GROUND PENETRATING RADAR BACKSCATTER FOR UNDERGROUND UTILITY ASSETS MATERIAL RECOGNITION

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ABSTRACT: Ground Penetration Radar is the subsurface imaging tool that widely used in most of the engineering practices in the modern cities. It is well established for accurately detecting the planimetric position (x, y) and the depth (z) of the underground utility assets. These two parameters of the underground utility asset are the focus of all the underground utility assets mapping projects. As such, utilization of ground penetrating radar for underground utility assets mapping has been misunderstood where it can only retrieve limited information. Nevertheless, the backscatter reflection that recorded by the ground penetrating radar system are in fact entitle to provide more information apart from these two parameters. The backscatters reflections are very practical for estimating the radius of the utility assets and identifying the material types (mild steel, ductile iron, clay and etc.) of the utility assets. In this paper, the ground penetrating radar backscatter characteristics of each utility asset are figured out and validated through a series of tests conducted on selected test site with known parameter. Results, pinpointed that the unique ground penetrating radar backscatter of the utility assets are functional for material recognition apart from conventional utility assets detection and localization. This provides a new benchmark in application of ground penetrating radar for utility assets material recognition using these unique backscatter reflections. Thereby, the good agreement between the backscatter reflections of ground penetrating radar with respective utility assets in term of radiometry (i.e. material types, and condition assessment for civil infrastructure management and maintenance), is opening a platform for valuable addition to the ground penetrating radar software improvement with new material recognition facility in the near future in addition to current practical utility detection and localization facilities.

1.0 INTRODUCTION

Trenchless work always requires a high resolution, rapid and economic subsurface sensing of the ground. Ground Penetrating Radar (GPR) has been widely used for detecting the subsurface heterogeneities by using electromagnetic waves especially for archaeology, civil engineering, geotechnical investigation as well as mine exploration (Enes et al., 2010, Jeng et al., 2011, and Lester and Bernold, 2007). In these geophysical applications, GPR is well established for detecting the superficial bodies, particularly for locating the planimetric position and depth of the objects or structures in the subsurface. Owing to GPR is recognized as the most potential imaging tool for locating the buried targets, there is an increasing interest in using non-destructive testing method for locating and detecting the underground utility assets. In this context, the application of GPR system in subsurface utility mapping are aimed to extract the geometry information of the underground utility assets, particularly the planimetric position (x, y) and depth (z) of the pipes and cables (Thomas et al., 2009).

Most of the utility pipelines are positioned underneath today city's street or footpath since long time ago. In the trenchless works, a set of complete and reliable information of these existing utility pipelines is much needed by the utility companies, surveyors, planner, engineers, contractors and streetworkers. In this regards, the application of

GPR for extracting geometry properties of the utility pipelines is well established. However, the practical function of GPR in extracting the radiometry properties of the utility pipelines is not fully developed. According to Pasolli et al., (2009), the applications of GPR have been widely used for object detection and location, rather than for identify the material or estimate the size and shape of the object.

Based on this argument, it has led to misunderstanding that application of GPR for subsurface investigation only limited to extraction of geometry properties of the subsurface heterogeneities (e.g.: rocks, sandstone blocks, tunnels and buried utilities) only. On the contrary, the application of GPR particularly for material property characterization is still a bottleneck, therefore subject to numerous investigations. In fact, the variations in the dielectric wave recorded by the GPR can be quantified to obtain new information of the subsurface. The dielectric wave has a lot of information which can be related to the parameters significant to hydrology, soil mechanics, and material property characterizations (Bradford, 2011). Moreover, the dielectric wave also efficient for quantified the properties of the host materials and the nature and size of the superficial bodies as well (Grandjean et al., 2000). The variation of the dielectric wave over the GPR band are hence rich with information, but this aspect of the GPR signal is rarely been explored by the researchers.

