Web-Controlled GPR System for Remote Data Acquisition and Surface Reflection Suppression

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***Abstract*—Ground Penetrating Radar (GPR) is a widely used tool for subsurface utility detection, but conventional workflows often require on-site expert presence for both data acquisition and interpretation. This paper presents a web-controlled GPR system that enables remote operation and real-time analysis through a custom web-based dashboard. The system integrates commercially available GPR hardware (Noggin 250) with programmable APIs from the Spidar NIC500N, allowing remote control of scanning parameters and live radargram visualization. A key innovation is the implementation of an analytical reference signal subtraction technique for suppressing surface reflections in radargrams. This method enhances the visibility of deeper anomalies such as buried utilities and reduces reliance on post-processing. Experimental validation across two surface types—dry soil and interlock pavement—demonstrates the system's effectiveness in real-time filtering and its comparability to commercial post-survey software. The proposed architecture improves operational efficiency, supports non-expert field deployment, and enables expert-guided interpretation remotely. Future extensions include integration with autonomous scanning platforms and GPS-based geo-referencing for spatial mapping and infrastructure planning.**

***Index Terms*—Ground Penetrating Radar (GPR), Web-based remote sensing, Surface reflection suppression, Reference signal subtraction, Real-time data acquisition.**

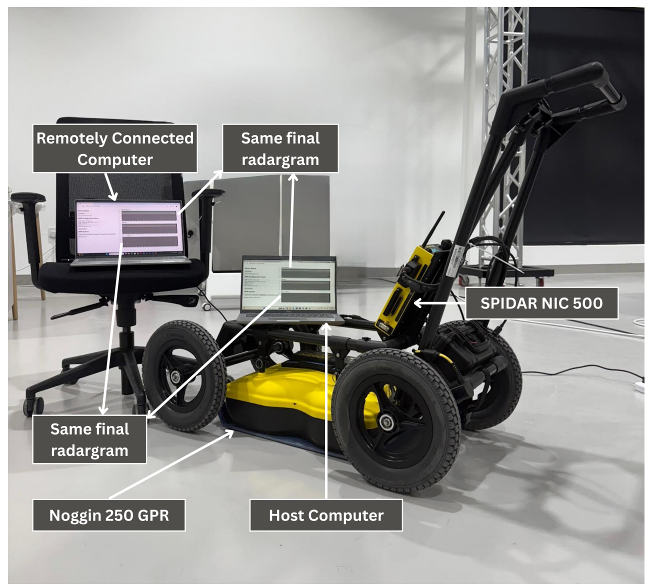


Fig. 1: GPR device integrated with a customized web interface for real-time data sharing and remote parameter control

I. Introduction

Engineering innovations increasingly aim to enhance human comfort, safety, and efficiency, particularly in labor-intensive and high-risk environments. Robotics has emerged as a key enabler in this transformation, offering intelligent automation solutions that can significantly reshape industrial workflows. For example, robotic systems designed for adaptive object grasping [1], [2] and imitation-based learning [3] are revolutionizing operations in warehouses, logistics centers, and recycling facilities. These systems reduce physical fatigue, improve throughput, and enable scalable, data-driven decision-making—ushering in a new era of smart infrastructure.

This convergence of robotics and remote technologies is particularly impactful in utility services, where infrastructure complexity and environmental conditions pose unique challenges [4], [5]. In Dubai, the Dubai Electricity and Water Authority (DEWA) manages a vast and intricate network of electricity and water infrastructure, including large-scale underground cable installations. Accurate subsurface scanning is critical to avoid damaging existing utilities, ensure safety, and optimize routing for new deployments.

Ground Penetrating Radar (GPR) is a widely adopted tool for subsurface utility detection due to its non-invasive nature and high-resolution imaging capabilities [6]. However, its deployment in Dubai's extreme climate presents notable challenges. Manual operation of GPR devices is physically exhausting, especially over large areas, and interpreting radar data requires specialized expertise that is often not available on-site. These limitations can lead to delays, misinterpretations, and increased operational risks.

To address these challenges, we propose a web-based remote GPR interpretation system, illustrated in Fig. 1. In this architecture, a field operator simply moves the GPR device, while live data is streamed to remote experts via a custom-designed web dashboard. The interface not only allows experts to monitor radargrams in real time but also provides full control over system parameters such as samples per trace, sampling time, and trace period. This dynamic interaction enables experts to fine-tune the data acquisition process remotely, improving the accuracy and relevance of the collected data while minimizing the need for on-site adjustments.

