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Feature Extraction for Underground Object Reconstruction from Ground Penetrating Radar (GPR) data

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ABSTRACT

Ground Penetrating Radar (GPR) is very beneficial for underground object scanning and detection. It utilises radar pulses as the signal, hence it able to penetrate surfaces in obtaining the underneath information without disturbing and destructing the ground. However, its radargram output in hyperbolic signal are very challenging to be analysed. Thus, suitable algorithm has to be designed and developed to interpret the data. This work highlights on the usage of drop-flow algorithm in detecting important features of the hyperbolic signal. Previous study has shown that these features is promising in understanding and further, reconstructing the GPR data. Results show that the features extracted from the hyperbolic signal able to be identified for further processing, which is necessary for visualization purpose.

Keywords: drop-flow algorithm, GPR, underground object detection and reconstruction

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 materials are detected through antenna frequency. One of the preferred methods for data collection using GPR is the A-scan [1]. Due to its advantages that able to conduct analysis without destroying and damaging the scene, GPR has been utilised 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, where one of the them is with respect to its reflective output signal. GPR output, in radargram, resembles like a hyperbolic signal. Figure 1 shows a sample of hyperbolic signal characterising a buried object which is a box. From here, it can be seen that the signal does not represents the shape of the object at all, making the analysing of the signal very challenging. Hence, appropriate data processing is required to interpret and analyse the data.

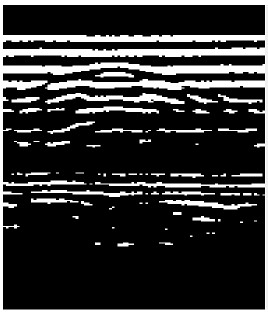

Figure 1. A sample of hyperbolic signal collected by a GPR representing a buried box

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One of the important analyses with GPR data is reconstruction. Due to its hyperbolic signal, the ability to reconstruct the signal into its representation of the shape of the buried object would be very beneficial and appreciated. Thus, researchers are now concentrating on suitable methods to reconstruct these hyperbolic signals.

This paper highlights on the usage of drop-flow algorithm for extracting the important features that might be useful in reconstructing the hyperbolic signal. Our previous study in [4] has proven that the extracted features are important and able to represent the shape of the buried object, which is important for reconstruction. The main, important work here is to understand the signal and detecting the features from the hyperbolic waveform that may able to represent something beneficial in reconstructing and analysing the GPR output. Similar work has been done, but in [5], only detection analysis and no reconstruction work has been done. On the other hand, researches in [6] and [7] are fusing GPR with other sensors to reconstruct and produce suitable results, which may produce a more complex data to be processed. Meanwhile researchers in [8] utilised an advanced system, which may be prohibitive to some.

2. MATERIAL AND METHODS

In this section, overall methodology used in this work will be discussed.

2.1 Signal Acquisition

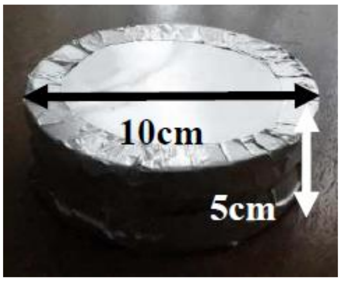
In this project, 800MHz antenna frequency of MALA Ramac GPR as shown in Figure 2 was used to collect the signal from the underground object. Samples representing basic shapes of cuboid, sphere, disc and cylinder were used. The samples were covered with aluminium foil and buried in a test bed of dry soil at the Malaysian Nuclear Agency (MNA) under the supervision and guidance from Non-Destructive Testing (NDT) Department. Aluminium is chosen due to its reliable reflector. Figure 3 shows the overall system used during data collection while Figure 4 shows the process of acquiring the signal. An A-type scanning named A1 along the length of the samples is conducted 5 times. Figure 5 shows the samples used and Figure 6 shows the layout of the test bed with buried cuboid. Figure 7 shows a sample of radargram obtained during the signal acquisition process.

Figure 2. 800MHz MALA Ramac GPR

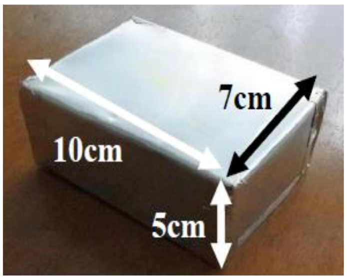
Figure 3. The test bed used in this study

Figure 4. Data collection process

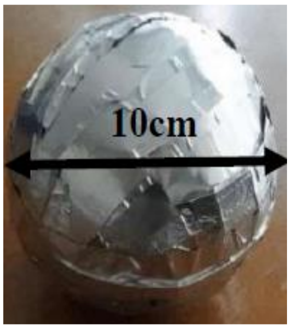
(a)



(b)



(c)



(d)

(e)

