EXTRACTION OF SIGNAL SIGNATURES FROM GROUND PENETRATING RADAR DATA FOR ARCHAEOLOGICAL INVESTIGATION

NURHAZIMAH HUSNA BINTI SHOKRI

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DEDICATION

Specially dedicated for my beloved:

Husband, Mohammad Irfan bin Tajun Arif

Father, Shokri bin Ismail

Mother, Hasbah binti Muslimin

Thanks for the loves, prayer and support

for my success

My siblings

Sharafina Aziyati, Mohd Fadlan, Farahiyah Asilah, Mohd Hafizuddin,

Mohd Hamdi, and Muhammad Izzat Khairuddin

Thanks for always being supportive

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ABSTRACT

Archaeology is a study of ancient material remains and human activities through previously era. Various methods have been used in archaeological data detection purposes, such as magnetic, electromagnetic and earth resistance techniques. The basis of these techniques based on its ability as prospecting tool to determine position, generate images and underground mapping. Currently, the Ground Penetrating Radar (GPR) method has been applied in archaeological prospection to reveal the near surface composition of artefacts. However, the lacking of the analysis of GPR radagram and the used of conventional method which is time consuming and laborious for findings archaeology vestiges are still been applied. This research was conducted to evaluate the capability and effectiveness of GPR in archaeological prospection. The first objective of the study is to identify the signal properties of electromagnetic wave penetrations which are the velocity and dielectric permittivity on different subsurface sediment and object buried. The second objective is to analyse the power of reflectivity of archaeological vestiges at sites and the final objective is to generate three dimensional (3D) time-slices data of archaeological area. To achieve the aims of the study, data acquisition at three different test sites involving of simulation test bed at Universiti Teknologi Malaysia and two real sites at Sungai Batu, Merbok, Kedah and Pudu Jail, Kuala Lumpur with different artefacts have been performed using GPR. The real sites selected in this study were suggested by the archaeologist from the Department of National Heritage, Malaysia. For all sites, grid lines were established to aid in GPR scanning and this method is the best applied in the generation of 3D models of the scanned images. Accordingly, each transversal and longitudinal line was scanned with the aim of deriving the signal signatures to discover the existence of artefacts and the electromagnetic properties of the sediment and artefacts. Besides, 3D model and time-slices are generated for better interpretation of the results. Based on the fitted velocity results obtained, it were successfully derived the dielectric permittivity of the sediment of the three test sites with a value of 14.793-25.000, 4.000-6.250, and 4.000-18.367 respectively. The observed values are comparable to the published values provided in previous study. In addition, the dielectric permittivities of artefacts were derived with a value of 9.000-14.060, 5.325-18.367, and 7.438-11.111 respectively. Moreover, the 3D models and time slices of the GPR data radagram were generated to enhance the radargram analysis. As conclusion, the results from this study can facilitate archaeologists to identify buried archaeological artefacts for planning stage of archaeological prospection in Malaysia which largely contributes to the Department of National Heritage and to the knowledge for rest of the world.

