Underground object reconstruction from Ground Penetrating Radar (GPR) data – An investigative study of feature extraction

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Abstract. Ground Penetrating Radar (GPR) is very useful for underground object detection as its signal able to penetrate surfaces in obtaining the underneath information. However, its radargram output in hyperbolic signal are very challenging to be analyzed. This work investigates the suitability of selected data processing methods in extracting important features of the signal in order to understand and reconstruct it to make it more beneficial. Results show that with suitable combination of data processing, it able to extract the peak of the hyperbolic signal accordingly and further reconstruction can be made.

1. Introduction

Ground Penetrating Radar (GPR), also known as georadar or subsurface radar, is a non-destructive technology that able to detect underground objects through its scanning. It transmits electromagnetic signal that reflected when scanning materials through antenna frequency. Several methods can be applied in scanning underground objects, but the A-scan is the most preferred [1]. Due to its advantages that able to conduct monitoring and analysis without destroying and damaging the scene, GPR has been utilized for various applications like road inspections [1], archaeology [2] and forensic investigation such as detecting clandestine grave [3].

However, it comes with a few limitations. One of them is with respect to its reflected output signal. GPR output, in radargram, which resembles like a hyperbolic signal, makes it very difficult to be interpreted and analyzed. Several applications that utilize GPR require a full detection and reconstruction of the data for visualization purpose. Hence, appropriate data processing is required.

This paper highlights an investigative study of several feature extraction methods in analyzing the hyperbolic signal from GPR and reconstruct them. The main, important work here is to understand the signal and detecting the feature from the hyperbolic waveform that may able to represent something beneficial in reconstruct and analyzing the GPR output. Similar work has been done, but in [4], only detection analysis and no reconstruction work has been done. On the other hand, researches in [5] [6] are fusing GPR with others to reconstruct and produce suitable results, and [7] utilized an advanced system, which may be prohibitive to some.
2. Methodology
In this section, overall methodology used to study on how reconstruction can be performed from GPR signal will be discussed.

2.1 Signal Acquisition
In this project, 800MHz antenna frequency of MALA Ramac GPR was used to collect the signal from the underground object. The sample, which is a cuboid shape covered with aluminum foil as shown in Figure 1(a), is buried in a test bed of dry soil at the Malaysian Nuclear Agency (MNA) under the supervision and guidance from Non-Destructive Testing (NDT) Department. The overall layout of the test bed with the buried object and the GPR can be seen from Figure 1(b). Aluminum is chosen being a reliable reflector. An A-type scanning named A1 along the length of the cuboid is conducted 5 times. Figure 2 shows the overall system during data collection and Figure 3 shows the process of acquiring the signal. Figure 4 shows a sample of radargram obtained during the signal acquisition process.

![Figure 1](image1.png)

(a) The buried cuboid with its measurement; (b) The layout of the buried object with respect to the test bed, where the GPR position is in blue

![Figure 2](image2.png)  ![Figure 3](image3.png)

Figure 2. The test bed used in this study  Figure 3. Data collection process
Figure 4. The radargram of the GPR

2.2 Signal Processing
As the GPR data are in radargram, which are signals in hyperbolic shape, suitable signal processing needed to extract relevant features in reconstructing the data. First, the signal undergoes several processes in removing the noises and enhancing the features. As can be seen from the sample of radargram data, the signal consists of other data as well, hence it needs to be cropped to remove unwanted signal. Then, the cropped data is filtered to remove noises. Several filter methods were chosen based from previous work, i.e., median filter, average filter, Gaussian filter and Wiener filter, in order to find out the best approaches for radargram processing. After that, the signal is enhanced using Otsu method to highlight its features, i.e., the peak of the hyperbolic data. Once the peak has been detected, several suitable measurements were conducted to ensure suitability of the peak for reconstructing the buried object. Basic reconstruction of the object is mapped together with the hyperbolic signal to show functionality of the selected features. To validate the results, the measurements were recorded and errors were calculated.

3. Results & Discussion
In order to understand more on the hyperbolic signal, a scan along the width of the object is also conducted and named as A4 scanning. Figure 5 shows the difference of radargram data representing A1 and A4 scanning respectively. As can be seen from here, the hyperbolic data shows a longer signal representing the A1 scan (scanning along the length of the cuboid) compared to the A4 scan (scanning along the width), hence confirming the hypothesis that the data represents the buried object. Thus, only these were selected to be processed further and cropped. The lines above the hyperbolic signal are
assumed to represent the soil covering the buried object. Figure 6 shows the cropped signal of 5 measurements for A1 scan respectively.

![Figure 5. Raw data of: (a) A1 and (b) A4 scanning](image)

![Figure 6. Cropped hyperbolic signal of the 5 measurements taken: (a) Scan 1, (b) Scan 2, (c) Scan 3, (d) Scan 4, (e) Scan 5](image)

As mentioned in the Methodology, the cropped signals were filtered using several methods in finding the suitable ones for radargram processing. Figure 7 shows the resulted filtered signal performed on the first measurement of data (Scan 1). It can be seen that filter method like Gaussian is not suitable for radargram processing, but further analysis can be seen in the validation part afterwards.
Figure 7. Output of filter processes towards Scan 1 data: (a) median filter, (b) average filter, (c) Gaussian filter, (d) Wiener filter

For this investigative study, the peak of the hyperbolic signal of the radargram data is chosen to represent the top surface of the buried cuboid object. To ensure in using the correct measurement representing the peak, the image of the hyperbolic signal is converted into its respective binary values using Otsu method. From the actual measurement, it is known that the location of the edge of the object is at the x-axis value of 115 cm. Thus, this value is used for validating the filtered results and reconstructing the buried object. Table 1 shows the comparison of peak location for respective scans and their errors. It can be seen that median filter work best in getting the features from the hyperbolic signal, i.e., the peak. Figure 8 shows the investigative reconstruction results based on the results and hypothesis made in this work, where a box representing the buried object with real dimension is fitted together with the radargram to show potential reconstruction results.

Table 1. Performance of different filter method in extracting the GPR signal

| Scan | Actual Peak Location (cm) | Peak Location from Filtered Signal (cm) | Error (|actual – filtered|) (cm) |
|------|--------------------------|----------------------------------------|-------------------|
|      |                          | Median | Average | Gaussian | Wiener | Median | Average | Gaussian | Wiener |
| 1    | 115                      | 104    | 102.5   | 104      | 98     | 11     | 12.5    | 11       | 17     |
| 2    | 115                      | 105.5  | 105     | 106      | 105    | 9.5    | 10      | 9        | 10     |
| 3    | 115                      | 114    | 105.5   | 106.5    | 110.5  | 1      | 9.5     | 8.5      | 4.5    |
| 4    | 115                      | 111.5  | 117.5   | 107      | 115.5  | 3.5    | 2.5     | 8        | 0.5    |
| 5    | 115                      | 113.5  | 112.5   | 114      | 115    | 1.5    | 2.5     | 1        | 0      |
|      |                          |        |         |          |        | Average| 5.3     | 7.4      | 7.5    | 6.4    |

Figure 8. Reconstruction of the buried object (in red) fitted with respect to its radargram signal
4. Conclusion
This work studied the potential of selected methods in extracting beneficial feature from GPR radargram hyperbolic signal that can be utilized for reconstruction and visualization of the data for underground scanning. Results show that median filter, combined with suitable other processing, able to extract the peak of the hyperbolic signal representing the edge of the cuboid buried object. The preliminary reconstruction result shows promising work, however, due to this scope of work which were conducted in a controlled environment, more investigation is needed with further processing to other types of data is required.

References
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