Application of Technology of UAV-Mounted Ground Penetrating Radar in the Study of the Thickness of Soil Plow Layer

Jianshan Hou, Youqian Yan and Peitong Cong*
College of Water Conservancy and Civil Engineering, South China Agricultural University, 510642 Guangzhou, China
Email: 2802062305@qq.com

Abstract. When the detection field is a large field, the traditional ground penetrating radar system has the problems of low detection efficiency and high labor cost. Aiming at this problem, an integrated system of UAV-mounted ground penetrating radar is designed, and a detection method based on UAV-mounted ground penetrating radar is proposed. Taking a small area of cultivated land in Taiyuan, Shanxi as an example, the detection method of UAV-mounted ground penetrating radar is applied to measure the thickness of soil cultivated layer. After the collected data is extracted and linearly interpolated, the thickness of the cultivated soil layer obtained by image analysis is similar to the measured thickness of the soil cultivated layer, which highlights the advantages of high efficiency and low cost based on the detection method of UAV-mounted ground penetrating radar, making the detection of concealed loose bodies in large sites becomes possible.

Keywords. UAV, ground penetrating radar, integrated system, radar host, amplitude value.

1. Introduction

Ground-penetrating radar detection technology has been widely used in many industries because of its non-destructive, high-efficiency, and high-precision characteristics. At present, domestic ground-penetrating radar detection mainly relies on manual hand-held and hand-pushed detection and scanning to obtain real-time ground-penetrating radar images. In order to improve detection efficiency, domestic scholars have carried out research on vehicle-mounted ground penetrating radar, focusing on the impact of detection distance, detection speed, antenna selection on detection results of non-contact ground penetrating radar vehicle-mounted system [1] and vehicle-mounted array ground penetrating radar Radar local hazard detection technology [2]. Although the domestic and foreign countries have accelerated the pace of integrated research on UAV-radar integration in recent years, a UAV-equipped synthetic aperture (SAR) imaging system for detecting landmines and explosive devices has been proposed [3], and an unmanned aerial vehicle-stepped frequency continuous wave (SFCW) radar for buried mine detection has been introduced [4], the research on the integrated integration of unmanned aerial vehicle and ground penetrating radar is still in the exploratory stage [5-6]. Although the detection technology of the vehicle-mounted ground penetrating radar can quickly obtain the geological radar image, there are problems that the radar image collected is distorted and the measurement accuracy is insufficient due to the excessive speed of the car [7-9]. To this end, this article discusses the application of UAV-mounted ground penetrating radar detection technology, which can be used to efficiently detect large-scale flat areas and steep mountains.
2. Hardware System

2.1. UAV Platform
The DOPX35 fire extinguishing UAV is designed with 6 rotors and the whole machine is made of carbon fiber. The CNC folding arm can minimize the transportation volume and facilitate transportation. The wheelbase is about 2 meters, the empty machine weighs 35 kg (including battery), and it uses pure electric power. The flight time is 15-20 minutes, the maximum take-off weight is 80 kg, the payload is 35kg, and the maximum flight speed is 20 m/s. This UAV is mainly suitable for large-scale logistics, emergency rescue, and forest fire extinguishing occasions.

2.2. The Working Principle and Parameter Setting of GPR
Ground penetrating radar uses high-frequency electromagnetic waves in the form of broadband short pulses, which are transmitted underground from the transmitting antenna T [10]. The electromagnetic waves propagate in the underground medium and are reflected by the underground target or stratum boundary and then received by the receiving antenna R (figure 1). The radar host receives the electromagnetic wave signal through the optical fiber and converts the electromagnetic wave signal into a time series signal. Time required for pulse electromagnetic wave travel:

\[ t = \frac{\sqrt{4h^2 + s^2}}{v} \]  

where the buried depth of the target body is \( h \), the distance between the transmitting antenna and the receiving antenna is \( s \), the propagation speed of electromagnetic waves in the medium is \( v \). The value of \( v \) can be approximated by equation (2):

\[ v = \frac{c}{\sqrt{\varepsilon}} \]  

where \( c \) is the vacuum wave velocity of electromagnetic waves, which equals 3.0×10^8 m/s; \( \varepsilon \) is the relative permittivity of the medium.