ABSTRAK

Arkeologi adalah kajian mengenai sejarah manusia purba lama melalui tinggalan bahan dan aktiviti kehidupan mereka pada era terdahulu. Pelbagai kaedah telah digunakan bagi tujuan mengesan data arkeologi seperti teknik magnet, elektromagnet dan rintangan bumi. Teknik asas ini adalah berdasarkan keupayaannya sebagai alat prospek untuk menentu kedudukan, menjana imej dan pemetaan bawah tanah. Pada masa ini, kaedah radar penembusan tanah (GPR) telah digunakan dalam prospek arkeologi bagi mendedahkan komposisi artifak yang hampir di permukaan bumi. Namun, kelemahan dalam mengenalpastikan radargram GPR dan penggunaan teknik konvensional yang memakan masa yang panjang dan tenaga kerja yang banyak dalam pencarian sisa-sisa arkeologi masih digunakan. Kajian ini dilakukan untuk menilai keupayaan dan keberkesanan GPR dalam prospek arkeologi. Objektif pertama kajian ini adalah untuk mengenal pasti sifat isyarat penembusan gelombang elektromagnetik seperti perbezaan halaju dan ketelusan dielektrik pada sedimen di bawah permukaan dan objek yang tertanam. Objektif kedua adalah untuk menganalisa kuasa pembalikkan kesan arkeologi di tapak kajian dan objektif terakhir adalah untuk menghasilkan tiga dimensi (3D) hirisan masa kawasan arkeologi tersebut. Untuk mencapai objektif kajian ini, pengambilan data dilaksanakan di tiga tapak berbeza yang terdiri daripada tapak simulasi di Universiti Teknologi Malaysia dan dua tapak sebenar iaitu di Sungai Batu, Merbok, Kedah dan Penjara Pudu, Kuala Lumpur dengan artifak yang berbeza menggunakan GPR. Tapak sebenar yang dipilih dalam kajian ini telah dicadangkan oleh ahli arkeologi daripada Jabatan Warisan Negara, Malaysia. Bagi kesemua tapak kajian, garisan grid telah ditandakan untuk membantu pengimbasan GPR dan kaedah ini adalah kaedah yang terbaik digunakan dalam penjanaan model 3D daripada imej terimbas. Seterusnya setiap garisan membujur dan melintang diimbas dengan tujuan untuk menerbitkan tanda isyarat bagi mengesan kewujudan artifak dan sifat-sifat elektromagnet bagi sedimen dan artifak. Di samping itu, model 3D dan hirisan masa dijana untuk membuat interpretasi yang lebih baik terhadap keputusan yang dihasilkan. Berdasarkan kepada keputusan halaju sepadan yang diperolehi, ianya berjaya menerbitkan nilai ketelusan dielektrik sedimen bagi ketiga-tiga tapak kajian dengan nilai masing-masing adalah 14.793-25.000, 4.000- 6.250 dan 4.000-18.367. Nilai cerapan ini setara dengan nilai yang telah diterbitkan dalam kajian terdahulu. Selanjutnya, nilai ketelusan dielektrik bagi artifak telah diterbitkan dengan nilai masing-masing adalah 9.000-14.060, 5.325-18.367 dan 7.438-11.111. Seterusnya, model 3D dan hirisan masa daripada data radargram GPR telah dijana untuk meningkatkan analisis radargram. Kesimpulannya, hasil daripada kajian ini boleh memudahkan ahli arkeologi untuk mengenalpasti artifak arkeologi yang tertanam untuk peringkat perancangan cari gali arkeologi di Malaysia pada masa hadapan yang sebahagian besarnya menyumbang kepada Bahagian Arkeologi, Jabatan Warisan Negara dan sumbangan pengetahuan kepada seluruh dunia.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVATIONS

DNH	-	Department of National Heritage
UNESCO	-	United Nations Educational, Scientific and Cultural Organization
GPR	-	Ground Penetrating Radar
UTM	-	Universiti Teknologi Malaysia
3D	-	Three Dimensional
2D	-	Two Dimensional
DC	-	Direct Current
FGHT	-	Faculty Geoinformation and Real Estate
USM	-	University of Science Malaysia
pXRF	-	The portable X-ray fluorescence
labXPF	-	Laboratory X-ray fluorescence
XRF	-	X-ray fluorescence
MHz	-	Megahertz
m	-	Metre
CO	-	Common Offset Mode
X-Cuts	-	Longitudinal
Y-Cuts	-	Transversal
C- Scans	-	Depth Slide
Pr	-	Power Reflectivity

CHAPTER 1

INTRODUCTION

1.0 Background of the study

Archaeology is the study of the ancient and recent human past through material remains. In Malaysia, Division of Archaeology which is under the Department of National Heritage (DNH) is responsible in preserving, conserving, protecting and promoting the rich treasures of Malaysian heritage as designated by the National Heritage Act. This division ensures that conservation principles implemented are following the rules and standards that are internationally recognized especially by the United Nations Educational, Scientific and Cultural Organization, (UNESCO). It aims to conserve and enhance the historical significance of heritage sites in question that will be the state of facts and historical references (Joel Brown *et al.*, 2009).