Therefore, in order to exploit the gap in the application of GPR especially in underground utility assets mapping, this paper focuses on material property characterization using GPR backscatter. This is intend to correct the misconception in the utility industries which claimed that application of GPR in trenchless work only limited to extraction of geometry properties of the subsurface heterogeneities. In doing this, few sets of data were acquired at the test sites using dual frequencies GPR system. These data were then undergone pre-processing to remove the unwanted background echoes. Based on the absolute pattern of GPR backscatter, the utility material property characteristic such as clay, mild steel, ductile iron, high density polyethylene, and etc. were extracted. After that, the results of the experiments that systematically tested and compared at the selected test site were presented in last part of this paper.

2.0 GPR IMAGING

Trenchless technologies are widely used for the task of subsurface investigation. These including magnetic flux leakage detector, inductive line tracer, ground penetrating radar, pipe cable locator and etc. (Hao et al., 2012, Ni et al., 2010 and Roger et al., 2012). Among these technologies mentioned above, GPR is well known as the best technologies owing to its speed of data acquisition, user friendly and low cost consumption for obtaining reliable information of the subsurface heterogeneities (He et al., 2007, Ni et al., 2010, Reppert et al., 2000 and Rogers et al., 2009). For this reason, GPR was chosen for this study to ascertain the material property of the buried pipelines based on the backscatter reflection recorded by the GPR.

In current market, most of the GPR system are designed and operated in the range of frequencies from 10MHz to 1GHz. The operation of GPR is similar to others radar device, where the transmitter will transmits short electromagnetic (EM) pulse to the ground and the receiver will receives the reflection from the targets. Suppose that if there is an object buried in the subsurface (refers Figure 1). The measurement of GPR is principally along a line with equidistant intervals. At each position, the transmitter will transmit EM wave to the ground where the EM wave will be partially scattered discontinuity in the dielectric relative permittivity (ε_r). Then, the incident wave will reflect back to the surface and recorded by the receiver with a time delay (Δt) after the signals travels with the distance (2.d) from antenna to the scatterer and back to the receiver with speed of light (c_m). For measuring the time delay, equation 1 is used (Seyfried et al., 2012):

$$\text{Timedelay}, \Delta t = \frac{2.d}{c_m}$$

(1)

The echo delay (t_0) is increasing symmetrically to the left and right in the position of Y_n and Y_{-n} forming a hyperbola pattern in the radargram where the apex of a hyperbola denotes the position of the objects. For object which is buried deeper in the ground, the intensity recorded in radargram is less than the object which is buried shallower. The signal attenuation in the earth is dependent on the radiation pattern of the antenna, hence the intensity are generally weaker at the branches of the hyperbola. For measuring the hyperbola reflection, equation 2 proposed by (Chen et al., 2004, Ristic et al., 2009 and Wang and Su, 2011) is used:

$$\frac{t_n{}^2}{t_o{}^2} - \frac{4(y_n - y_0)^2}{(vt_0)^2} = 1$$

(2)

where v represents the velocity of the EM wave, t_n represents the echo delay in position y_n and t_0 represents the echo delay as well . Then, discretization of equation (2) can be quantified by allowing the *dt* and *dx* be the time and spatial sampling intervals (Liu et al., 2010):

$$\frac{i_n{}^2}{i_o{}^2} - \frac{4(j_n - j_0)^2 (dx)^2}{i_o{}^2 (vdt)^2} = 1 \qquad (3)$$

where (i_o, j_0) represents the hyperbola apex which shows the location of the object.

