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A comprehensive case study on underground object detection

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Abstract: Underground Object Detection using Ground Penetrating Radar (GPR) System
This project aims to develop an efficient and non-invasive method for detecting buried objects using Ground Penetrating Radar (GPR) technology. The proposed system utilizes GPR to identify and locate underground utilities such as water pipes, gas pipes, and buried cables. By analyzing the reflected radar signals, the system can determine the depth and location of these objects with high accuracy. This project has significant implications for urban planning, infrastructure management, and utility maintenance, as it enables the detection of underground objects without excavation, reducing costs and environmental disruption. The outcome of this project will provide a reliable and efficient solution for underground object detection, ensuring safer and more efficient utility management.

Keywords: Underground object detection, GPR system, Damage prevention

INTRODUCTION

The detection of underground objects such as water pipes, gas pipes, and buried cables is a critical task in urban planning, infrastructure management, and utility maintenance. Accidental damage to these underground utilities can lead to significant economic losses, environmental hazards, and disruption of essential services

This project aims to develop an efficient and accurate method for detecting underground objects using Ground Penetrating Radar (GPR) technology. Specifically, this project focuses on the detection of:

1. Water Pipes: Accurate detection of water pipes to prevent damage during excavation and construction activities.
2. Gas Pipes: Reliable detection of gas pipes to ensure public safety and prevent potential gas leaks.
3. Buried Cables: Efficient detection of buried cables to prevent damage during excavation and construction activities.

BLOCK DIAGRAM

By leveraging GPR technology, this project aims to provide a non-invasive and accurate solution for underground object detection, reducing the risks associated with accidental damage and promoting safer and more efficient urban management practices.

The use of GPR technology for underground object detection offers several advantages, including high accuracy, non-invasive operation, and real-time data acquisition. Additionally, GPR technology can penetrate various types of soil and pavement, making it an ideal solution for detecting underground objects in urban environments.
The successful implementation of this project will have significant impacts on various industries, including construction, utility management, and urban planning. By providing accurate and reliable detection of underground objects, this project will help reduce the risks associated with accidental damage, promote safer and more efficient urban management practices, and support sustainable urban development.

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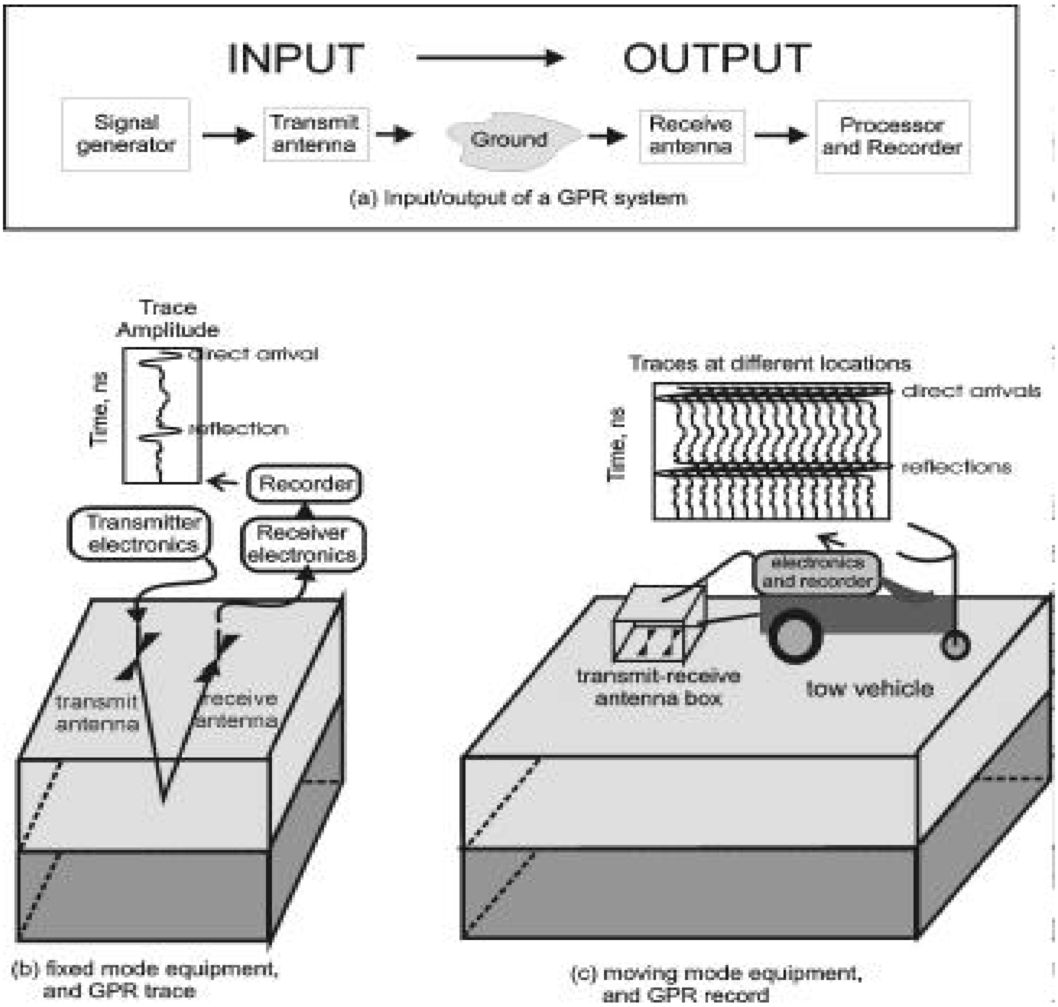

