Enhancing Ground Penetrating Radar with Augmented Reality Systems for Underground Utility Management

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ABSTRACT

Successful maintenance and development of underground infrastructures depends on the ability to access underground utilities efficiently. In general, obtaining accurate positions and conditions of subterranean utilities is not trivial due to inaccurate data records and occlusions that are common in densely populated urban areas. Limited access to underground resources poses challenges to underground utilities management. Ground-penetrating radar (GPR) is an effective sensing tools widely used for underground sensing. Combining high accuracy GPR data and augmented reality (AR) poses enables accurate real time visualizations of the buried objects. Although GPR and AR collect and visualize high accuracy data, intensive computation is required. This work presents a novel GPR-AR system that decreases post-processing time significantly while maintaining a neutral format across GPR-AR data collection methods regardless of varying Internet or GPS connection strengths. The methods explored in this work to mitigate failures of previous systems include automated and georeferenced post processing, the classification of underground assets using artificial intelligence, and real time data collection path visualizations. This work also lays a foundation for the potential combinations of a 5G GPR-AR system in which the temporal gap between data collection and visualization can be alleviated.

Keywords: Utility Management, Ground Penetrating Radar, Augmented Reality, SLAM, 5G, Geographic Information Systems, Building Information Systems, ARCore

1. INTRODUCTION

In urban regions and rural areas alike, GPR has proven to be a useful method for locating vital utilities in a subterranean environment, including water and sewage pipes, and power cables, etc. A problem with these subterranean infrastructures is that, more often than not, the records of their exact positions and orientations are either not comprehensive, incorrect, or absent [1]. In any of these situations, gaining access to these utilities for maintenance or replacement can be challenging, costly and even dangerous. To resolve this issue, many cities have moved towards implementing systems that map entire underground utility networks. GPR has become a standard tool in solving this mapping problem as it is non-invasive and highly accurate [2, 3]. There are still problems that exist with GPR systems. When completing a GPR scan, it is important to keep track of the local and global coordinates in order to associate the detected subsurface features. In a general GPR system, wheel-encoder is utilized to measure survey distance. However it requires performing GPR survey along a straight route [1, 4] which can be a problem when many topographies and urban landscapes are complex. In addition, it limits GPR operation flexibility.

In light of the aforementioned issues, GPR systems have recently been paired with AR systems in order to provide very accurate local positional coordinates corresponding to GPR scans. Many applications have been created with frameworks such as Tango [5, 1]. Tango utilizes a cellular devices inertial measurement unit data and a combination of cameras to define a user's local position and orientation. Project Tango was later suspended by its founders at Google. Google has since shifted its efforts to focus on ArCore. This work uses ARCore 6 and a Google Pixel cellular device for position capture. The Pixel was developed using Unity and it was used in combination with a GSSI SIR 30 GPR. In [1], an XBee Bluetooth (BT) shield was used for GPR Scan triggering

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on an Arduino. In this paper, the same BT shield is used to trigger data collection on Unity application on board of the Pixel device. This application is operated in parallel with the GPR device and wheel-encoder. The wheel-encoder is used to trigger a GPR scan as well as trigger an Arduino micro-controller to send a message to the Pixel device through Bluetooth transmitter. At this point, the Pixel reads the message and collects a local position coordinate and sends it to a database on a local server via Wifi. This paper seeks to enhance previous GPR/AR systems and will begin a brief overview of GPR systems and the functions in section 2. Section 3 will describe the ArCore Framework, Section 4 shows the system developed and results obtained from a specific field test. Section 5 contains the conclusion and discussion of potential future applications.