Unlike conventional GPR systems that require on-site expertise and manual data tuning, our architecture enables remote expert intervention and automated signal refinement, reducing operational overhead and improving detection accuracy. The system further incorporates a signal processing technique, referred to as *reference signal subtraction*, for suppressing surface reflections in the radargram. By averaging traces over clean surface regions—areas free of known anomalies—and filtering out shallow signals, the method produces a processed radargram with reflections only from deeper anomalies, such as buried utilities. The processed radargram can then be fed to image processing methods for intelligent detection [7].

This paper outlines the problem context, presents the system architecture and implementation, details the signal suppression methodology, and provides experimental validation. We conclude with a discussion of future enhancements, including GPS integration for geo-referencing and broader applications in urban infrastructure monitoring.

II. Related Work

Recent advancements in Ground Penetrating Radar (GPR) and Internet of Things (IoT)-based sensing have significantly expanded the capabilities of subsurface exploration and remote monitoring. However, most existing systems are limited by offline workflows, lack of expert interaction during data acquisition, and inadequate handling of surface reflections—issues that are particularly pronounced in challenging field environments like Dubai.

A. Conventional GPR Systems

GPR is widely used for utility mapping, archaeological surveys, and structural diagnostics [8]. Traditional systems typically involve manual operation and post-acquisition processing steps such as time-zero correction, gain adjustment, and background removal. These workflows introduce latency and rely heavily on expert interpretation after data collection. Additionally, radargrams are often dominated by strong surface reflections, which obscure deeper anomalies and complicate analysis.

To address interpretation challenges, recent studies have applied machine learning (ML) and deep learning (DL) techniques for tasks such as hyperbola detection, object classification, and layer segmentation [9]. While these methods show promise in automating radargram analysis, they are primarily designed for offline use and do not support real-time feedback or adaptive control during scanning.

B. IoT-Based Remote Sensing Architectures

IoT platforms have enabled real-time monitoring in domains such as precision agriculture [10], landslide detection [11], and permafrost tracking [12]. These systems typically rely on low-bandwidth, discrete sensors and are optimized for periodic data collection rather than continuous, high-resolution imaging. In contrast, GPR generates high-volume waveform data that demands robust transmission and processing capabilities.

Some remote GPR systems have been deployed on vehicles or UAVs for large-scale surveying. However, these platforms often function as passive data collectors, lacking mechanisms for live expert interaction or dynamic parameter control. As a result, data quality and relevance can suffer, especially when field operators lack domain expertise.

C. Gap in Integrated Real-Time Systems

Despite the complementary strengths of GPR and IoT technologies, current systems do not offer integrated solutions for real-time data sharing, remote parameter adjustment, and live signal enhancement. Surface reflections continue to dominate radargrams, reducing the visibility of deeper features and increasing post-processing complexity. Moreover, the absence of expert involvement during acquisition often leads to suboptimal scanning strategies and missed anomalies.

These limitations highlight the need for a system that combines high-bandwidth GPR imaging with IoT-inspired remote accessibility. The proposed solution addresses this gap by enabling live data streaming, expert-driven control of acquisition parameters (e.g., gain, time window, scan rate), and real-time surface reflection suppression—capabilities that are essential for accurate and efficient subsurface utility detection in urban environments.

III. Problem Statement

Despite the widespread use of Ground Penetrating Radar (GPR) for subsurface utility detection, current systems face two critical limitations that hinder their effectiveness in large-scale urban deployments:

1) **Lack of adaptive and expert-guided data acquisition:** Conventional GPR systems operate in isolation, without support for real-time data sharing or remote expert intervention. This means either the expert must be physically present during data collection, or the field operator must proceed without expert guidance—often resulting in suboptimal scans, misinterpretation, and inaccurate analysis.
2) **Signal clutter from surface reflections:** Radargrams are frequently dominated by strong reflections from shallow surfaces, which obscure deeper anomalies. These surface-rich radargrams are difficult to process automatically and often require manual post-survey interpretation. This not only delays results but also introduces variability based on the expertise of the analyst.

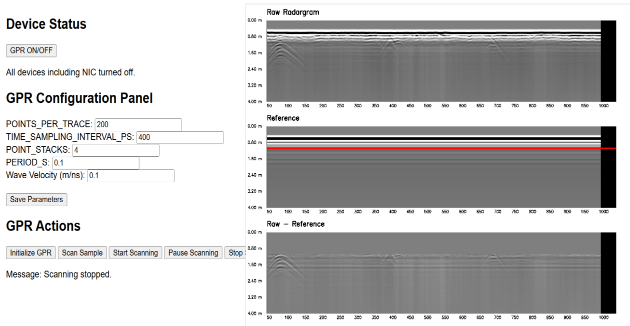


Fig. 2: Web-based dashboard for live GPR control, radargram visualization, and reflection-suppressed data display.