During the measurement operation, the ground penetrating radar collects the waveform sequence on the point to be measured, and then forms a longitudinal section view composed of many recording tracks. The GPR profile is processed and interpreted by interpretation software, and the target information of the profile below the detection line can be obtained [11-12].

![Figure 1. Working principle diagram of GPR.](image)

The Transceiver Separate Radar (PluseEKKO) produced by Sensors&Software of Canada has the advantages of strong anti-interference ability, high signal-to-noise ratio, common center point, common offset, wide-angle acquisition and transmission acquisition [13]. This ground penetrating radar is mainly composed of radar host (including master and slave), optical fiber, transmitter, receiver, antenna and other parts. The acquisition parameters of this detection are shown in table 1.
Table 1. Acquisition parameters of GPR.

| Parameter                  | Value          |
|----------------------------|----------------|
| Antenna center frequency   | 200 MHz        |
| Antenna length             | 1 m            |
| Antenna spacing            | 0.5 m          |
| Dot pitch                  | 0.1 m          |
| Sampling window            | 120 ns         |
| Collection interval        | 0.8 ns         |
| Overlap times              | 64             |
| Battery voltage            | 12 V           |

3. Integrated System of UAV Equipped with GPR

3.1. Mounted Device and Mounted Mode
The detection uses a 200MHz antenna, and the designed carrying device has a length and width of 60.6 cm×46 cm (figure 2). The shaded part is fixed by 6 pine wood strips. (1), (5) are transmitting antenna and transmitter, receiving antenna and receiver respectively; (2) is the battery of the radar host; (4) is the radar host; the dotted rectangular frame (3) is a pine board, and the four corners of the carrying device are equipped with galvanized hooks. In the schematic diagram of the ground penetrating radar carried by the UAV (figure 3), 1 is the UAV; 2 is the radar host; 3 is the transmitter; 4 is the receiver; 5 is the main end (computer) of the wireless signal transmission system; 6 is the slave of the wireless signal transmission system; 7 is the optical fiber; 8 is the wireless transmission system [14-15].

Figure 2. Plan view of the mounted device.

Figure 3. Schematic diagram of UAV equipped with GPR.
3.2. GPR Protection Device
Use a lightweight plastic box (with the opening of the plastic box facing down) that conforms to the mounted device to cover the mounted device from top to bottom, and drill a small hole where the radar host transmits the wireless signal to ensure the signal strength. In order to avoid the ground penetrating radar from receiving the ground impact when it descends and touches the ground, a sponge pad is added at the bottom of the carrying device to buffer the ground impact.

3.3. Radar Host Signal Reception
The radar host has its own wireless LAN (WLAN) transceiver. After the radar host is started and stabilized, search for the wireless network name of the radar host on the main end (computer) of the wireless signal transmission system, enter the password, and open the control website to control the radar host.

4. Test and Analysis
In August 2020, a UAV equipped with EKKO ground penetrating radar was used to detect a farmland in Taiyuan. This measurement operation is divided into three parts: preliminary preparation and flight, extraction of valid data, and data visualization.

4.1. Preparation and Flight
In this experiment, a piece of flat cultivated land in Taiyuan was selected as the operation area. The number of trees in the operation area is small, thereby reducing the safety threats when the UAV takes off. It can ensure that the UAV can normally receive strong GPS signals, and it can also ensure that the main terminal (computer) of the wireless signal system receives the signal transmitted by the WLAN in the ground penetrating radar host to ensure the normal operation of the UAV and the ground penetrating radar. According to UAV landing site requirements and flight environment requirements, plan a suitable UAV route (figure 4). The depth of the detection target is 5 meters, and the detection target is in shallow soil. Therefore, the parameters of the ground penetrating radar are selected as shown in table 1. The contact measurement method of ground-coupled antenna is used for data collection [16]. The vertical distance from the reference line when the drone is operating horizontally is about 5m. When operating vertically, control the UAV to land the ground penetrating radar to the ground measurement area. After the measurement is maintained for 3-5 seconds, the UAV is lifted up, and the ground penetrating radar is slowly translated to the next measurement point, and then slowly vertical whereabouts (figure 4). Collect the data of the points to be measured in this way.