Figure 5. Samples used in this project: (a) Overall samples, (b) Dimension of disc, (c) Cuboid, (d) Sphere, (e) Cylinder

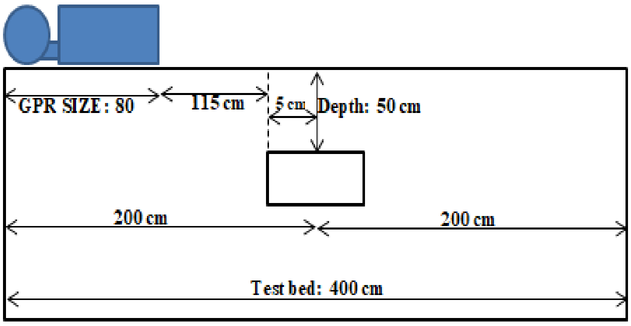


Figure 6. The layout of the buried object with respect to the test bed, where the GPR position is in blue

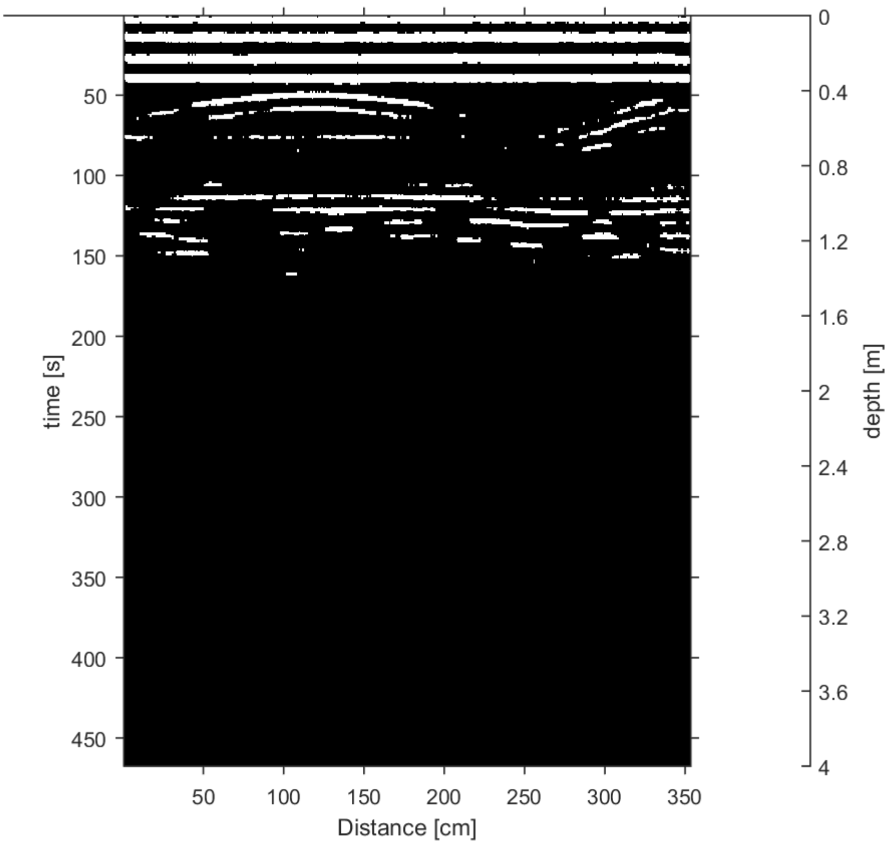


Figure 7. The radargram of the GPR

2.2 Signal Processing

As the GPR output data are in radargram, which are signals in hyperbolic shape, suitable processing methods are needed to understand and reconstruct the signal, and accomplish this project. 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. At this preliminary stage, the peak of the hyperbolic signal is the interest feature and will be focused and extracted. Once the peak has been detected, several suitable measurements were conducted to ensure correctness and suitability of the peak in representing the buried object for reconstructing it later on. 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.

From here, it can be clearly seen that the extracted feature, i.e., the peak of the hyperbolic signal, did represent something beneficial for the buried object; hence, useful for reconstruction. Thus, further analysis on how these features can be extracted is conducted. A method called drop-flow algorithm is chosen [9]. Drop-flow algorithm simulated the motion of a falling droplet that flows down the edge of the hyperbolic signal due to gravity and stops when it reaches the bottom of the signal. From here, features of the signal like apex / peak, rising and trailing legs can be detected. Figure 8 shows a demonstration on drop-flow algorithm in detecting these features from the hyperbolic signal.