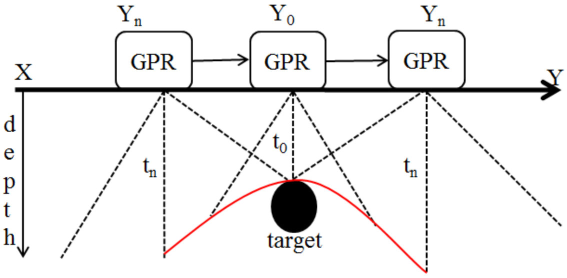


Figure 1: Formation of hyperbola in radargram

According to this geometry information of the object, the hyperbola reflection pattern could be used for extraction of various parameters such as radius, spatial orientation, relative permittivity and etc. of the subsurface heterogeneities because the reflected incident wave represents the EM discontinuity of the target. These reflected signals are known as the radar backscatter and it measures in decibel (dB). As mentioned by Toropainen (1995), the radar backscatter is measured using equation (4):

$$\sigma_{cp} = \sigma_{s\perp}\left[\frac{1-\exp(-2\sigma_t d)}{2\sigma_t} + 2[\Gamma_2]^2 d\exp(-2\sigma_t d) + \frac{|\Gamma_2|^4}{2\sigma_t}\exp(-2\sigma_t d)(1-\exp(-2\sigma_t d))\right]$$

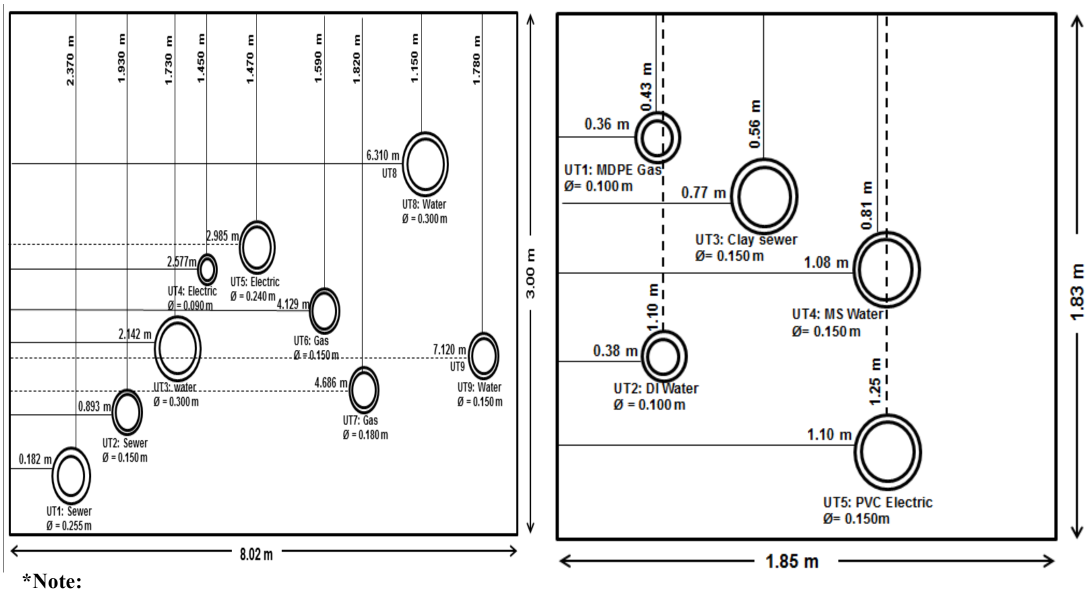
(4)

where the first term of equation (4) represents the backscatter of the incident wave, the second term represents the forward scattered wave, the third term represents the reduced incident wave's backscatter, Γ_2 represents the voltage reflectance coefficient at lower surface, σ_t represents cross-section of the material and d is the distance travel by the signal. With these reflection patterns that recorded in the radargram, the material properties of the subsurface heterogeneities can be extracted directly through close inspection.