Fig.1 Block Diagram

METHODOLOGY

Ground Penetrating Radar (GPR): -

Ground Penetrating Radar (GPR) is a non-invasive method used to detect objects and structures beneath the ground. The process begins with the GPR equipment, which includes a radar transmitter (antenna) and a receiver. The transmitter sends high-frequency radio waves into the ground.

When these waves encounter an object, like a pipe or cable, some of the waves bounce back to the surface. The receiver picks up these reflected waves, and the data is then analyzed to create an image of the underground features.

The GPR system works by emitting short pulses of radio waves that travel through the ground at different speeds depending on the material they encounter. When the waves reach a boundary between different materials (e.g., between soil and metal), they are reflected back to the surface. The time it takes for the waves to return to the receiver helps determine how deep the object is located. The amount of reflection also gives clues about the type of material beneath the surface.

The GPR system records and processes these signals to create a profile of the subsurface. This profile, or radar image, shows the depth and shape of the objects below. In some systems, the data can be displayed in real-time, allowing operators to adjust the equipment or survey area as needed. The radar waves can penetrate different depths depending on the frequency of the radar and the type of soil, with lower frequencies able to reach deeper but with less resolution, and higher frequencies providing better detail but at shallower depths.

Once the data is gathered, the GPR results are analyzed to identify objects. The reflection patterns allow experts to distinguish between different materials, such as pipes, cables, rocks, or voids. A clear reflection from a metal pipe, for instance, will appear differently than a reflection from a plastic pipe or air pocket. Specialized software may be used to convert the data into 2D or 3D images, helping to precisely locate and map the underground features.

The effectiveness of GPR depends on factors like the type of soil, moisture content, and the depth of the object. In dry or highly compacted soils, the radar waves may not travel as easily, reducing the system's effectiveness. Wet soils or soils with high moisture content generally allow better penetration and clearer data. It is also important for the GPR system to be properly calibrated and for operators to have experience interpreting the radar images, ensuring accurate detection and mapping of underground structures objects.

