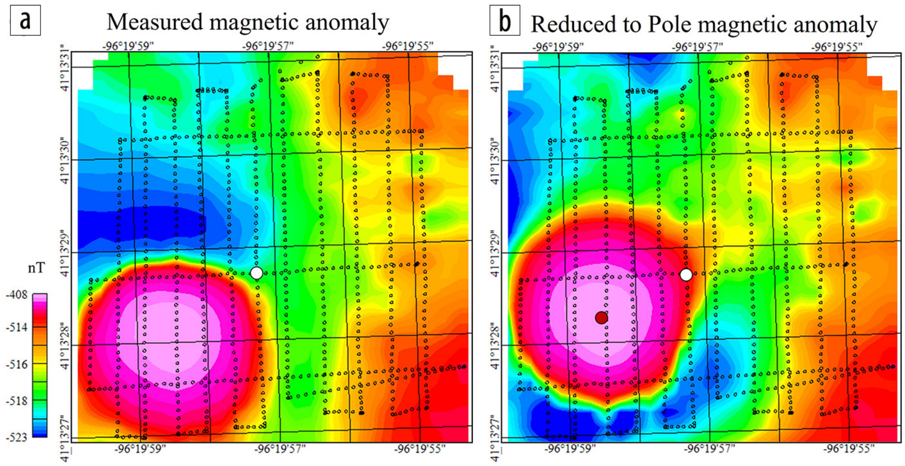

Figure 4. (a) Magnetic anomaly (after the ambient field was removed). Sorenson well location from the database is marked by a white circle. The flight path is shown with black dots. Note that magnetic anomalies are skewed due to nonverticality of the ambient magnetic field (the inclination is 68.2° and declination is 2.6°). (b) RTP magnetic anomaly. The well's location is interpreted in the center of the pronounced magnetic anomaly (marked by a red circle), which is approximately 35 m to the southeast of the well's database coordinates.

Conclusions

We assembled a low-cost magnetic acquisition system from an ENVI PRO proton magnetometer and DJI Matrice 600 Pro drone. The system is capable of flying for about 20 minutes on a single set of batteries. We conducted several test flights and concluded that a drone speed of 2 m/s and flight elevation of 7 m (sensor clearance of 5 m) are the optimal flight parameters to minimize swinging of the sensor beneath the drone and to mitigate noise. We acquired magnetic data over the Sorenson well in eastern Nebraska, which allowed us to successfully locate the well approximately 35 m southwest of its published location. Despite its low cost, our system appears to be efficient and allows us to acquire reliable magnetic data. TLE

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Data and materials availability

Data associated with this research are available and can be obtained by contacting the corresponding author.

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