In early July 2015, two cannons of 3 m long and 30 cm wide and other artefacts which are believed to be originated from the 18th century have been dug up from a 0.82m depth at a construction site in Kampung Tanjung, Kuala Terengganu. According to the Archaeology Division, they expected more cannons are buried in that area and suggested that the place might be once part of the Malay sultanate (Shamsidar Ahmad and Masri, 2014). Figure 1.1 shows the cannon found in Kuala Terengganu. On 15th January 2016, there is an invitation by DNH to detect archaeology vestiges using a geophysical tool which is Ground Penetrating Radar (GPR) at Ladang Sungai Batu, Merbok, Kedah. It is due to the findings of stones arrangement that looks like wall of some historic structure, as shown in Figure 1.2.

Sungai Batu is a well-known area for archaeological remnants as a lot of findings were discovered in the area including the third iron smelting site in 5th BC using furnace (tool to melting iron ore), religious site in 325-254 BC and beads.

Figure 1.1: The cannon found in Kuala Terengganu from a 0.82m depth.

Figure 1.2: Stones arrangement that looks like wall of historic structure.

There are several methods used in archaeological data detection purposes such as magnetic, electromagnetic and earth resistance techniques (Drahor, 2011). The root of these techniques is based on their ability as prospection tool to position, generate images and produce map of subsurface artefact. Currently, GPR method can help solve the archaeological prospection to reveal the near surface composition of artefacts (Atya *et al.*, 2012).

GPR has been used to identify buried archaeology for many years (Atya *et al.*, 2012). GPR is a non-destructive technique that enable the buried artefacts to be detected without changing the environment (Szymczyk.P and Szymczyk.M, 2015). The technique used is by manipulating the high and low frequency radar waves (electromagnetic waves) to interpret the subsurface. GPR has been used to locate many things including buried tanks, utilities, and remains of the building, (Martínez *et al.*, 2015), mapping land mines and archaeology vestiges (Novo *et al.*, 2014), among others. GPR depth penetration are dependent on the type of soil and its conditions, humidity, and frequency of the signal (Brevik *et al.*, 2015). High frequency antenna gives better resolution but it cannot penetrate as deep as lower frequency antenna and vice versa (Urban *et al.*, 2014). GPR component comprises of a transmitting and receiving antenna. Transmitter antenna transmits electromagnetic signals (waves) to penetrate the ground and the signals are reflected back from the objects. Then, the reflected signals are received by the receiver antenna and stowed away in the memory of the attached Toughbook (Millard *et al.*, 2002). The time travel acquired from the measurement determine the depth of the surface to the object detected, and the position are determined from the highest peaks of signals reflected and its dielectric properties (Hansen *et al.*, 2014).

Extraction of signatures from GPR data for archaeological investigation was the main objective of the research. One of the signatures that were be extracted is the power reflectivity that was produced while processing the GPR radargram. The power reflectivity (Pr) can be identified by the amplitude achieved in the software used. The amplitude changes between the different medium signals it is through (Wang *et al.*, 2015). By knowing the power reflectivity (Pr), the archaeological vestiges can be 3D modelled. In terms of GPR processing, it involves several procedures such as subtract DC, static correction, gain function, background removal and migration (Zhao *et al.*, 2015). The procedure chosen for data processing depends on the data quality of the GPR image (Shamsidar Ahmad and Masri, 2014). The most important in GPR detecting is the data on the differences in dielectric properties of the archaeological vestiges and its surrounding. The archaeological vestiges that are made out of steel or metal are easily detected but if the archaeological vestiges are made out of a material that have similarity in dielectric properties with the soil around it, then detections are harder to interpret (Santos *et al.*, 2014).

This research proposes to appraise the capability and efficiency of GPR in archaeological prospection. In this study, GPR scanning were performed at the simulation test bed developed in UTM campus and real test sites proposed by the DNH. GPR radargram help interpret the materials based on the signals reflected (amplitude) and later a 3D modelling was produced using the power reflectivity (Pr). GPR generates the 2D reflection profiles from which the spatial extent of targets is obtained by using Reflex Software. The 3D time-slices of the GPR data were generated in this study to allow enhanced target identification of potential archaeological interest before planning excavation. Results from this study can be used as a guideline to evaluate the capability and effectiveness of GPR to identify buried archaeological vestiges for future archaeological prospection in Malaysia which largely contributes to Division of Archaeology, DNH.

