Integrated development of aeromagnetic system based on UAV platform and its application in mineral resources exploration

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Abstract. The geophysical measurement method based on the Unmanned Aerial Vehicle (UAV) platform is an emerging branch of airborne geophysical technology. Based on the unmanned helicopter platform, this paper develops a set of aeromagnetic field measurement system and used it in the field of mineral resources exploration with complex terrain condition. The aeromagnetic survey of the crisis mines in the Maanshan area of China was carried out using a UAV aeromagnetic measurement system. Three-dimensional inversion of the underground geologic structure was carried out, and discover the magnetite deposits in the deep and peripheral areas of the mining areas, which provided technical support for determining the drilling position for the crisis mine secondary exploration.

1. Introduction

In recent years, with the maturity and intelligent development of drone platforms, UAV aerial geophysical has become an emerging branch of airborne geophysical technology. The UAV platform has been widely used in digital photogrammetry, geological survey, disaster monitoring and other fields due to its strong environmental adaptability, low application cost and high personnel safety. The aeromagnetic exploration system based on the UAV platform has a broad application prospect by measuring the earth's magnetic field signals and realizing the mineral resources survey and structural division. In recent years, Magsurvey, the Netherlands, Fugro, Carleton, and Japanese companies have developed aeromagnetic measurement systems based on UAV platforms, which have been effective in volcano monitoring, mineral exploration, and unexploded ordnance detection [1,2].

Tikhonov and Arsenin solved the ill-posed problem of inversion by applying the minimum norm constraint to physical property parameters through regularization technique [3]. Tarantola and Valette described the method of using the damped least square method to solve generalized nonlinear inversion problems, so as to obtain stable solutions [4]. Pilkington proposed the use of preconditioned conjugate gradient algorithm to solve the discrete inversion problem of magnetic data, reducing the need for memory and avoiding a lot of multiplication [5]. In this paper, the unmanned helicopter is selected as the aeromagnetic equipment carrying platform for the integrated development of the UAV aeromagnetic measurement system. We apply the aeromagnetic measurement system based on UAV to the application of crisis minerals in Maanshan area of China, and the three-dimensional inversion of aeromagnetic data was carried out to identify the ore deposits in the deep and marginal of mineral resources.
2. Aeromagnetic measurement system

The aeromagnetic measurement system consists of two major parts: the UAV platform and the aeromagnetic measurement equipment. The UAV platform was selected as an oil-powered unmanned helicopter with a maximum payload of 45 kg, a battery life of 2 hours, and a general cruising speed of 60 km/h. The aeromagnetic measurement equipment consists of a fluxgate magnetometer, a high-precision potassium pump magnetometer, an altimeter, an inertial navigation module, a data collector, and a data processing platform (Figure 1).

![Figure 1. Aeromagnetic measurement system based on the UAV platform.](image)

The interference field generated by the UAV platform itself mainly includes three parts: constant field, induction field and eddy current field. In order to eliminate the interference field brought by the UAV platform, the traditional method is to eliminate the interference by using the post-compensation algorithm (Noriega, 2013). In this paper, the magnetic interference field is compensated by the method of post-compensation. In order to obtain better compensation result, the magnetometer should be far away from the UAV body, but considering flight safety, the magnetometer is placed in the front of the drone in a hard-framed manner, and the gradient value of the magnetic interference field at the position of the magnetometer is small. Other equipment is placed in the center of the UAV body. The integrated UAV aeromagnetic measurement system is shown in Figure 2. The magnetometer is located at the front of the UAV platform at a position of 2.4 meters. The UAV and the magnetometer are connected by a carbon fiber rod. The other electronic equipment is located in the center of the UAV and is processed by a rectifying device to ensure the safety and stability of the flight.

![Figure 2. Aeromagnetic survey integrated system based on UAV and the actual flight test.](image)

3. 3D inversion theory and method

The relationship between potential field observation data and physical property parameters is generally linear:
where, the column vector \( d \) is the ground observation data, which can be any kind of potential field data, and its dimension is \( N \). The column vector \( m \) is the physical parameter, and its dimension is \( m \). The matrix \( A \) represents the forward operator connecting the observed data \( d \) with the physical parameter \( m \), and is an \( n \)-by-\( m \) matrix. \( W_m \) is a reference model determined based on prior information. Then the conjugate gradient method is used to solve the linear equation. The depth weighting function and the horizontal weighting function \( W_z \) and \( W_h \) is:

\[
W_z = \frac{1}{(x+z_0)^{\beta/2}} \frac{1}{(H-z_0)^{\beta/2}},
\]

\[
W_h = \begin{cases} 
\frac{1}{(|d_f(x,y)|^T)} & |d_f(x,y)| \geq 1, \\
1 & |d_f(x,y)| < 1,
\end{cases}
\]

\[
W_m = W_z W_h.
\]

the objective function is:

\[
\phi = \phi_d + \alpha \phi_m = ||Ak - \Delta T||_2 + \alpha ||W_m k||_2
\]

the conjugate gradient algorithm is used to solve the inversion results iteratively.

We construct a model with two prisms, and the ranges of the two prisms are 500m to 800m and 1100m to 1400m in the \( x \) direction, 600m to 900m in the \( y \) direction, and 200m to 400m and 300m to 600m in the \( z \) direction. The inclination of magnetization is 90° and the declination of magnetization is 0°.

**Figure 3.** The magnetization Angle is 90°, and the theoretical magnetic anomaly data of the two rectangular models are simulated forward.(a)Za; (b)Hax; (c)Hay; (d)\( \Delta T \).

The inversion results are shown in Figure 4.
It can be seen from the figure 4 that the central position of the two prisms inversion models still fits well with the position of the actual prisms. It shows that this method is feasible and accurate. Moreover, this method is fast in calculation, and it is easier to get valuable results through reasonable constraint upper and lower limits.

4. Aeromagnetic data measured in Ma'anshan area
The survey area is located in Ma'anshan City, Anhui Province, China. The mining of mineral resources in the survey area is relatively high, and the ground infrastructure and topographic conditions have brought great difficulties to the traditional ground geophysical work (Figure 5). In order to find mines in the deep and outer areas of the old mines in the area, we carried out a 1:10000 scale high-precision aeromagnetic work based on UAV platform in the area. the magnetic data need to been processed by a standard workflow (Figure 6) to obtain the magnetic anomaly corresponding with the underground geological sources.
Figure 6. The magnetic data processing workflow.

Figure 7. Inversion results of aeromagnetic data from Ma'anshan. (a) Horizontal slice ($z=300m$); (b) Vertical slice; (c) Slice map.

We use the 3D inversion method to interpret the aeromagnetic data. It can be seen from the inversion results that the inversion results are basically consistent with the measured data. And the depth of the orebody is about 1200m. The accuracy of this method is further demonstrated.

5. Conclusion
The aeromagnetic measurement system based on the UAV platform can complete regional magnetic field measurement with safety, high efficiency and high sampling rate. In this paper, a stable aeromagnetic measurement system with high resolution is developed based on the unmanned helicopter platform. In order to detect more mineral resources in the crisis mine, the practical UAV aeromagnetic measurement system is applied to the magnetic anomaly measurement of the mine.
mine, and the data is corrected by the standard aeromagnetic data processing workflow, and then the magnetic anomaly of underground geological structures is obtained. The 3D forward and inversion method is used to interpret the aeromagnetic data in detail, and many magnetite anomalies are found in the periphery and deep areas, which advantageously supports the next-step drilling work.

References

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