3.0 FIELD MEASUREMENT AND PROCESSING

3.1 Description of Test Site

This study was conducted at two test sites which were purposely built for understanding the backscatter characteristic of the underground utility assets. These test sites were composed of dimensions of 9.74 x 8.02 x 3 m and 1.85 x 1.85 x 1.83 m, which filled with different types of host materials. However, homogenous host materials are used in this study as inhomogeneous host materials will complicate the detection of target in a radargram. This is also mentioned by Liu et al., (2010), where complex host material composition will burden the extraction and target detection in the practical application of GPR. Several types of utility features were buried in these test sites (refers Figure 2). The structure of these test sites were representative of the actual civil engineering contexts. The actual civil engineering contexts and the geophysical anomalies in the real world can be correlated with these test sites with no doubt. In this regards, the along pipe scanning data acquisition was conducted using IDS DetectorDuo* GPR system. This system was chosen due to its good system parameter with optimal frequency (250 MHz and 700 MHz) for subsurface investigation by real time interpretation and ease of use (Ingegneria dei Sistemi S.p.A., 2007). According to Jaw and Mazlan (2011) and Mazlan et al., (2010), the best scanning technique for acquiring data using GPR is along pipe scanning owing to its capability in acquiring data with high accuracy, deeper signal penetrating for better target detectability.



***Note:**
PVC = Polyvinyl chloride
DI= Ductile Iron
MDPE = Medium-density polyethylene
HDPE = High-density polyethylene
MS = Mild Steel

(a) (b)

Figure 2: The utility details (a) test bed 1 and (b) test bed 2

3.2 Data Processing

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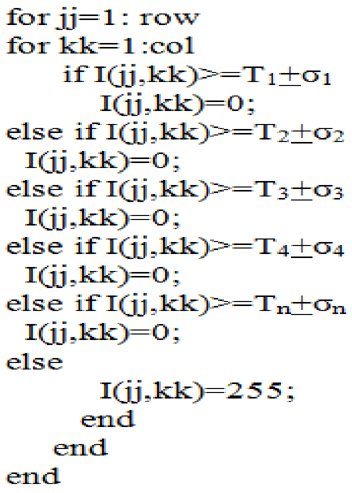
[*] Trademark of Ingegneria dei Sistemi S.p.A.

The pre-processing steps used below were based on author personal opinion where users can tailor their own signal processing routines to suit with different GPR system according to their data interpretation experiences. For data processing, the depth scale of the data was first being aligned to the actual position of the investigated area using remove start time function for improving the signal-to-noise ratio (SNR) of the radargram. Then, clear-x filter was applied to the radargram to remove the unwanted background echoes caused by non-target such as cavities in the background removal process (Kim et al., 2007). After removing the background noise, the bandpass filtering was applied to filter the noise outside the target region leaving behind the main GPR signal of the target's interest (Jol, 2009). After that, linear and smooth gain functions were applied to the radargram accordingly using the system default or user-defined mathematical or multiplication operation. The data were now eligible for interpretation and analysis where the utility features can be extracted from the radargram.

3.3 Thresholding Segmentation

The unique backscatters of the buried pipelines detected from the radargram were extracted through image thresholding. The complex background due to non-target was separated from the unique backscatter of the target using the image grey level histogram. According to Tobias and Rui (2002), the bimodal or nearly bimodal histogram works well for separating the target interest from the background if the image grey level was greater than certain threshold levels. In this study, the target interests backscatters belong to the buried pipelines were selected using the rule where difference in threshold values (T) in successive iterations was smaller than T_0 which represents the threshold value for initiate the iteration using MATLAB® coding shows in Figure 3.



```
for jj=1: row
for kk=1:col
     if I(jj,kk)>=T1±σ1
        I(jj,kk)=0;
else  if I(jj,kk)>=T2±σ2
  I(jj,kk)=0;
else  if I(jj,kk)>=T3±σ3
  I(jj,kk)=0;
else  if I(jj,kk)>=T4±σ4
  I(jj,kk)=0;
else  if I(jj,kk)>=Tn±σn
  I(jj,kk)=0;
else
        I(jj,kk)=255;
      end
   end
end
```

