A New Semi-airborne Transient Electromagnetic System and Application of Detecting Underground Conductor in East Ujimqin Banner, China

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Abstract—**Airborne electromagnetic method (AEM) as an efficient, regional geophysical electromagnetic method has been widely used in geological survey, mineral exploration, environmental monitoring and other fields, but not in China for the civil aviation law and the safety consideration. We introduce a new semi-airborne transient electromagnetic (S-ATEM) system based on the unmanned aerial vehicle (UAV), and use a grounded electrical wire source which can provide a larger moment compare to the traditional AEM. We have taken an survey in East Ujimqin Banner, north east of China and the survey result indicates that the S-ATEM system has a greater investigation depth compared to the ground TEM system, and with more efficient, low cost, and safety.**

Keywords—s-atem system; UAV; induction magnetic sensor; field survey

I. Introduction

Airborne electromagnetic method originated in the fifties and sixties of the last century, it is an efficient, regional geophysical electromagnetic method. Helicopter or fixed-wing aircraft is used as the flying platform in traditional airborne electromagnetic system. The transmitting system and the receiving system are both mounted on the flying platform. The mobility of the flying platform makes it very suitable for large area exploration. But there are two major issues limiting the application of the airborne electromagnetic method. Firstly, the limitation of magnetic moment generated by magnetic source mounted on the flying platform. Secondly, the small transmitter-receiver distance couldn't get a considerable investigation depth.

Semi-airborne transient electromagnetic system is a hybrid ground-air system that combines the use of a large ground wire or loop transmitter with an airborne receiver. The purpose of the semi-airborne transient electromagnetic system is to improve the investigation depth of airborne electromagnetic system. Elliott developed a fixed loop airborne transient electromagnetic (FLAIRTEM) system[1], which uses magnetic source. The side length of the transmitter loop is usually several kilometers, and had make many testing surveys in Australia and Papua New Guinea over a number of mineral deposits[2]. Mogi et al. from Japan developed a new airborne EM system named grounded electrical source airborne transient electromagnetic (GREATEM) system[3]. The GREATEM can obtain a greater depth of investigation using a grounded wire source and a long transmitter-receiver distance. Then they use the GREATEM for the volcanic structure[4, 8], the coastal zone underground structure[5, 7], and the tunnel investigation[6]. Previous studies show that GREATEM can be used in both resistive and conductive area. The investigation depth of GREATEM can be up to 800m at resistive area and more than 300m at a conductive area. Richard Smith et al. makes a comparison of survey data from airborne (GEOTEM), semi-airborne (TerraAir), and ground (PROTEM) electromagnetic systems[9]. It shows that semi-airborne EM system has a greater investigation depth compared with traditional airborne EM system, and has a lower cost compared with ground based TEM systems.

We introduce a new semi-airborne transient electromagnetic (S-ATEM) system in this paper. The S-ATEM system uses a grounded electrical wire source more than 2km length and a three-component induction coil which mounted on a towed bird. The bird is towed under the unmanned aerial vehicle (UAV), a high-precision inertial navigation system (INS) is also mounted on the bird, which can monitor and log the coordinates and attitude of the EM sensors. The S-ATEM can be widely used in geological survey, mineral exploration, environmental monitoring, and other fields due to the small size, light weight, low cost, easy implementation, and safety comparing to the traditional airborne EM systems.

II. Methodology

A. S-ATEM System

Fig.1 shows an overview of the S-ATEM system, includes transmitter unit, receiver unit, aerial platform unit, and data processing unit, the specification of S-ATEM is showed in TABLE I.

The transmitter unit consists of power generator, square pulse transmitter, several kilometers cable and grounded electrodes. The outputted bipolar square current pulse with specific frequency can radiate electromagnetic signal into the ground by the transmitting wire. The max output voltage is 1000V, and the max output current is 40A. The duty cycle of the transmitter can be adjusted from 0 to 100%, and the repeated frequency can be selected from 10kHz to 15s according to the expected survey depth.