In brief, this study focuses on the effect of GPR radargram which are the power reflectivity, (Pr) towards the archaeological vestiges that were investigated. Also, it will focus on finding out the relative difference between archaeological vestiges and surrounding soils with their velocity and dielectric permittivity of signals travel. The study was also investigating the implementation of digital signal-processing techniques that can enhance GPR data interpretations. Other than that, 3D model of the GPR data were generated to help better understanding of the spatial extent of the target.

1.1 Problem statement

GPR is an instrument used to investigate the shallow subsurface of the earth, construction materials, road and bridges. There are more means in which a GPR usage can be applied such as in detecting soil moisture, water content and archaeological purposes. In Malaysia, the major problem in archaeological prospection is the lacking of interpretation of the GPR radargram. Accordingly, the findings and excavation process take time. Thus, by knowing the easiest way for finding the artefacts using GPR radargram makes shorten the time taken. Nowadays, some of archaeological site in Malaysia still implement the conventional technique which uses the trial parcel technique that chosen according to the higher level of subsurface. The trial parcel is a squares marking that has been dug on the ground and then it is excavated square by square alternately as shown in Figure 1.3. Therefore, by the physical characteristic of GPR data, 2D radargram and 3D modelling will help the time of findings an artefacts and may shorten the excavation process as it gives the precise and accurate position of an object buried underground. Therefore, this study intends to prove that GPR applications are more suitable and results in better perception in findings archaeological vestiges.

Figure 1.3: The trial parcel for excavation processed.

Furthermore, the conventional excavation processes requires more man power as there is an inaccurate identification of the buried artefact. Inaccurate identification of the artefact results in imprecise location of the archaeological remnant thus the need of more man power to search for the artefact. The locations are randomly chosen by selecting the high level ground. By using GPR, detection of artefact can be identified resulting in less requirement of man power used for excavation process.

Moreover, there are also miss-interpretation and miss-detection of the archaeology vestiges. Most local researchers are using only 2D images to locate the buried object. In order to analyse data from GPR, a high understanding of each application in the software provided which are subtract DC, static correction, gain function, background removal and migration is needed. Each application has different purposes and users need to choose wisely based on their own findings. Radargram image by non-metal objects does not produce clear images. Therefore, users are typically not sure about the objects and might miss-interpret the dimension and shape of the object. GPR users also might miss-detect the buried objects if the objects are buried too deep inside the ground due to the complete hyperbola formation. Hence, the presence of GPR technology in underground detecting or findings needs to be studied continuously and improved for better understanding. Eventually, this help in making the detection process and interpretation to be carried out effectively through 3D modelling and also by considering the dielectric properties of the object and surrounding soil.

To conclude, this study focuses on the dielectric properties and power reflectivity, (Pr) of signal to the archaeology vestiges materials which are the outcome received through the investigation. Eventually valued as the relative difference between archaeology vestiges and surrounding soil. The study also investigates the implementation of digital signal-processing techniques that can enhance GPR data interpretations through 3D modelling.

1.2 Aim of the study

Aim of the study was to investigate the effect of GPR reflectance towards the relative difference between the archaeology vestiges and surrounding soil. The study also investigates the implementation of digital signal-processing techniques that can enhance GPR data interpretations. Besides, the study also aims to generate 3D model of the GPR data to help better understanding of the spatial extent of target (vestiges).

1.3 Objectives of the study

The objectives are divided to the following points:

- To identify the signal properties of electromagnetic wave penetrations which are the fitted velocity and dielectric permittivity on different subsurface sediment and object buried.
- To analyse the power of reflectivity of archaeological vestiges at sites.
- To generate 3D time-slices data of archaeological prospection.