2. GROUND PENETRATING RADAR

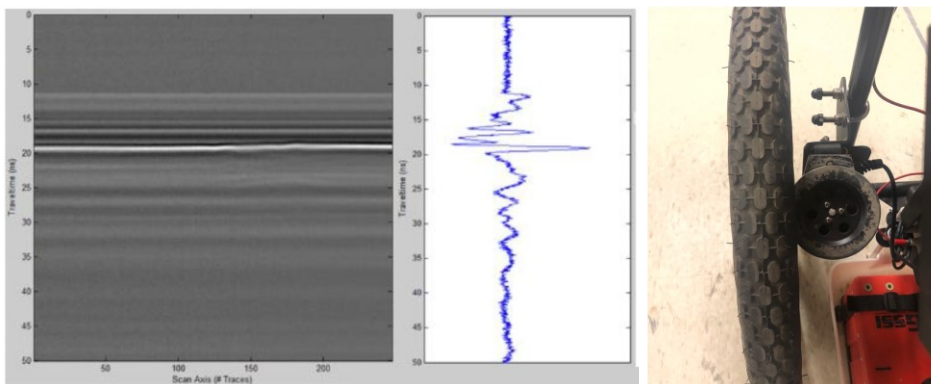

Figure 1. [2] An example of a GPR B-scan and A-scan (left) and a wheel-encoder (right).

GPR is a non-invasive radar technique that can create detailed images of underground objects and utilities. For this paper, it is only essential to understand the basics of a GPR system which involves electromagnetic signal transmission and receiving [7 , 8 , 9 , 10]. In its operation, an EM is sent out from the transmission antenna. The received signal can be plotted as as A-scan waveform shown in Fig. 1. Many A-scans can be stacked next to each other to create a B-scan image.

In conventional GPR scans, GPR moves along a straight route, and a wheel encoders is used to record the local coordinate data. Due to the radial displacement triggering mechanism on a wheel-encoder, any curvature in a user's path will not be correctly captured. A user must predesignate an entire testing region in a grid fashion in order to keep positioning data accurate and consistent. This predesignating often takes a lot of time and resources during the data collection process.

3. ARCORE

As Augmented Reality becomes more commonplace in various applications, businesses, and academic settings, numerous frameworks have been created to assist with the developing process. Many AR Frameworks rely on multiple cameras such as a wide fish-eye lens and an RGB lens [1]. In order to make AR more ubiquitous among smartphone devices, both Google's ArCore and Apple's ArKit frameworks are built using only RGB lenses and IMU data [6]. This paper focuses on ArCore as the main framework of choice.

3.1 ArCore Framework

ArCore uses a few unique features to track local positions. It is equipped with a GPS and a magnetometer for positioning, and an RGB Camera, Accelerometer, and a Gyroscope for motion tracking [6]. A number of machine learning, computer vision, and image processing algorithms are applied for area mapping. As a user moves with the device, the camera refers to these mappings in order to calibrate local position. The technique behind this local position tracking is known as Simultaneous Localisation and Mapping (SLAM). Specifically, this framework utilizes Concurrent Odometry and Mapping (COM). COM relies on feature point extraction completed by various machine learning algorithms. To exemplify the usage of ArCore tracking, Fig. 2 shows an indoor data collection loop-closure test. In the test, local coordinate data were captured at a rate of 60 frames per section (fps). The user held the Pixel device, turned the Unity application on, and moved from a starting

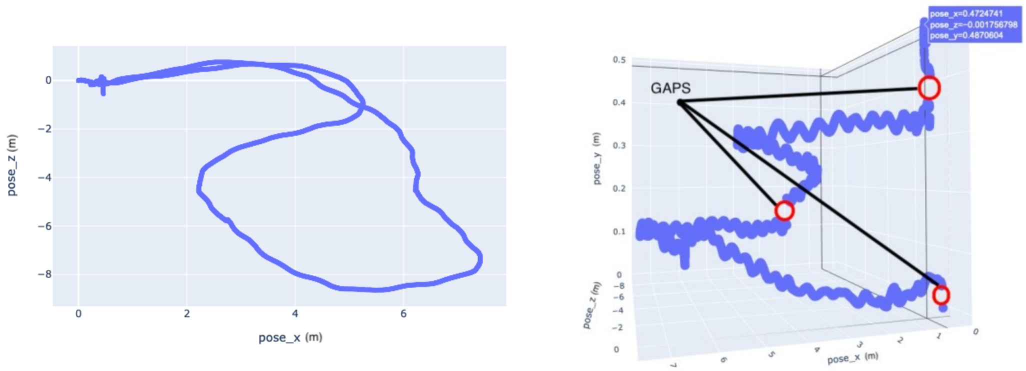

Figure 2. An indoor test of ArCore's pose tracking exemplifying loop-closure. On the left is 2d coordinate space and on the right is the 3d coordinate space.

