Research on Application of Ground Penetrating Radar in Detecting Underground Void Areas and Pipelines

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Abstract—With the development of the urban process, the demand for pipeline detection in urban underground vacant areas is becoming more and more urgent. This article attempts to use geological radar detection methods. First, FDTD forward simulation is performed on common underground vacant areas and pipelines to analyze electromagnetic wave propagation and imaging Characteristics, and finally select the site where the water channel is buried for on-site measurement; the results show that the geological radar evacuates the underground, the pipeline detection effect is obvious, the on-site measured image signal is greatly disturbed, and the simulated vacancy zone and pipeline signals are simulated The original feature can provide positive help for the discrimination of the measured image. Similarly, the inversion of the measured image can improve the accuracy of the discrimination.

1. Introduction
With the acceleration of national construction, in the efficient and rapid development, many engineering problems and their drawbacks are often encountered. For example, engineering quality problems caused by cutting corners; hidden geological disasters such as water inrush and mud inrush during tunnel construction. Those with minor problems will result in loss of property and time, while others will cause casualties. Real-time effective monitoring is a breakthrough to solve the above problems, which puts higher requirements on the existing detection methods. With the rapid development of electronic technology and the application of modern processing technology, Ground Penetrating Radar (GPR) technology has developed rapidly, the advantages of GPR detection are: high resolution; accuracy up to millimeter level; high efficiency: light and portable equipment, easy operation, sustainable work, highly intelligent from data collection to image processing; non-destructive: meets the requirements of non-destructive testing objects required in many situations. Therefore, GPR is widely used in many fields, such as tunnel advance prediction\cite{1},\cite{3}, resource and mineral exploration\cite{4}, geotechnical engineering testing, environmental engineering, etc. Relevant scholars\cite{5} based on summarizing the experience of radar applications in various fields, gave reference values for the selection of radar parameters for different types of projects in order to obtain high-quality original images. Xiao Hongyue et al. also summarized the radar image characteristics of typical geological phenomena on the basis of summarizing measured data\cite{6}. Du Xingzhong\cite{7} analyzed the factors affecting the detection depth and resolution of the GPR, and discussed the effects of electrical
parameters, system parameters, and the spacing of the transceiver antennas on the imaging accuracy of the GPR. More and more scholars try to use different signal processing methods to process the radar image, which effectively improves the signal-to-noise ratio of the image\cite{8}. GPR reflected wave signals are mainly composed of ground reflected waves, backscattered waves generated by discontinuous underground media and uneven structure, and random interference waves. For complex underground environment detection, the interference signals are strong and often mask the original image spectrum characteristics of the target. Establishing an image database of conventional targets under ideal conditions and grasping the spectral characteristics will help to accurately interpret images in actual detection. Li Jing et al. carried out radar simulation on the geological conditions of specific targets, and initially achieved certain results\cite{9}-\cite{12}. This paper simulates the detection of common void areas and pipelines in cities, which has beneficial effects on the application of geological radar detection methods.

2. GPR principle

GPR is mainly composed of three parts: the host, the transmitting system, and the receiving system. The control unit in the transmission system generates a high-frequency broadband pulsed electrical signal, which is converted into an electromagnetic wave signal through the transmitting antenna (T) and sent to the target medium. After being reflected by the interface of the target medium, it is returned and received by the receiving antenna (R). Due to the difference in dielectric constant, conductivity, and attenuation coefficient of different medium, when passing through the medium interface, a strong reflection occurs. The reflected electromagnetic wave signal is converted into an electrical signal by the control unit of the receiving system, and the electrical signal is transmitted to the host system. The DAD control unit of the host system digitizes the reflected electrical signal data and displays the results in the host system computer. The GPR launch angle is generally 60° to 70°, and the ranging length $x=\left(7\sim10\right)r$ must be guaranteed to fully reflect the information of the target to be measured, where $r$ is the estimated depth of the object to be measured. The key part of the whole principle is the propagation of electromagnetic waves in space. By simulating the propagation of electromagnetic waves in space to discover its spectral characteristics, it is completely feasible in principle.

![Figure 1. The principle diagram of GPR](image-url)
3. Typical target simulation

The finite-difference time-domain method (FDTD) is an efficient method to solve the Maxwell equation of electromagnetic wave propagation in space, the process of electromagnetic wave propagation is the alternating superposition of electric and magnetic fields in space. FDTD discretizes Maxwell's curl equation into a difference equation, and solves iteratively on the time axis to determine the position and distribution of electromagnetic waves in space at various time points.

The propagation distance of electromagnetic waves in space is theoretically infinity, and the boundary conditions of electromagnetic wave absorption during simulation calculation are important factors that affect the accuracy of simulation. This simulation uses the perfect matching layer (PML) boundary, which has a better effect on traveling wave absorption, occupies only a small storage space, reduces the calculation of the computer, and increases the processing speed. The main reason for choosing PML is that its absorption of waves has nothing to do with the frequency of waves and the angle of incidence, improving the absorption effect.

3.1. Circular Tube Simulation

Establish a grooved geometric model as shown in the figure below, in a rectangular groove with a length of 250 cm and a depth of 50 cm, the relative dielectric constant of the upper medium is 6, the electrical conductivity is 0.01, the depth is 20 cm, the relative dielectric constant of the lower medium is 20, the electrical conductivity is 0.1, and the depth is 30 cm. A pipe with a diameter of 8 cm is arranged in the middle of the rectangular groove.