***NOTE:**

T= Threshold value

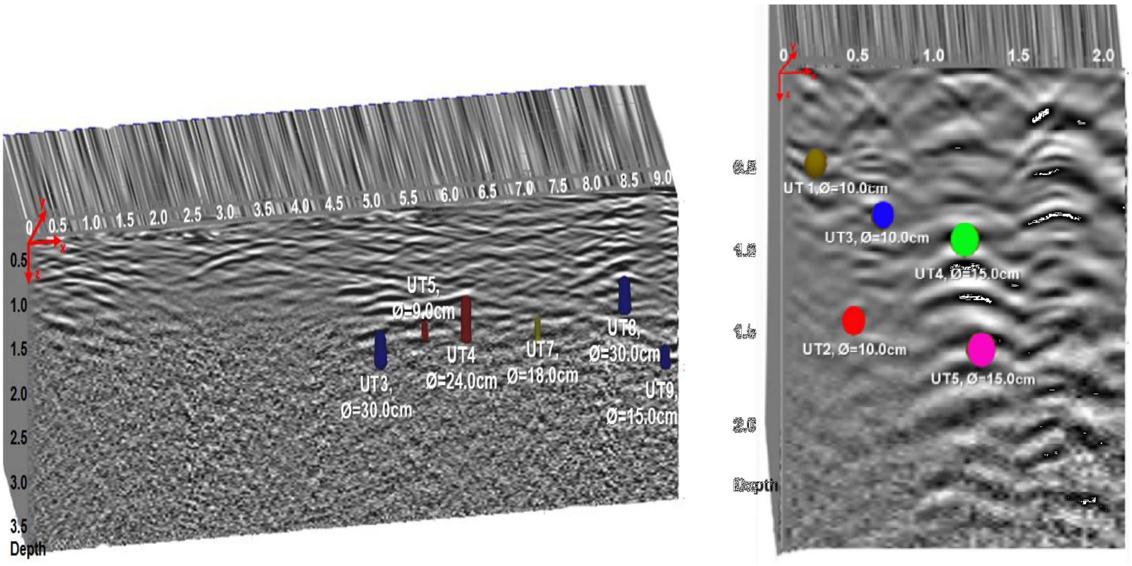
σ= The standard deviation

$n = n^{th}$ of utility

Figure 3: The MATLAB® coding for thresholding segmentation

4.0 RESULTS AND DISCUSSION

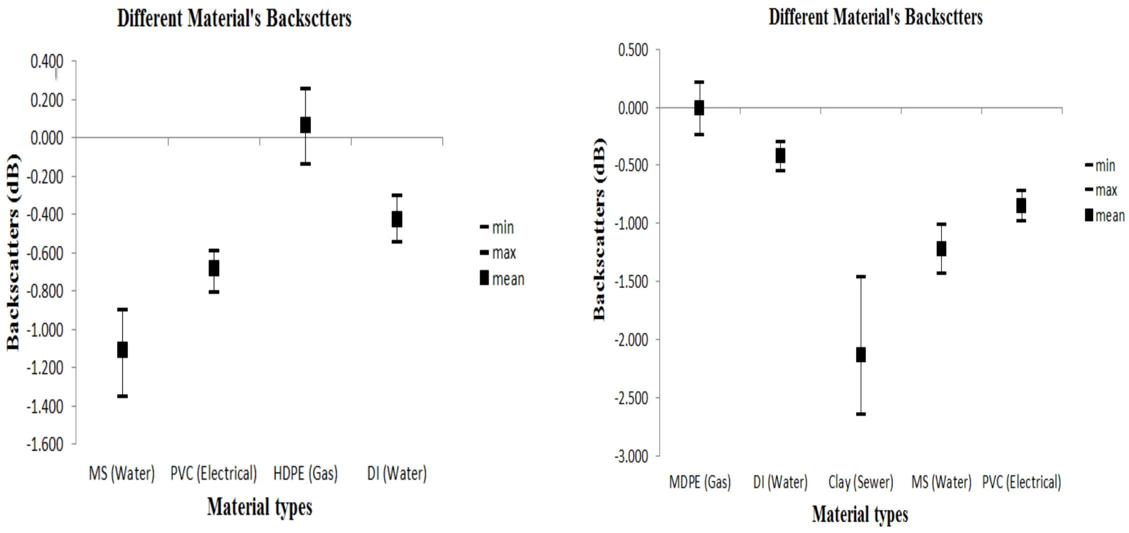
The results of utility detection for test bed 1 and test bed 2 were shows in Figure 4 (a) and (b). The cross-section of the buried pipelines that being detected in this study were symbolize by the coloured circles in Figure 4 (a) and (b).