1.4 Scope of the Study

Most GPR surveys for archaeology purposes were conducted using standard procedures of data collection and processing. Hence, the scopes of this study focuses on historical remains and archaeological vestiges detection using GPR and the fine points are as follow:

i. Simulation test site for archaeological vestiges detection

Simulation test site has been established for preliminary results. By conducting a test bed, the shape and size of the buried object can be defined. The test bed is established at a large area in front of the T06, FGHT.

ii. Determination dielectric properties of soil at the test site

Soil condition can be determined by dielectric properties that are provided from GPR radargam; its humidity, type and water flow. From the time travel recorded, the velocity and depth can be determined using REFLEX software.

iii. Identification and Interpretation of GPR Reflectivity of the Archaeological Artefacts

GPR used in the study are the dual- antenna with a frequency of 250 and 750MHz and antenna with frequency of 700 and 900MHz. The models of the equipment are the IDS-DUO GPR and Ris Hi Mod version 2.0 which are available at the faculty. The equipment IDS-DUO GPR is equipped with IDS-DUO software to record the data meanwhile Ris Hi Mod version 2.0 is equipped with the K2 FASTWAVE software. The data processing which involves filtering and generation are performed using the Reflex3DScan software. Filtering refers to background removal and image filtering respectively. In addition, the process integrates the identification of the peaks amplitude of power reflectivity in the radargram that consists of its own dielectric properties which are conductivity, velocity, relative permittivity and attenuation of the object and medium through signal travel.

GPR scanning was performed on the archaeological sites with two dataset that differentiates the low frequency GPR antenna and high frequency GPR antenna. These tests were run respectively. The tests involve GPR scanning on the suggested archaeological sites which is at simulation test bed designed to be as Kampung Tanjung Kuala Terengganu, and two real site at Ladang Sungai Batu, Merbok, Kedah and Pudu Jail, Kuala Lumpur.

iv. 3D modelling and tomographic mapping of the distribution of archaeological vestiges

Interpretation of hyperbola in the GPR radargram helps to identify the archaeological vestiges. Numerical extractions from the features are important for visual inspection. Therefore, to achieve this purpose, spatial modelling and analysis was performed to extract the features of the soil. Aside from that, the features of objects or archaeological vestiges was be generated to allow enhanced identification of the archaeological vestiges.

v. The effectiveness factor for the observed value

The effectiveness factor is the validation of the observed values. This was done by comparing between the observed values and the published value, thus the material scanned by GPR can be recognised.

1.5 Significant of Study

The benefits of the study are as follows:

i. Expanding GPR application in Malaysia

The excavation of archaeological vestiges or historical remains is a long process. In order to shorten the time of the process, GPR technology can be used as it ensures there are artefacts or archaeological vestiges underneath. GPR has the ability in subsurface positioning technology. Therefore, GPR is a suitable tool in determining the objects buried road damage, crack building and utilities in the subsurface.

ii. Improving GPR radargram enhancement

There a lot of benefits from the GPR data (radargam). Besides determining the position of the buried objects, radargram also gives a lot of information needed such as type of soil, material of the object, humidity of soil and water flow. The information is based on the dialectic properties that are generated on the radargram. There is a more advanced process of GPR data enhancement which is modelling data collection into 3D modelling that allows users to visualize the object buried; its dimension and type.

iii. To support users, academics and researches.

This study will help users, academics and researches to discover more about the use of GPR. It also benefits NHD in the aspect of providing faster way in detecting archaeological vestiges.

1.6 Methodology of the Study

To ensure the study achieves the aforementioned objectives, the methodology's workflow and process is planned from the establishment until the conclusion of the study. The steps involves are preliminary study, data collection, program development and data analysis. The literature reviews were used to understand the procedure to carry out the underground survey work. The instrument used is GPR Detection Duo and the measurement technique were studied thoroughly and included in Chapter 3. The overall process is shown in **Figure 1.4**.