The receiver unit includes a multi-channel receiver, three-component induction magnetic sensor and INS. Multi-channel receiver is installed under the bottom of the UAV. The magnetic sensor and INS are towed in the bird suspended beneath the UAV with a distance of about 25m. The receiver has six 24 bit, 48ksps ADCs to record the electromagnetic signals of three orthogonal components, and sets different channel gain from 256 to 1/4 for data recording. A new orthogonal three-component induction magnetic sensor is designed for the S-ATEM system, with the characteristic of larger effective area, higher resonant frequency and lower noise for a greater depth investigation.

The dynamic attitude measurement accuracy of INS is 0.1 degree, even the attitude accuracy can reach 0.05 degree when do the differential calculation with the base station data on the ground. An UAV with payload more than 80kg is chosen for the consideration of system weight and safety.

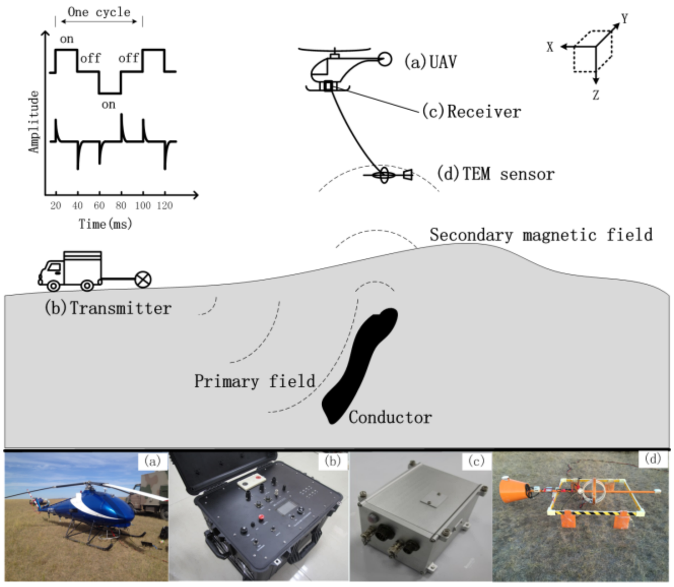

Fig. 1. Overview of S-ATEM system (a) UAV platform (b) Transmitter (c) Multi-component receiver (d) Towed bird. Towed bird contained the three-component induction magnetic sensor and INS.

B. Data Processing

Data processing has four main parts and the flow chart is show in Fig.2.

a) Motion-induced noise correction

Motion-induced noise is removed by the ensemble empirical mode decomposition (EEMD) method. It decompose the EM signal into N order intrinsic mode functions (IMFs) and residual function, and rejects the IMFs of low frequency component which is considered to be the motion-induced noise. After reconstruction, a motion noise free EM signal can be obtained.

b) Attitude correction

The attitude and coordinate data is collected for attitude correction and inversion using INS unit and GPS logger. Attitude data includes yaw, pitch, and roll representing angles of the bird. A rotation matrix for attitude correction of the raw EM data makes the attitude correction simply. The matrix R is three by three with the variety of δ_Y, δ_P and δ_R representing yaw, pitch, and roll of the bird respectively. The corrected data is calculated by the formula $H = RH'$, where H is the raw survey data and H' is the corrected data.

TABLE I. SPECIFICATIONS OF S-ATEM SYSTEM

Specification of Transmitter	
Input power	AC 50/60Hz 380V,50kW
Output waveform	Bipolar square wave
Base frequency	15s~10kHz
Current duty	0~100%
Output current	1A~40A
Output voltage	20V~1000V
Maximum power	20kW
Synchronization	GPS + OCXO
Synchronization accuracy	100ns
Current waveform digital record	Yes,48kSPS, 24bit, 0.5A resolution
Specification of Multi-channel Receiver	
Observing field	X, Y, Z
ADC Channels	6
Signal gain	0.25,1,4,16,32,64,128,256
Sampling rate	48kSPS
Input signal range	-10V~10V
ADC bit width	24bit
Dynamic range	160dB
Synchronization	GPS + OCXO
Control interface	RS232, RS485
Attitude monitoring and accuracy	Three-axis,±0.05 degree
Position accuracy	Centimeter after differential processing
Controller and processer	ARM+DSP
Control mode	WIFI and digital radio
Storage capacity	32GB
Power consumption	8W
Weight(with battery)	3.2kg
Specification of Induction Magnetic Sensor	
Effective area(m^2)	X (5700) Y (5800) Z (24000)
Resonant frequency(kHz)	X (29.7) Y (23.5) Z (9.7)
Noise level	1mV @20kHz (18nT/s) 83uV @1kHz (1.4nT/s)
Bird weight	18.7 kg