point, around an indoor lab space, and back to the original starting point. The position tracking resolution is 1 micrometer. The user began by holding the device at roughly 0.1 meters above the ground and attempted to lift the device higher as the walked around the loop feature.

Fig. 2 (right) shows gaps in the data collection for altitude measurement. This occurs when a user moves the device too quickly in any direction. The device may take time to re-calibrate which results in a small discontinuity of the coordinate data. Such effect can be avoid when the device is mounted on a platform which does not change position abruptly.

3.2 ArCore Data Management

ArCore has a number of different features that assist with managing data. It is important to recognize that data collected in GPR systems is typically very large and complicated to process 11. A streamlined data flow is typically configured to transfer data from the GPR to a database either hosted on the Internet, or hosted locally. ArCore in combination with Unity allows users to create HTTP requests to servers allowing smooth flow of data either via Ethernet or over WiFi.

4. SYSTEM INTEGRATION

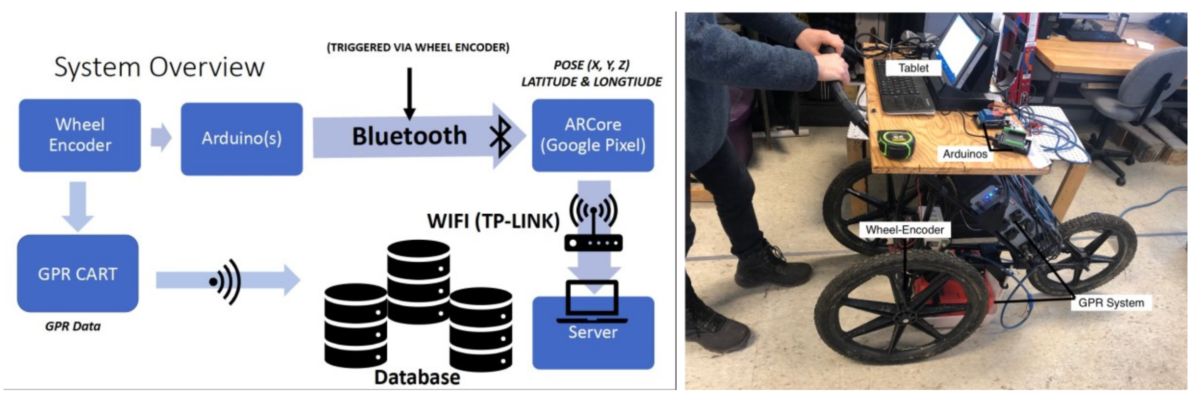

Figure 3. Fully functional GPR-AR system enabling detailed local position tracking of GPR scans via wheel-encoder triggered pose data points.

4.1 System Configuration

The overall system developed in this paper has two main software entities. The system uses ArCore and Unity on a google pixel. The other end consists of an application written in Python and deployed to a tablet. This tablet is attached a GPR system that completes and visualizes GPR scans in real time. Fig. 3a shows the overall system as it has been described and Fig. 3b shows the physical GPR cart system on the right.

4.2 Mobile Development

Using the ArCore framework and Unity as described above, this application is designed to capture local position coordinates upon receiving a Bluetooth signal from the GPR cart setup via a wheel-encoder. The wheel encoder sends a signal to our system every 12.138 cm. The data collection pipeline is implemented as follows: 1. Turn on application and make a Bluetooth connection to the Bluetooth controller Arduino located on the GPR cart. After the connection is established, messages can be sent successfully back and forth between GPR and the ARcore mobile device. The mobile device running the application can be placed on the GPR cart. Upon a signal being received from the Arduino, the pose coordinates are then collected by the mobile device and immediately sent to a database. Fig. 4 shows the graphical user interface for the mobile device.