(a) (b)

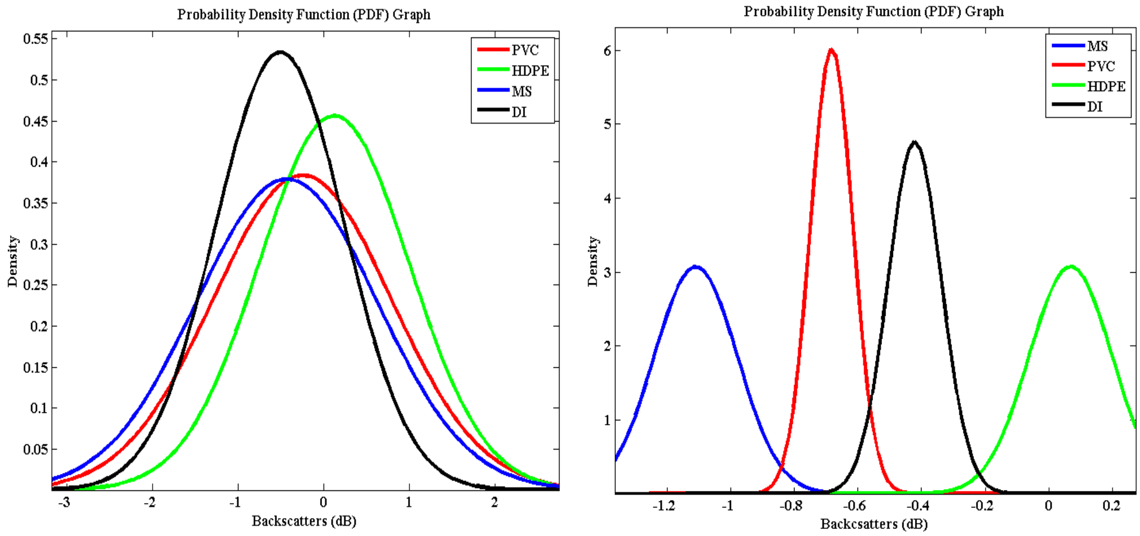
Figure 4: Results of buried pipelines detection for (a) test bed 1 and (b) test bed 2

Referring to Figure 4 (a) and (b), there were six utilities out of a total of nine buried pipelines in test bed 1 were detected whilst all the buried pipelines in test bed 2 were successfully being detected. The absolute backscatter for each detected buried pipelines were extracted with relating to its manufacture materials (clay, ductile iron, mild steel, and etc.). However, some of these materials contain same properties such as Polyvinyl chloride (PVC) and polyethylene (PE), the backscatter value was hence overlapped. In this sense, the absolute backscatter for these materials were hardly can be distinguished. For addressing this problem, thresholding segmentation was performed using Matlab® to separate the genuine reflection of the utilities from the spurious reflection caused by non-target features due to surrounding mediums. Figure 5 shows the absolute GPR backscatter of each detected utility for test bed 1 and test bed 2 whilst the results of threshoding segmentation for test bed 1 and test bed 2 were show in Figure 6 and 7 respectively.