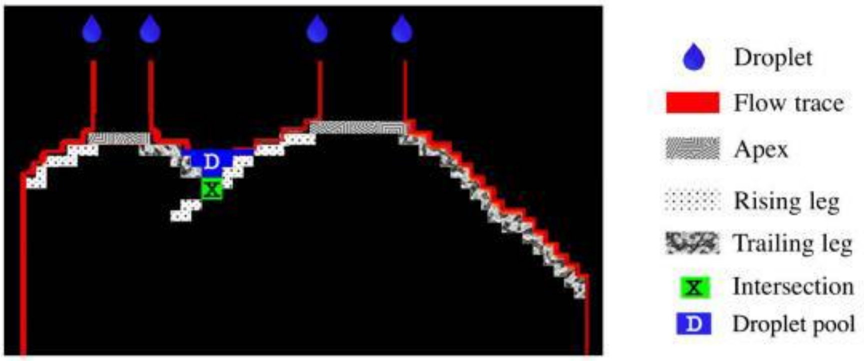


Figure 8. GPR hyperbolic decomposition using drop-flow algorithm [9]

The drop-flow algorithm resembles the action of a drop falling. The gradients between the current pixel and the surrounding pixels define the flow direction with downward flows receiving additional priority. This method is represented as in Figure 9 by factoring five neighbouring pixels into one-pixel (n_1) directly below the current pixel; two pixels to the left (n_2, n_5) and two pixels to the right (n_3, n_4). The whole image space, P, is made up of *M* columns and *N* rows, and is represented by an *M* x *N* matrix.

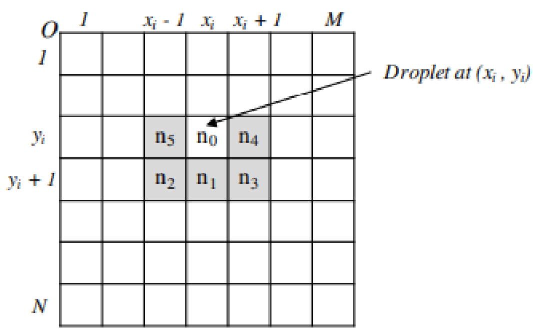


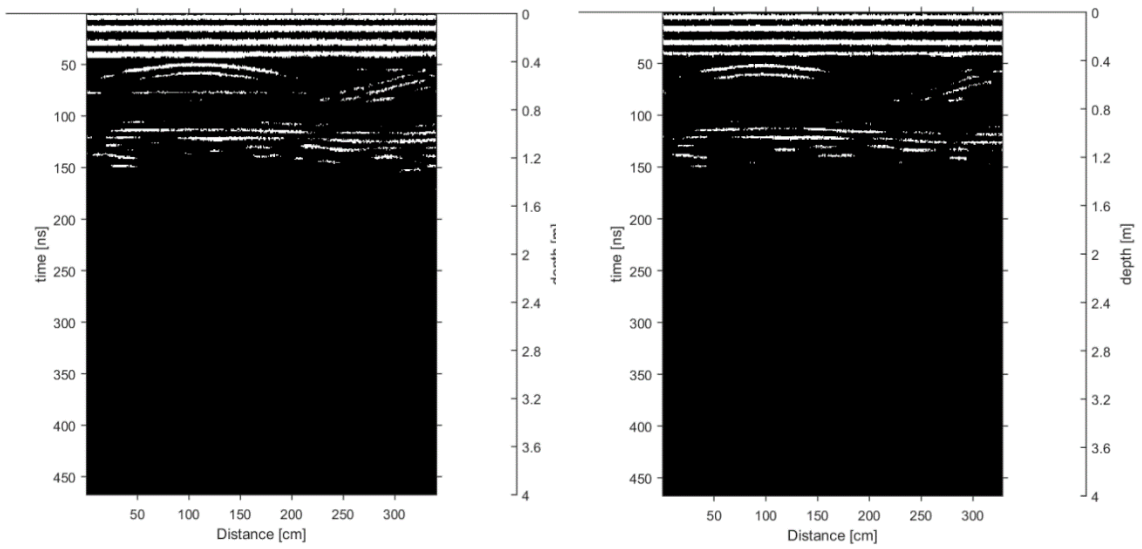
Figure 9. Droplet at the five-neighbouring pixel [9]

To avoid an infinite looping, the algorithm will keep track of the droplet's previous, present and future flow directions. If the flow directions are shifted back and forward repeatedly, the algorithm will cause the droplet flowing to n_2 or n_3 to jump out of the local concave depending on its inertia. As a result, flow trace *T* is determined by the current pixel strip (S_i), the weight of its flowing into nearby pixels (W_i) and the droplet strip inertia ($\overrightarrow{I_l}$) as described in Equation (1).

$$T(S_{i+1}) = f(S_i, W_i, \overrightarrow{I_l}), \qquad \text{for i = 0, 1, 2, ...} \qquad (1)$$