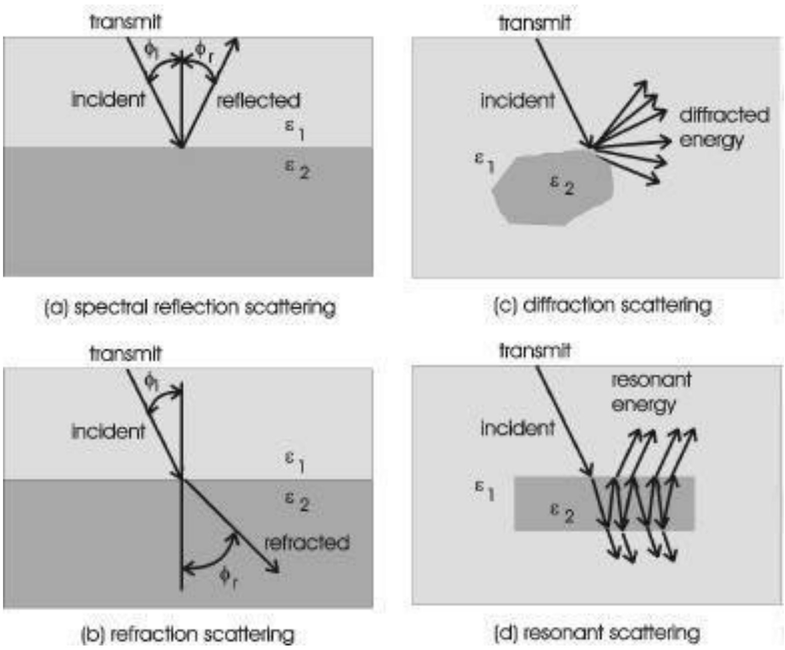

FIGURE 2 Scattering mechanisms

(a)specular reflection scattering, (b) refraction scattering, (c) diffraction scattering, (b) and (d) resonant scattering.

If the interface is smooth and continuous (e.g., a layer boundary), and velocity of the wave in the lower boundary (e.g., the object, or lower layer) is greater than velocity in the host material, then the wave within the object we'll travel along the interface with a velocity that is equal to velocity of wave in the object. The angle where this occurs is called critical angle, and can be determined by the following equation.

$$\frac{\sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1}} = \frac{v_1}{v_2} = \sin\varphi$$

CASE I: - DETECTION OF UNDERGROUND ELECTRICAL CABLES

Ground Penetrating Radar (GPR) is a non-invasive method used to detect underground objects, including electric cables. It works by sending high-frequency radio waves into the ground. When these waves encounter an object, like a cable, they bounce back to the surface. The GPR system records the time it takes for the waves to return, creating an image that can help identify the location and depth of the cable.

To detect electric cables using GPR, you typically use a handheld or vehicle-mounted antenna that emits radar signals into the ground. The radar waves travel through the soil and are reflected by different materials, such as metal (the cable). Electric cables, especially those with metal cores, reflect these waves, making them visible in the radar data.

The GPR system analyzes these reflections, producing a visual representation of the underground environment. The presence of an electric cable appears as a clear anomaly or change in the pattern on the radar image. The system can help you determine the size, shape, and depth of the cable, depending on the material and the surrounding soil conditions.

However, GPR effectiveness can depend on the soil type. In dry or rocky soil, radar waves may not penetrate as deeply, which could make it harder to detect the cable. Conversely, in wet or sandy soil, GPR can work better because the waves travel more efficiently. Proper calibration and interpreting the radar data are essential to accurately detect and locate electric cables.

CASE II: - DETECTION OF UNDERGROUND GAS PIPES

Detecting underground gas pipelines with Ground Penetrating Radar (GPR) involves sending radar waves into the ground to locate subsurface objects. The GPR system uses an antenna that sends out electromagnetic pulses, and a receiver captures the signals that bounce back when they hit objects like a gas pipeline. Different frequencies of antennas are used depending on how deep the pipeline is. Lower frequencies (around 200 MHz) are good for detecting deep pipes, while higher frequencies (500 MHz) provide better details for shallow pipes.

When the radar waves travel through the soil, they bounce back differently when they hit objects with different properties, like the metal of a gas pipeline. These reflections create patterns that can be seen in the GPR data, usually appearing as hyperbolic shapes. By analyzing these signals, technicians can locate the pipeline and estimate how deep it is based on the timing and strength of the reflected signals.

Interpreting GPR data requires care, as other underground features such as cables, rocks, or other pipes may also reflect radar waves. It is important to carefully study the patterns of the signals to make sure the identified reflections are indeed from the gas pipeline. Technicians often mark the suspected locations on the surface and verify them with utility maps or physical checks.

GPR is a reliable, non-invasive method for detecting underground pipelines. However, environmental factors like soil type and moisture levels can affect the accuracy of the radar signals. Calibration and careful data interpretation are important to ensure accurate results.

CASE III: - DETECTION OF UNDERGROUND WATER PIPES

Ground Penetrating Radar (GPR) can be used to detect water pipes underground by sending high-frequency radar waves into the ground. When these waves hit an object like a water pipe, they are reflected back to the surface. The GPR system records the time it takes for the waves to return, and this helps create a picture of what's beneath the ground.