![Diagram of GPR control system](image_url)
Figure 3. The simulation diagram of circular tube

The electromagnetic wave simulation grid step size is \( dx=dy=0.25 \text{cm} \), the time window is 12ns, the antenna center frequency is 1600 MHz, the transceiver antenna spacing is 2.5 cm, and the antenna step size is 2 cm. The simulation effect is shown in the figure, the layering line of the medium is obvious, and the electromagnetic wave at the circular tube is hyperbolic, the top of the hyperbola coincides with the top of the circular tube. The bottom reflection of the circular tube cannot be seen from the figure, that is, the bottom of the circular tube cannot be identified.

3.2. Cavity Simulation

Under the long-term effects of rain and load, it is easy to form a cavity at the junction of shallow stratum. In severe cases, it can cause ground collapse. The geometric model of cavity is established as shown below, the model is a rectangle with a length of 250 cm and a height of 35 cm, the medium is divided into three layers, the first and second layers are 15 cm high, and the third is 5 cm high. In the middle of the model, there are a number of hollow targets with uneven shapes (height 2～10 cm). The electromagnetic wave simulation grid step size is \( dx=dy=0.25 \text{cm} \), the time window is set to 12 ns, the antenna center frequency is 900 MHz, the transceiving antenna spacing is 2.5 cm, and the antenna step size is 2 cm.
Figure 4. The simulation diagram of cavity

The demarcation line of the first layer is more obvious, and hyperbolic reflections are formed at the sharp points of each angle. The larger the cavity, the stronger the reflection, and the obvious bottom signal is formed at the intersection of the hyperbola and the reflected wave at the bottom of the cavity. The medium thickness of the third layer is thin, and the upper target has serious attenuation of the electromagnetic wave. After multiple refractions and reflections of the electromagnetic wave, there are fewer effective signals at the bottom, which results in a blurred detection of the third layer boundary.

4. Detect example

4.1. Venue Overview

According to the geoelectric model, the reflection characteristics of target in common underground environment are simulated, and the field practice is verified. The site of GPR detection selected a large area of grassland in the Nanjing National Defense Park. There is a manhole cover in the grassland, and it is speculated that there is a pipeline under the grassland.
Use GPR to detect the geological conditions and pipeline data under the grassland. Figure 5 (a) is the grassland area to be detected, (b) is the manhole cover at the corner of the grassland, and (c) is the GPR detection work diagram.

The detection area is a rectangular ABCD of 35m×25m, the measurement line AD is 35 m, close to the sightseeing avenue, and it is the highest place; The measurement line DC is 25 m, and there is a manhole cover near each of the two corners A and D, it is speculated that there may be pipelines or sewage pipes in this area. For the grassland ABCD with a slope angle of about 10°, perform circular wiring detection (as shown in Fig.5), the principle of measuring line layout is to try to cover the entire area to be detected with a spacing of 2.5 m.

4.2. Radar Settings
This time use the RIS-k2 GPR of Italy IDS Company, the antenna frequency is 80 MHz. The radar is currently a highly intelligent product, only need to set the detection depth. The transmitter, receiver and control panel are transmitted by optical cable. The signal is returned to the computer after pre-amplification, and the host and the antenna can be operated at a long distance, that is, to avoid interference and the signal is not distorted. The signal-to-noise ratio is> 160 dB. The number of sampling points can be up to 8192, the detection time window is up to 25600 nsec, the number of overlays is up to 32768, and the dynamic range is>160 dB. A larger dynamic range helps reduce internal noise, which helps increase the detection depth, which is greater under the same conditions. The digital signal processing technology used by the radar can ensure that the radar signal has high stability. The higher signal stability ensures that the antenna's transmitted signal is as stable as possible near the center frequency, which provides the basis for radar detection depth and accuracy. Before the
measurement, the pre-detect gain of the radar is measured in a relatively flat terrain area, and the given radar parameters are accepted.

4.3. Results Processing
Comparing the electromagnetic wave characteristics of the above geoelectric model simulation, Real-time GPR detection image display, the shallow area within 3 m of the entire detection area has irregular waveforms, disturbed co-axial axes, intermittent layering of the soil layer, and strong reflections in the reflected waves in the local area. Based on this, it is speculated that the surface layer of this area is artificially filled with sand, stone and soil, and sufficient compaction treatment was not performed in the later stage. Since the measurement line AD is close to the entrance road, according to the inclined soil layer boundary shown in the image, the direction of lawn filling is estimated from top to bottom during construction, and this way of filling the soil layer meets the requirements of convenient construction. There is a typical hyperbola near the corner C, and the reflected energy is enhanced, the main frequency is reduced, the co-axial axis is abnormal, the phase is reversed to 180°, the center buried depth is about 0.7 m, it is estimated to be the buried position of the pipeline (as shown in Fig.6(a)). Similar features exist at the corresponding position of the measurement line AD, it is speculated that the pipeline merges to the manhole cover at the corner of the detection area.

Figure 6. The detection results of GPR
According to the line AE image, there is a strong reflection waveform at a depth of about 1.2 m in the middle of the measurement line (as shown in Fig 6(b)). Refer to the simulation results, there may be a cavity anomaly, and this phenomenon has also been verified on the measurement line AA.

5. Conclusion

By establishing the geoelectric model of underground vacancies and pipelines, it is feasible to simulate the propagation of the electromagnetic wave of GPR, and it can quickly find the propagation characteristics of the target, which can provide a reference for GPR detection in engineering.

Because it is a model established in an ideal state to exclude external interference, the obtained electromagnetic wave signal has the original characteristics. By analyzing the original spectrum characteristics of the electromagnetic waves in the model, it is helpful to distinguish the target when the field measurement conditions are complicated.

The line layout method adopted in this paper covers the entire area to be detected, and effectively obtains the underground environment information. The comparison between the different line images helps to improve the accuracy of the inference results; For other engineering practices, according to the specific underground environmental information required by the engineering, the measurement lines should be targeted to obtain high-quality original data to achieve the best detection effect.

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