![Figure 4. Contact measurement of ground-coupled antenna.](image)

4.2. Data Analysis
The profile detected by the ground penetrating radar includes the image segment when the drone is flying horizontally and the measurement segment when the ground penetrating radar touches the ground when the UAV is landing. To correct the image, the method is: use band-pass filtering and
background removal technology to eliminate random noise interference and improve the effective reflected wave signal-to-noise ratio; use automatic time-varying gain technology to compensate for medium absorption to increase the energy of the transmitted signal.

When the ground penetrating radar contacts the ground to collect the data of the point to be measured, the measurement time is about 3-5 seconds, and the acquisition mode is free run mode. The data obtained after measuring one point is a segment of data (hereinafter referred to as the measurement segment), so the amplitude values of the midpoints of the 12 measurement sections at different depths are regarded as the amplitude values of the 12 points at different depths. According to the planned route, the plane rectangular coordinate system xoy is established with point 3 in the route diagram as the origin (figure 5).

When x=0, the amplitude values of point 3, point 4, point 9, and point 10 at different depths are known, and the interpolation is performed by linear interpolation to obtain the amplitude values of different depths from point 3 to point 4, point 4 to point 9, and point 9 to point 10. In the same way, we can get the amplitude values of different depths from point 2 to point 11, point 1 to point 12, point 3 to point 1, point 4 to point 6, point 9 to point 7, and point 10 to point 12. In other words, we get the amplitude values of x=10.8, x=22.4, y=0, y=8.5, y=20.5, and y=30 at different depths. Use these amplitude values to make x=0, x=10.8, x=22.4, y=0, y=8.5, y=20.5, y=30 Cross-sectional view (figures 6 and 7), and further make their slice diagrams (figure 8). The shade of the color represents the magnitude of the amplitude value.

Figure 5. Schematic diagram of UAV route.

Figure 6. Cross-sectional view when x=0, 10.8 and 22.4.
When the electromagnetic wave emitted by the ground penetrating radar propagates from one medium to another medium, part of the electromagnetic wave is reflected [17], and the transmitted signal is relatively strong. It can be concluded from the slice diagram that when $z=18$ ns, the
transmitted signal is relatively strong. And when $z$ is less than 18 ns, the amplitude value is relatively high; when $z$ is greater than 18 ns, the amplitude value is relatively low. Therefore, it is inferred that $z=18$ ns is the interface between the cultivated soil layer and other layers. Through time-depth conversion, that is, equation (1), the thickness of the soil plow layer is 86.5 cm. Three points were selected from the detection area for excavation. The measured average thickness of the soil plow layer was 81.3 cm (figure 9).

Figure 9. The measurement of the thickness of the soil plow layer.

5. Conclusion
This article explores several key technical issues of the contact measurement technology of the ground-coupling antenna of the UAV-mounted ground penetrating radar, focusing on the application of the UAV-mounted ground penetrating radar detection technology in the thickness of the soil plow layer. Research indicates: The thickness of the cultivated soil layer obtained by image analysis is basically similar to the measured thickness of the cultivated soil layer. It shows that the technology of UAV-mounted ground penetrating radar has better application in detecting the thickness of soil plow layer. The experimental data collection points are relatively sparse, and the use of linear interpolation to obtain the data between the collection points will cause certain errors in the analysis of the experimental research results. The next step should be to reduce the distance between the collection points and further analyze the error.

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