To find water pipes, a GPR antenna is moved over the ground, sending radar signals down into the soil. Water pipes, whether made of metal or plastic, will reflect some of the radar waves back to the surface, creating a signal that can be detected. The GPR system analyzes the reflections and displays them as a visual image or graph.

The presence of a water pipe shows up as a distinct feature in the GPR data, often appearing as a continuous line or shape. The system can also give information about the depth and size of the pipe. For metal pipes, the radar waves will reflect more strongly, making it easier to identify. For plastic pipes, the radar reflection might be weaker, but it can still be detected depending on the pipe's material and the surrounding soil.

The effectiveness of GPR in detecting water pipes depends on the type of soil. For example, GPR works better in dry, sandy, or moist soil, where the radar waves can travel more easily. In very hard or rocky soil, the radar signals might not penetrate deeply enough. Skilled operators must analyze the radar images carefully to distinguish between pipes and other underground objects.

2) LITERATURE REVIEW

1. Underground Object Detection Based On Radio Propagation Characteristics

SUHERMAN1, ERWIN WIJAYANTO1,ALIHANAFIAH RAMBE1, NAEMAH MUBARAKAH1, YULIANTA SIREGAR1, MARWAN AL-AKAIDI2

This paper proposes a multipoint radio reception system for underground object detection, moving beyond traditional single-point GPR. Initial experiments (97-130 MHz) showed model errors, leading to a gradient comparison method to optimize frequency selection. Testing at higher frequencies (500 MHz - 1 GHz) identified 537.69 MHz as optimal. Object reconstruction used multipath propagation analysis, with supervised detection achieving at least 30% better precision than unsupervised methods, and object presence causing up to a 2.68% average signal reduction.

1. Underground Object Detection Using Antiresonant Antennas

J. Patrick Donohoe1 Josh R. Fairley2, Larry N. Lynch3

Given a horizontal dipole over ground, the variation in the antenna input impedance attributable to a

nearby underground anomaly (tunnel) is investigated via finite difference time-domain (FDTD) simulation. The dipole is driven with a broadband source to locate the dominant resonant and antiresonant frequencies and to compute the impedance effects associated with the tunnel over the entire frequency band. The characteristics of the total fields and the fields scattered by the tunnel are analyzed at the resonant and antiresonant frequencies. The effectiveness of the antiresonant dipole as a near-field probe for buried object detection is demonstrated.

1. Underground Power Cable Detection and Inspection Technology Based on Magnetic Field Sensing at Ground Surface Level

Xu Sun1, Wing Kin Lee1, Yunhe Hou1, and Philip W. T. Pong1

This paper introduces a novel magnetic field sensing technique for underground power cable detection and inspection. It reconstructs cable current sources using measured magnetic fields at the surface, employing a stochastic optimization algorithm based on an artificial immune system. Simulations of 11- and 132-kV cables demonstrate accurate reconstruction of electrical and spatial parameters. The method enables remote detection of cable location and depth without prior knowledge, applicable to various cable configurations and requiring no signal injection.

Detailed Comprehensive Study Analysis of Object Detection Using Deep Learning Models – Case Study

Mahi Sewatia, Deepa Rani

Assistant Professor, J.C Bose University of Science, and Technology, YMCA, Faridabad, India This paper Many applications in computer vision they need precise and efficient detection systems. This demand coincides with the rise of the application of deep learning techniques in almost all areas of machine learning and artificial vision. This work presents a study that encompasses different detection systems based on deep learning, providing a unified comparison between different frameworks in order to carry out a technical comparison of the performance measures of the studied methods Many applications in computer vision they need precise and efficient detection systems. This demand coincides with the rise of the application of deep learning techniques in almost all areas of machine learning and artificial vision.

This work presents a study that encompasses different detection systems based on deep learning, providing a unified comparison between different frameworks in order to carry out a technical comparison of the performance measures of the studied methods Review of machine learning algorithms for automatic detection of underground objects in GPR images Leila Carolina Martoni Amaral, Aditya Roshan, Alireza Bayat Journal of Pipeline Systems Engineering and Practice 13 (2), 04021082, 2022

Ground-penetrating radar (GPR) is a nondestructive tool that has gained popularity aftergiving promising results in different areas—such as utility engineering, transportation engineering, civil engineering, and geology—with relatively low cost. Even as the number of applications for GPR increases, the interpretation of GPR data is still challenging, in part due to varying ground conditions.