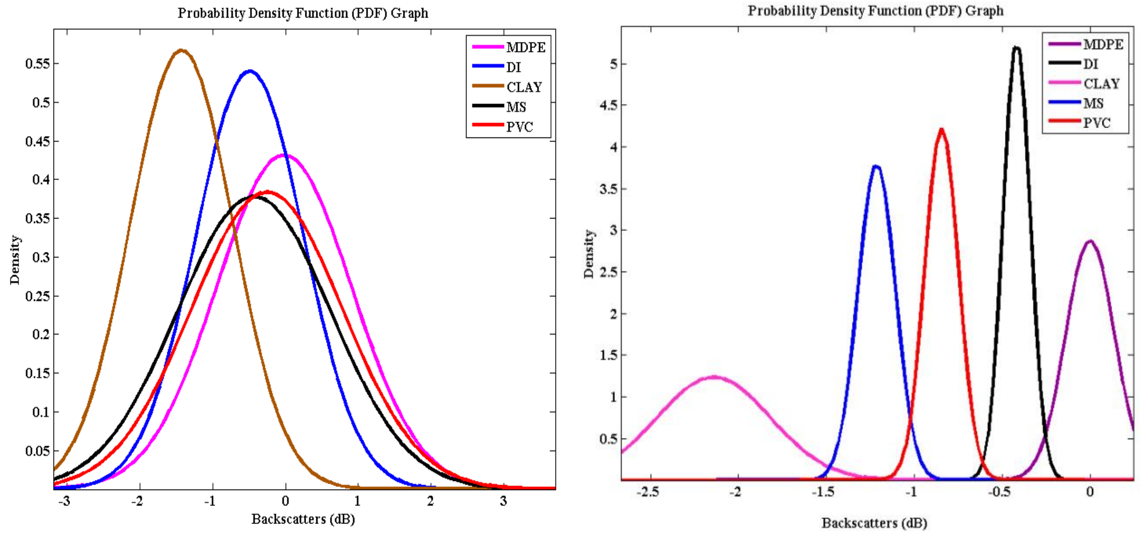
(a) Test bed 1 (b) Test bed 2

Figure 5: Backscatter value according to utility material property



(a) Before thresholding (b) After thresholding

Figure 6: Unique backscatter of different utility's material for test bed 1



(a) Before thresholding (b) After thresholding

Figure 7: Unique backscatter of different utility's material for test bed 2

As refers to the unique backscatter ranges, user can easily distinguish the types of utility. However, the stakeholders often tend to overlook the role of these unique backscatter ranges, particularly for material recognition. Results of this study successfully proved that variation of the dielectric wave over the GPR band are hence rich with information. With the aids of further advance processing, the unique backscatters values can be used for characterize the physical properties of the underground utility assets, rather than just to extract the geometry properties of these subsurface heterogeneities. This was because the existing GPR system or processing tools do not have material recognition function. With regards to this, the finding shows that the basic processing using the Commercial Off-The-Shelf (COTS) products was inadequate for feature recognition in current industries. Subsequently, the unique GPR backscatters introduced in this work can readily ingested as interface tool for feature material recognition, as it is very useful for reporting on the utility status or conditions, such as defects of pipes or cables due to aging and weathering.

5.0 CONCLUSION

This study was conducted to understand the material property characteristic using GPR backscatter. Through this study, the unique backscatters of different utility material have been presented. This finding proven that backscatter reflection measured by the GPR are not only for extracting the geometry information of the utility, however, it can use for identified the material of the buried pipelines. In this sense, the application of GPR for underground utility assets mapping is not limited to retrieve the planimetric position and depth only. With the finding from this study, it successfully clarified the misconceptions and ambiguities in underground utility assets mapping industries which claimed that GPR is only for retrieving geometry information of the utility. Therefore, this work has set a new benchmark related to material property characterization using GPR backscatters. With continuous exploration in this aspect, it opens up new platform to the application of GPR particularly for utility industries with new material recognition facility in addition to current practical utility detection and localization facilities.

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