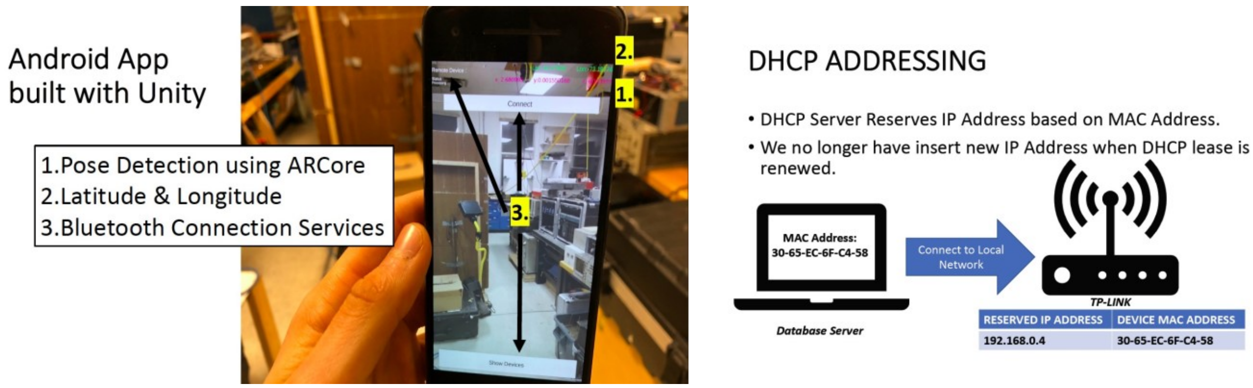

Figure 4. Mobile device application built with ArCore and Unity the collects pose upon Bluetooth transmission (left).Explanation of DHCP Address Reservation (right).