c) Stacking and filtering

Data stacking and filtering is used to minimize the random noise and cultural noise. The speed of UAV is about 15m/s, and the repeated base frequency is 12.5Hz, we can get the lateral resolution up to 30m and stack cycle signal up to 50 times when taking time interval of 2s. It may be more effective to use 4s interval or overlap 50% of each neighbor interval in noisy environment. A median filter is also used to smoothing the decay after we got the transient curve.

d) One-dimension model inversion

One dimension occam's inversion based on smooth model is used for the inversion of the field data underground, and we can get the structure subsurface by comparing the field curve to the theoretical curve.

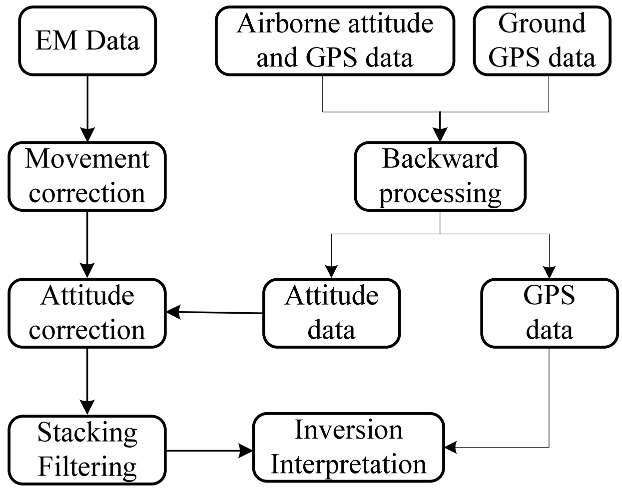

Fig. 2. Data processing flow chart of S-ATEM system

III. Application and Result

The survey site is located in the East Ujimqin Banner, north east of China, which is belonged to the middle east Inner Mongolia Plateau with an average altitude of about 913m. The survey area is about eight square kilometers, we had designed 11 flight lines spaced 200m, and each line has a length of 5km. A 2.2km long transmitter wire was placed in the middle of the survey area along a straight road. The source signal was a square waveform current of 20A with 50% duty cycle at 12.5 Hz. Due to the UAV duration capacity, there are less than 9 lines can be covered in each flight. The flight path was showed in Fig.3 which looks like a clip. To verify the inversion result, we compared a piece of data to a borehole, which is showed at the arrow point in Fig.3. The inversion result showed in Fig.4 is plotted by a pseudo-color map. The black dash line is the borehole location, and the borehole data is showed in the right of Fig. 4.

There are 4 resistivity layers at the borehole location from surface to the deep in resistivity profile. The resistivity of the first layer is about 300~500Ωm, and the depth is from surface to 30m underground, corresponding to the perched sediment and gravel bed layers of the borehole data. The perched sediment and gravel bed has the similar resistivity due to the influence of surface weathering and precipitation. The resistivity of the second layer is about 1000~2000Ωm, and the depth is from 30m to 150m underground, corresponding to the oxidized pedestal rock and limestone layers of the borehole data with resistivity difference is not obviously. The resistivity is about 300~500Ωm in the middle and 500~800Ωm at the border of the third layer. There are two reasons under this circumstance, one is the gradually varied at the contacted region of the two lithology layers, the other is the occam's inversion based on a smooth model. The depth is from 150m to 300m underground, corresponding to the granite layer with strong pyritization. The last layer corresponding to the sandstone layer of the borehole data, the pressure make the sandstone hard and density, showing a high resistivity more than 2000Ωm.

