A Methodology to Complete and Visualize the GPR Data

*R. Samet, M. Ozkan-Okay (Ankara University), O. P. Markovskyi (National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”)

SUMMARY

Ground Penetrating Radar (GPR) is a geophysical method that is used for investigating and visualizing the underground structures. The usage of GPR in underground research and applications has been increasing recently because it can detect underground structures quickly and accurately. There are some important factors that affect the success of GPR research and applications. One of the factors is the data collection parameters which are under the control of users and can be adjusted according to the aim of the research. Other factors are the research area properties and the structural states of the underground structures. These properties are out of the control of users. Data can be collected incompletely due to such properties as technical failures, rugged terrains, the presence of obstacles, negatively affected electromagnetic signals, etc. These incomplete data make it difficult to visualize and interpret the underground structure with high accuracy. In this study, a methodology is proposed to complete the missing data and predict and visualize the underground structure closest to the original shape in order to contribute to the solution of this problem.
1. Introduction

Ground Penetrating Radar (GPR) is a widely used method to investigate underground structures (anomalies). GPR data are used to obtain a map of the underground. The usage of GPR in near-surface research and applications has been increasing recently because it can detect the anomalies quickly and accurately.

There are some factors that affect the success of the research and applications carried out with GPR. These are the data collection parameters (antenna frequency, sampling interval, profile interval, etc.), the properties of the search area (ground structure, rugged terrains, etc.) and the structural states of the underground objects (it may be damaged, fragmented, maybe in the form of debris, etc.). The data collection parameters are under the control of the users and these parameters can be adjusted according to the aim of research and applications. Another important factor in the investigation of the underground structure is the properties of the search area. These properties are out of the control of users. Data can be collected incompletely due to such properties as technical failures, rugged terrains, the presence of obstacles, negatively affected electromagnetic signals, etc. These incomplete data make it difficult to accurately visualize and interpret the underground structures. When the underground structure is damaged, it is important to find and predict the original shape of the structure using the collected data. In this study, a methodology is proposed to complete the missing data and predict and visualize the underground structure closest to the original shape in order to contribute to the solution of this problem. The proposed methodology consists of four stages. At the first stage, the GPR data set (profiles) is created and preprocessing is applied to make the collected data set appropriate. In the second stage, the anomalies are extracted from the profiles of the data set and the meaningless points (noise) are removed from the image. In the third stage, the missing regions (incomplete data) are completed with interpolation techniques. In the final stage, the rough view of the underground structure is obtained and visualized by image processing techniques.

The study carried out within the scope of the above purpose is organized as follows. In Section 2, the methodology to be followed is proposed to complete the missing data and predict and visualize the underground structure. In Section 3, the implementation of proposed methodology on real data is presented. The Section 4 concludes the study.

2. Proposed Methodology

GPR data consist of \( N \) parallel profiles. Each profile consists of \( M \) traces. Each trace consists of \( K \) sample values (Fig. 1).

![Figure 1](image)

**Figure 1.** (a) Profiles; (b) Traces; (c) Sampling values

The following methodology is proposed to complete the missing data and predict and visualize the underground structure:

1. GPR data set creation and preprocessing;
2. Extraction of anomalies from the profiles of GPR data set;
3. Completing the missing regions with interpolation techniques;
4. Visualization of the underground structures.
2.1 GPR data set creation and preprocessing

In general GPR research and applications, the search area is gridded and the data set is created by collecting the profiles along parallel lines in one direction (Bristow 2009, Conyers 2004). Different numbers of profiles are collected from the search area according to the size and data collection parameters of search area (Samet et al. 2017). The created data set is passed through a number of preprocesses and turned into data set to be ready for applying the other stages of the proposed methodology. In this stage, raw data are improved by standard data processing techniques (trace editing, spectral analysis, band-pass filtering, high pass filtering, background removal, gain, and migration, etc.).

2.2 Extraction of anomalies from the profiles of GPR data set

The sampling values of profiles in the regions without anomalies are close to each other and they are defined according to the properties of the search area. On the other hand, the sampling values of profiles in the regions with anomalies are also close to each other and they are defined according to the properties of the anomalies. So, the sampling values in regions with and without anomalies differ from each other greatly. This feature is used to extract the anomalies from the profiles. The average and standard deviation values are calculated to perform the extraction process. A threshold value is determined using these calculated values (Eq.1).

\[ t = \frac{\sum_{n=1}^{N} (\text{mean}(P^n) + \text{std}(P^n))}{N}, \]  

where \( N \) is the number of profiles, \( P^n \) is the \( n^{th} \) sampling value. The region above the threshold value is extracted from the profile and placed in a 3-dimensional cube (Ozkan Okay and Samet 2017). There may be appeared the meaningless points (noise) in the obtained data after thresholding. This noise is removed from the image by various filtering techniques (mean, median and Wiener filters).