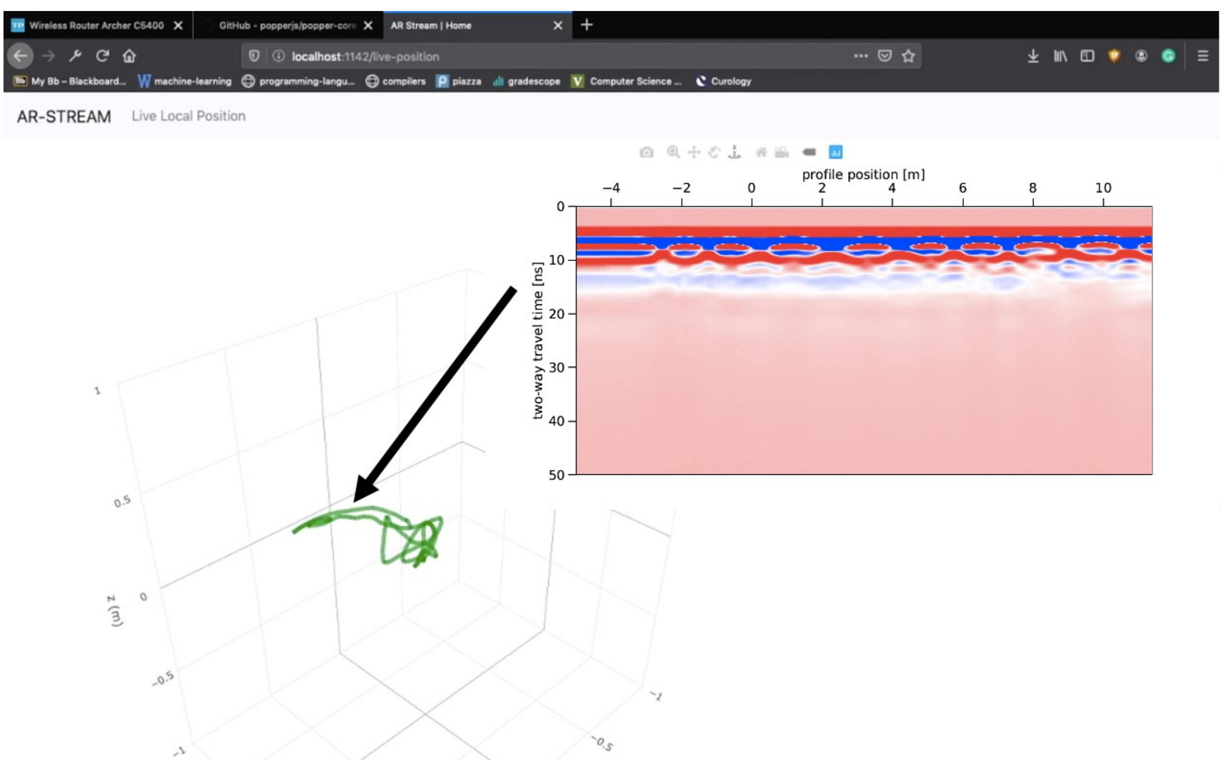

Figure 5. Web application hosted on local server built to collect and visualize position data live. This image shows the 3D plot where position data will be viewed upon the signal sent from the wheel-encoder in the system.

4.3 Local Server

On the other end of the server is an application built with Python that runs a local server.This local server has a database that collects data from the mobile application via WiFi. The WiFi is utilized via a router that set up a local network. The local server is visualized using HTML, CSS, and JavaScript in a web application. The web application shows live positional coordinate data as a scan is completed. This live positional data console on the web application can be viewed in Fig. 5. Both the local positional data as well at GPS coordinates are collected and sent to the database via WiFi, therefore, there is the option to display local coordinates or global coordinates on the web application for a user to make use of. Local and global coordinates are captured simultaneously by the mobile device upon receiving a message from the wheel-encoder triggered Arduino. These coordinates are immediately sent to the local server and linked in a database row resembling the following tuple: (x, y, z, lat, long).

The information is displayed using a web socket. Web sockets are used to keep sockets open to communication using TCP/IP. In this way, the server can broadcast information to all clients simultaneously. On a local server, which was used in this project, latency was not an issue therefore multiple users could stream the incoming positional data at once by connecting to the same local network and navigating to the IP address and port specified by the application.

One benefit of this local server in comparison to Pereira's [1] is the use of DHCP address reservation. This involves reserving an IP address for a device on a local server so that no other device can use it indefinitely. This is useful as past systems had to comply with DHCP leases which change IP addresses every 1 to 2 weeks. Dynamic IP addresses, although important for security protocols, are inhibiting to servers needing to be accessed repeatedly on a local server. If the IP address of the server is to change, all devices in a data topology must adapt to the new IP address in order to send data successfully. Therefore, DHCP address reservations are an integral part of this system to minimize time spent on IP address configuration.