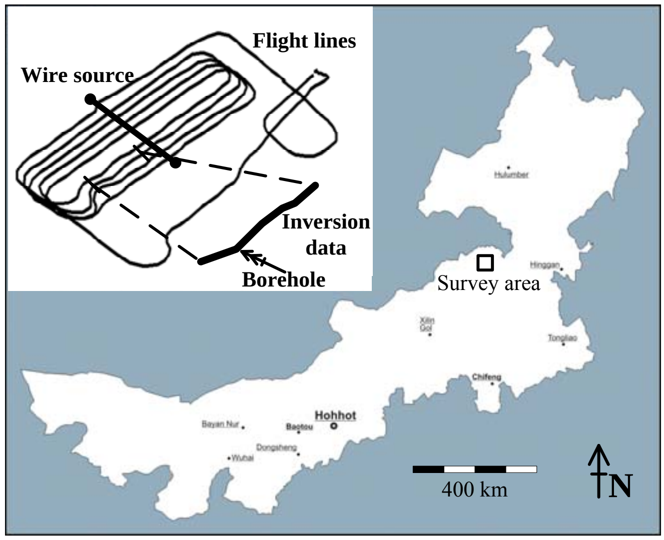

Fig. 3. Survey site location and flight information

As comparing the inversion profile to the borehole lithology, the inversion result and borehole data fit well with each other, the resistivity anomy and the layer segmentation mostly accords with the borehole data, and it proves that the S-ATEM system can successfully and effectively detected underground resistivity distribution of subsurface.

IV. Conclusion

we introduced a new S-ATEM system based on UAV, including system configuration and data processing method. A testing survey was also carried out to validate the applicability of the S-ATEM. The testing survey result demonstrates that the S-ATEM system has an investigation depth more than 400m, and the advantages of lower cost, portable , higher efficiency, and more safety compared with the traditional EM system.

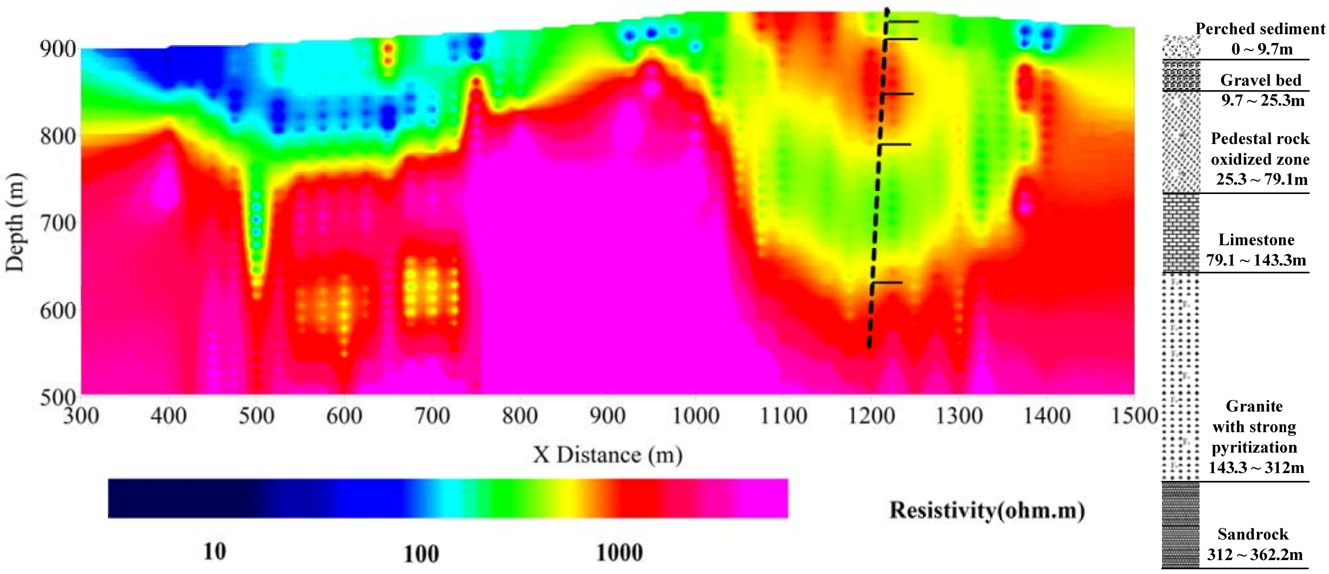

Fig. 4. Inversion profile and comparing to borehole lithology layer

ACKNOWLEDGMENT

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