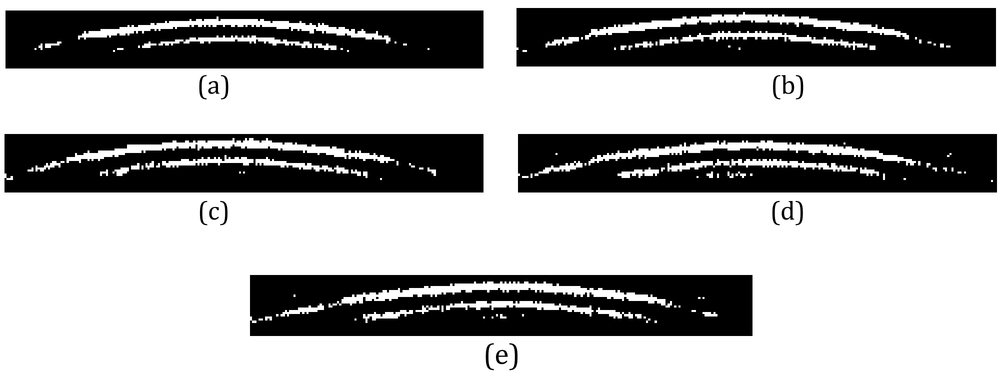
3. RESULTS AND DISCUSSION

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 10 shows the difference of radargram data representing A1 and A4 scanning respectively. As can be 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 11 shows the cropped signal of 5 measurements for A1 scan respectively for the buried cuboid.



(a) (b)

Figure 10. Raw data of: (a) A1 and (b) A4 scanning



(a) (b) (c) (d) (e)

Figure 11. Cropped hyperbolic signal of the 5 measurements taken: (a) Scan 1, (b) Scan 2, (c) Scan 3, (d) Scan 4, (e) Scan 5

As mentioned in Section 2, the cropped signals were filtered using several methods in finding the suitable ones for radargram processing. Figure 12 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.

Figure 12. Output of filter processes towards Scan 1 data: (a) median filter, (b) average filter, (c) Gaussian filter, (d) Wiener filter

For this study, the peak of the hyperbolic signal of the radargram 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 value using Otsu method. From the actual measurement, it is known that the location of the edge of the object (i.e., cuboid) 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 13 shows the investigative reconstruction results based on the 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 features from 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

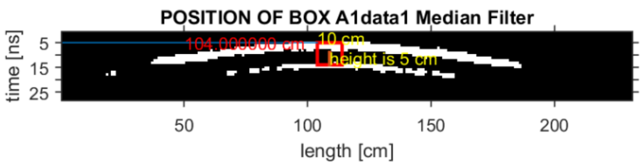
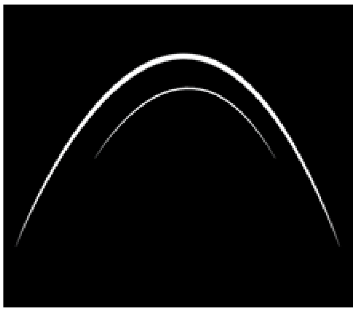
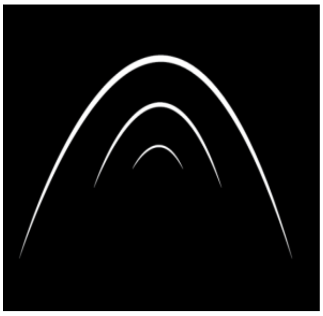
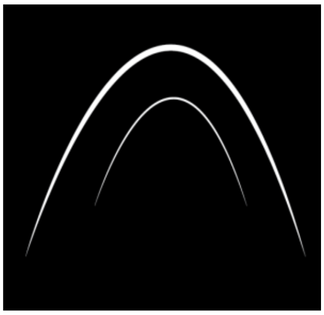
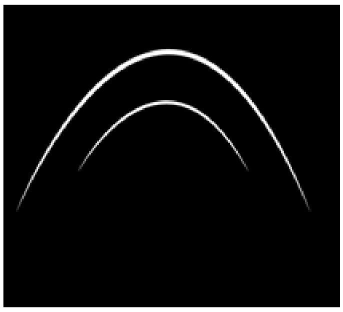


Figure 13. Reconstruction of the buried object (in red) fitted with respect to its radargram signal

Due to the importance of obtaining the features representing these hyperbolic signal, drop-flow algorithm is applied. Table 2 shows the results obtained after the drop-flow algorithm is performed to the signal. As can be seen from this table, every signal has its own signature shape of features, which is very beneficial for further processing like reconstruction later on.

Table 2 Extracted signal from the hyperbolic signal of buried objects

Object	Extracted Signal
Sphere	
Cylinder	
Disc	
Cuboid	

4. CONCLUSION

This work studied the potential of selected methods in extracting beneficial features from GPR radargram hyperbolic signal that can be utilised 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-shape buried object. Then, suitable method of drop-flow algorithm is applied and it is proven able to represent the signal accordingly with distinctive features of respective buried objects. 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.

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