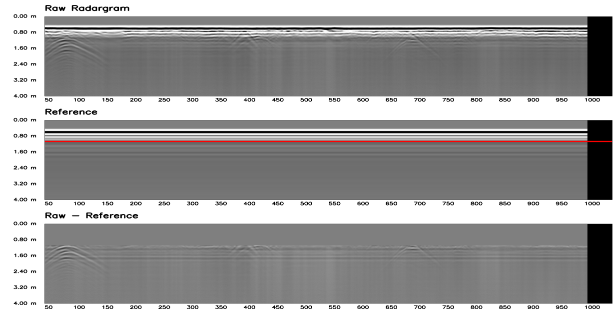


Fig. 3: GPR processing workflow: raw radargram, reference signal with threshold index, and final processed radargram.

These challenges highlight the need for a system that enables dynamic, expert-guided data acquisition and real-time signal enhancement. As illustrated in Fig. 2, our proposed solution integrates a web-based interface for remote control and visualization with a reference signal subtraction technique for suppressing surface reflections during acquisition. This architecture improves data quality, reduces reliance on post-processing, and supports scalable subsurface analysis in field environments.

IV. Web-Based GPR Acquisition and Control

The proposed system integrates the Noggin 250, a 250 MHz single-frequency Ground Penetrating Radar (GPR), with the Spidar NIC500N [13], which streams raw trace data to a locally connected processing unit. Each trace consists of 200 voltage samples captured at 400 ps intervals, with a trace period of 0.1 s. These acquisition parameters are configurable and can be adjusted based on survey requirements. The collected traces are assembled into a radargram for visualization and further processing.

The Spidar SDK provides HTTP-based APIs [14] for live data access and system control, enabling adjustments to parameters such as sampling rate, trace length, and trace period. While these APIs offer granular control, their direct use can be challenging for non-technical users. To address this, we developed a custom web-based interface that abstracts the underlying API commands and provides intuitive controls for scan initiation, parameter adjustment, and real-time radargram visualization.

Using this interface, the system supports a flexible workflow for surface reflection suppression. Initially, the operator collects a set of reference traces over a known clean surface. These traces are averaged and stored as a reference signal. During the actual survey, incoming data is processed in real time using this reference signal to suppress surface reflections and highlight deeper anomalies.

As shown in Fig. 2, the web dashboard displays the live radargram alongside the reference signal and the reflection-suppressed output. This integrated view enables remote experts to monitor scans in real time, compare with baseline data, and interpret subsurface anomalies with improved clarity. The analytical details of the reflection suppression technique are described in the following section.

V. Reference Signal Subtraction for Surface Reflection Suppression

To enhance the clarity of subsurface features in GPR data, we implement an analytical filtering technique based on reference signal subtraction. The primary goal of this method is to suppress strong surface reflections, which often dominate raw GPR traces and obscure deeper anomalies such as buried utilities or voids.

A. Reference Signal Construction

The process begins by collecting a set of GPR traces over a known clean surface area. These traces are averaged to form a single reference signal $R = [r_1, r_2, \dots, r_N]$, where $N = 50$ is the number of samples per trace. The mean value of the reference signal is computed as:

$$\mu_R = \frac{1}{N} \sum_{i=1}^{N} r_i$$

To identify the boundary between surface and subsurface reflections, we compute a running mean $\bar{r}_i$ over a sliding window of size w (e.g., $w = 11$):

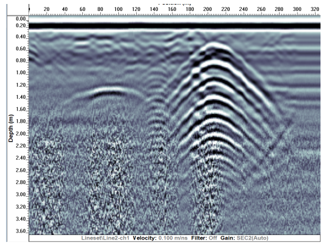
$$\bar{r}_i = \frac{1}{w} \sum_{j=i}^{i+w-1} r_j$$

Starting from the deepest index and moving upward, each running mean value is compared against a threshold defined as $0.4\mu_R$. The first index T where $\bar{r}_i > 0.4\mu_R$ is identified as the *threshold index*, which separates surface-level reflections from deeper subsurface signals.

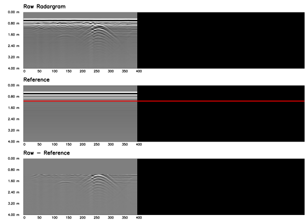
B. Live Trace Filtering

During live data acquisition, each incoming trace $S = [s_1, s_2, \dots, s_N]$ is processed by zeroing out all samples below the threshold index T, and subtracting the reference signal from the remaining samples:

(a) GPR Scanning

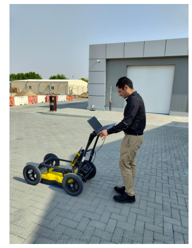


(b) Radargram using EKKO



(c) Processed radargram using our method

Fig. 4: Surface 1: Dry soil with buried water pipes



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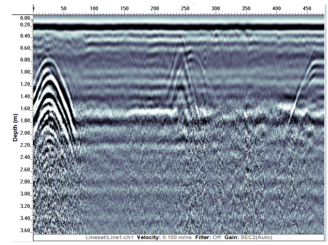
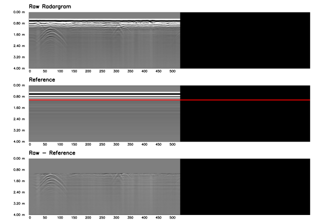