The future of mine safety: a comprehensive review of anti-collision systems based on computer vision in underground mines. Mohamed Imam, Karim Baïna, Youness Tabii, El Mostafa Ressami, Youssef Adlaoui, Intissar Benzakour, El Hassan Abdelwahed.

Underground mining operations present critical safety hazards due to limited visibility and blind areas, which can lead to collisions between mobile machines and vehicles or persons, causing accidents and fatalities. This paper aims to survey the existing literature on anti-collision systems based on computer vision for pedestrian detection in underground mines, categorize them based on the types of sensors used, and evaluate their effectiveness in deep underground environments. Ground penetrating radar (GPR) is one of the common sensor system for underground inspection. GPR emits electromagnetic waves which can pass through objects. The reflecting waves are recorded and digitised, and then, the B-scan images are formed. According to the properties of scanning object, GPR creates higher or lower intensity values on the object regions. Thus, these changes in signal represent the properties of scanning object.

2. Review of machine learning algorithms for automatic detection of underground objects in GPR images

Leila Carolina Martoni Amaral, Aditya Roshan, Alireza Bayat Journal of Pipeline Systems Engineering and Practice

Ground-penetrating radar (GPR) is a nondestructive tool that has gained popularity after giving promising results in different areas—such as utility engineering, transportation engineering, civil engineering, and geology—with relatively low cost. Even as the number of applications for GPR increases, the interpretation of GPR data is still challenging, in part due to varying ground conditions. Researchers are continuously working on the development of new analysis methods to address these challenges.

DESIGN and DEVELOPMENT

1.Project Goal:

To develop a comprehensive system for detecting and mapping underground objects using Ground Penetrating Radar (GPR) technology.

1. System Components:
- GPR Unit: The core of the system, emitting and receiving electromagnetic waves to detect subsurface anomalies.
- Antenna: Transmits and receives the radar signals, with the frequency determining the depth and resolution of the survey.
- Data Acquisition Unit: Records and processes the radar signals, converting them into usable data.
- Positioning System: Integrates GPS or other positioning technologies to accurately locate detected objects.
- Display and Control Unit: Provides a user interface for controlling the system and visualizing the collected data.

2. Design Considerations:
- Frequency Selection: Choosing the appropriate antenna frequency based on the target depth and desired resolution.
- Data Processing: Implementing algorithms to filter noise, enhance signal clarity, and identify potential objects.
- User Interface: Designing an intuitive interface for data acquisition, visualization, and interpretation.
- Portability: Ensuring the system is portable and easy to maneuver in various field conditions.

3. Development Process:
- Component Integration: Integrating the GPR unit, antenna, data acquisition unit, positioning system, and display unit.
- Software Development: Creating software for data processing, visualization, and object identification.
- Testing and Calibration: Conducting field tests to calibrate the system and validate its accuracy.

4. Data Acquisition:
- Survey Planning: Defining the survey area and grid pattern to ensure comprehensive coverage.
- Data Collection: Acquiring GPR data by moving the antenna along the survey grid.
- Real-time Monitoring: Observing the data being collected in real-time to identify potential objects.

5. Data Processing:
- Noise Filtering: Removing unwanted signals caused by surface clutter, interference, or environmental factors.
- Signal Enhancement: Applying techniques to amplify the reflected signals from objects.
- Object Identification: Using algorithms to recognize patterns and anomalies indicative of buried objects.

6. Visualization and Interpretation:
- 2D/3D Imaging: Creating visual representations of the subsurface to highlight detected objects.

- Object Mapping: Plotting the location and depth of identified objects on a map.
- Data Analysis: Interpreting the data to determine the size, shape, and material of the objects.

CONCLUSION

In conclusion, Ground Penetrating Radar (GPR) has proven to be an effective non-invasive method for detecting underground objects across various applications. Studies have demonstrated its capability to identify buried anomalies in civil structures, detect illegal objects in sensitive areas, and locate defects in materials like wood timbers. The integration of advanced data processing techniques, such as background removal algorithms and machine learning models, has enhanced GPR's accuracy and real-time detection capabilities. However, factors like soil composition and moisture levels can influence its performance. Ongoing advancements in GPR technology and data interpretation methods continue to expand its potential in subsurface exploration and monitoring.

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