2.3 Completing the missing regions with interpolation techniques

There are some factors that affect the success of GPR research and applications. These are the data collection parameters, the search area properties, and the structural states of the underground objects. The data collection parameters are under the control of the users and these parameters can be adjusted according to the aim of research and applications. The search area properties and the structural states of the underground objects are out of the control of the users. GPR data may be collected incompletely due to some reasons such as; the technical failures could occur during data collection with GPR, the search area can include the rugged terrains and obstacles, the underground objects could be broken, fragmented and turned debris. Due to these reasons, some traces could not be collected; some sampling values could be lost or damaged, etc. As a result, the underground structures could be visualized incompletely and interpreted incorrectly (Annan 2009, Safont 2014). In this context, in order to visualize and interpret the underground structure with high accuracy, the weighted mean interpolation techniques were used to produce the missing data (Ozkan Okay and Samet 2017, Ozkan Okay and Samet 2018, Samet et al. 2015).

2.4 Visualization of the underground structure

After applying interpolation techniques, the rough view of the underground structure is obtained. In the next step, smoothing is applied to soften the sharp edges and regions. In order to visualize the underground structure whole, the gaps between the regions of structure are filled in. Finally, by applying morphological operations, a final view is obtained close to the original geometric shape of the underground structure.

3. Implementation of the Proposed Methodology on the Real Data Set

For the test and verification of the proposed methodology, the GPR data set of well-known underground objects should be used. A test area has been created to obtain data sets of this type. Various sizes of materials (pipes, stone wall, plastic drums, cavity, etc.) were embedded in the
underground of this test area. Such a way, the correct information about underground objects (object type, its depth, and sizes, etc.) could be obtained precisely. 20 parallel profiles were collected from the test area. Profile lengths are approximately 5 meters. The distance between profiles is approximately 25 cm. The directions of the obtained profiles from embedded wall structures were given in Fig. 2 (a). After the data collection and preprocessing operations, the view of 7th \((n = 1, 2, \ldots, 20)\) profile in the data set was shown in Fig. 2 (b).

![Image](image1.png)

**Figure 2.** (a) The embedded wall structure in the test area and (b) The view of abnormal profile

In order to test and verify the accuracy of the proposed interpolation technique, the collected original profile data should be artificially disrupted or detracted. To this end, some parts of the profile data were deleted. The anomalies were extracted from the disrupted or detracted profiles and placed in a 3-dimensional cube. The example of the obtained view of anomaly is shown in Fig. 3 (a). Next, the meaningless points (noise) were removed from the view by applying various filters (Fig. 3 (b)).

![Image](image2.png)

**Figure 3.** (a) The view of the anomaly with detracted or disrupted profile data and (b) The view of anomaly after removing noises

As seen in Fig. 3 (b), there are gaps in the left region of the wall structure. This was due to detraction or disruption made on the profiles. This is accepted as missing data or incomplete data.

Then, in order to produce the missing data, the gaps (due to the artificial detraction or disruption of profiles) in the regions forming the wall were filled as a whole. This was done by applying interpolation techniques. The obtained wall views were shown in Fig. 4 (a) and Fig. 4 (b).

![Image](image3.png)

**Figure 4.** (a) The wall view before interpolation (b) The wall view after interpolation and (c) The obtained final wall view
Morphological operations (erosion and dilation) were applied to the obtained wall views. After that, smoothing was applied to soften the sharp edges/areas and the geometric shape of the underground structure was obtained in a closest to the original (Fig. 4 (c)).

Conclusion

GPR is a widely used method to investigate the underground structures. The use of the GPR method has been increasing recently, as it detects underground structures quickly and accurately. In GPR research and applications, the data collection parameters, the research area properties and structural states of underground structures play an important role in the identification of underground structures. Due to factors such as technical failures, rugged terrains, the presence of obstacles the GPR data can be collected incompletely. These incomplete GPR data make it difficult to visualize and interpret the geometric shape of the underground structures with high accuracy.

In this study, a methodology was proposed to complete the missing data and predict and visualize the underground structure closest to the original shape. Within the scope of the proposed methodology, firstly, the data were collected from the test area and the preprocessing operations were applied to these data. In the second stage, the anomalies were extracted and the meaningless points were removed from obtained anomalies. After that, the gaps between the parts of the anomaly were filled in with the interpolation technique. At the final stage, the final view of the underground structure was obtained. The obtained result showed that due to the proposed methodology, the obtained view of the underground structure was close to the original object with high accuracy.

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References