(b) Radargram using EKKO



(c) Processed radargram using our method

Fig. 5: Surface 2: Interlock pavement with buried power cables

$$s'_i = \begin{cases} 0, & \text{if } i \leq T \\ s_i - r_i, & \text{if } i > T \end{cases}$$

This operation effectively removes surface clutter and retains only the meaningful deviations in deeper regions. The result is a filtered trace S' that emphasizes utility-level reflections while suppressing ground-level noise.

Figure 3 illustrates the processing workflow. The first plot shows the radargram of the raw GPR data, the second plot displays the radargram of the reference signal with a line marking the threshold index, and the third plot presents the final processed radargram, highlighting only the subsurface anomalies while excluding surface reflections.

C. Advantages

This reference signal subtraction technique is entirely analytical, lightweight, and interpretable. It does not rely on machine learning or statistical modeling, making it suitable for real-time deployment in field environments. Moreover, the thresholding mechanism adapts to varying surface conditions, allowing the system to maintain consistent performance across different survey sites.

VI. Experiments

A. Experimental Setup and Results

To validate the proposed system, we conducted experiments focusing on two key aspects: (1) implementation and control of the GPR system via the web-based interface, and (2) evaluation of the reference signal subtraction technique for surface reflection suppression. For comparison, radargram outputs generated using the vendor-provided EKKO software [15] are included. Notably, EKKO supports only post-survey analysis, whereas our system enables live processing.

1) Web Interface Implementation and Control: The custom-designed web interface was deployed and tested in a controlled laboratory environment. For remote operation, both the GPR-connected machine and the remote device (desktop or mobile) were connected to the same local network. This setup enabled seamless communication between the interface and the GPR system.

Using this configuration, we verified that the remote device could reliably start, stop, and pause GPR scanning, as well as adjust key parameters such as sampling rate, trace period, and number of samples per trace. Real-time radargram visualization confirmed the responsiveness of the control APIs and the effectiveness of the Spidar SDK integration.

2) Evaluation of Surface Reflection Suppression: To assess the performance of the reference signal subtraction technique, we tested the system on two distinct surface types:

- **Surface 1:** Dry soil with buried water pipes (Fig. 4)
- **Surface 2:** Interlock pavement with buried power cables (Fig. 5)

In both cases, reference traces were collected over clean surface areas and averaged to construct the reference signal. The threshold index was computed using the running mean method described earlier and is indicated by a red line in the center radargrams of Fig. 4c and Fig. 5c, respectively.

In both scenarios, the algorithm successfully estimated the threshold index and suppressed surface-level reflections, allowing deeper anomalies to be visualized with improved clarity. For comparison, we included radargrams generated by the commercial software after completing the scans on both surfaces (Fig. 4b and Fig. 5b). These radargrams clearly show dominant surface reflections.

In contrast, our proposed filtering method effectively suppresses surface reflections in real time. Furthermore, the subsurface radargrams generated by our system closely resemble those produced by the commercial software, with minor intensity differences that can be compensated using gain adjustments.

These results confirm the robustness and adaptability of the proposed analytical filtering method across varying surface profiles and utility types.

VII. Conclusion and Future Work

This paper presented a web-based GPR interpretation system designed to overcome key limitations of conventional GPR workflows in dynamic and challenging field environments. Built around commercially available hardware—the Noggin 250 GPR and the Spidar NIC500N—the system leverages HTTP-based APIs provided by the Spidar SDK to enable real-time data acquisition, remote control, and live radargram visualization through a custom-designed web interface. This architecture allows non-expert field operators to conduct surveys while remote experts monitor and interpret data in real time, improving both operational efficiency and analytical accuracy.

A central contribution of this work is the implementation of an analytical reference signal subtraction technique for suppressing surface reflections in radargrams. Through controlled experiments on two distinct surface types, we demonstrated the method's effectiveness in isolating utility-level reflections and enhancing subsurface visibility. The approach is lightweight, interpretable, and adaptable to varying surface conditions, making it well-suited for real-time deployment.

Future work will focus on extending the system's capabilities to support autonomous scanning platforms, such as mobile robots, enabling fully automated surveys. Additionally, we plan to integrate GPS functionality by coupling a GPS sensor with the GPR device and embedding geo-referencing features into the web interface. This enhancement will facilitate spatial mapping of detected utilities, improve traceability, and support long-term infrastructure planning and asset management.

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