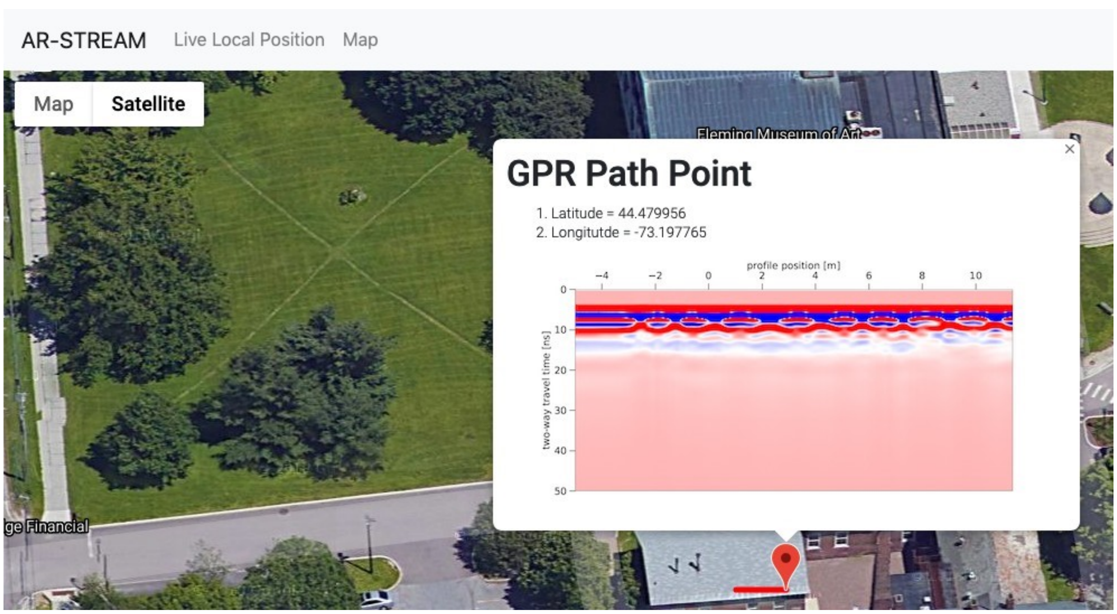

Figure 6. Additional section for the web application designed to display GPR data collection paths with real world coordinates.

4.4 Real World Coordinates

To develop geographic information system (GIS) for managing GPR survey data, it is important to translate local coordinates into real world geographic coordinates. There are several ways that this can be achieved. The common approach is to use GPS. However due to the resolution limit of commercial GPS, precise coordinates can hardly be obtained. To resolve such issue, in this design, the mobile device has been implemented to collect both GPS coordinates and local positional coordinates which are mapped to each other within a database. An example of this mapping is shown in Figure 6 which is developed using Google Maps Cloud API for JavaScript. The data in Figure 6 was an example dataset 1m in length collected inside of a research laboratory at the University of Vermont. The red line represents a line of travel that the AR-GPR system was taken for data collection. During this test, one GPS coordinate was able to be collected by the mobile device. As for resolution of this particular data set, we used wheel encoder distance based triggering. The wheel encoder triggered a scan as well as a local position point every 12.138cm. Therefore, there are 8 points collected over a 1m straight line test. For the resolution of local coordinates captured by ARCore, an example point from Figure 6 is shown below in meters:

$$X: 0.255724519m \quad Y: 0.4115324m \quad Z: 0.170235991m \tag{1}$$

In the scenario that latitude and longitude are not readily available, there is a solution to achieving accurate real world coordinate data. This scenario has been included as part of the data collection pipeline in this paper. In the event of recording data in a remote area with no access to GPS information, the first step is to map out an existing area of testing. An important part of this pre-processing should involve choosing what this research calls a stable landmark, or a recognizable feature in or around a data collection site that has a high probability of remaining unchanged for the duration of data collection and processing. Satellite or georeferenced aerial images must be recent and uninhibited by weather or distortion. After choosing a landmark, testers can go onsite to their testing location. Before any GPR data can be collected, it is important start collecting local positioning data with the ArCore mobile application described above. This way, the predefined landmark of the user's choosing will be designated with both local coordinates pertaining to the test site and global position coordinates. With this stable landmark fully located in both local and global space, all other local coordinates can have global coordinates interpolated with the Haversine Formula [12].

5. CONCLUSION AND FUTURE RESEARCH

The final results of this system integration resulted in an efficient pipeline to assist with mapping GPR scans with accurate local position data via an AR framework. The pipeline enhances previous GPR-AR systems via live streaming data to a local server and utilizing DHCP addressing.

There are many more advancements that can be made to the current system. For one, this pipeline can be appended to in order to include 3D visualization of targets underground. In its current state, GPR and positional data are sent to the database linked together for post processing. In the future, 3D visualizations of underground targets will add to the continuing success of GPR AR systems. This system also embraces the incoming solutions brought by the 5G revolution. In its current state, live streaming to the Internet may not always be quick enough to view without significant latency. As high speed wireless communication, such as 5G network becomes ubiquitous, this project can focus its efforts on to utilize high speed data transfer to realize real time cognitive sensing.

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