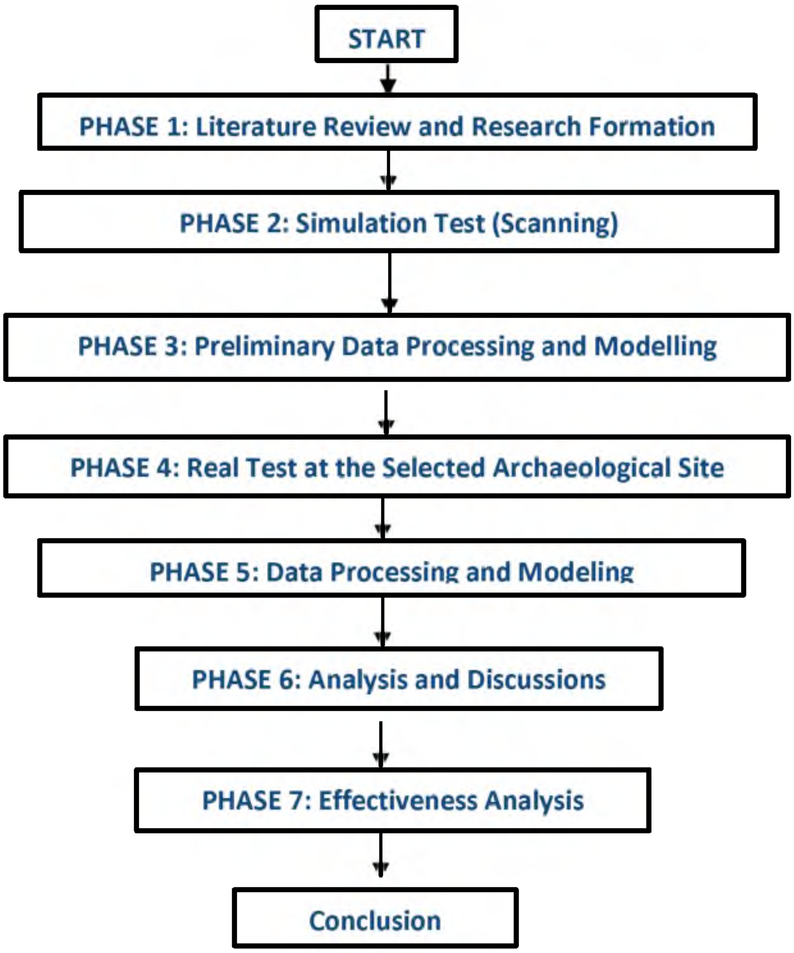

Figure 1.4: The illustration of operational framework design

1.7 Thesis Outline

The thesis contains five chapters and is described fleetingly as follows:

Chapter 1: This study highlights on the detection of archaeological vestiges using GPR. There are many possible places in Malaysia that can provide prehistoric times. Prehistoric age of the world is usually divided into four sections Palaeolithic, Mesolithic Age, Neolithic and Metal Age which means a lot of historical remains might be found in Malaysia. In order to make the findings and detection process easier, GPR is used as a tool. A little bit introduction about GPR, objectives, problem statement, scope, aims, and significant of study have been stated in this chapter. Besides, the methodologies of workflow are drawn to ensure that the procedure would work smoothly.

Chapter 2: On this chapter, literature reviews of the philosophy and theory of GPR as electromagnetic instrument were written. There are major issues that are mentioned and deliberated in this study which are: 1) Introduction, 2) Archaeology in Malaysia, 3) Archaeology Methods, 4) Case study in Archaeology area, 5) Capability of Ground Penetration Radar (GPR), 6) GPR processing workstation, 7) Characteristic Signal Reflection, 8) Reflex3DScan and 9) Conclusion. All the issues highlight the important knowledge in operating a GPR.

Chapter 3: This chapter reports on the workflow and process of each test site starting from research planning. Simulation of the test bed is conducted for preliminary result. It is to observe the capability of GPR to differentiate the soil used and material of the object by referring to the published relative dielectric permittivity (e_R), electrical conductivity (σ), and the velocity of the medium. The data from GPR was processed using reflex3DScan and Reflex2DQuick. Moreover, 3D formulation is formed in which it is the combination of X cross-section and Y cross-section called C-scan. C-scan was show the accurate pattern of substance in the subsurface in accordance to the size and shape of the object buried. Then, real site data collections were performed. The same process as the one used for the test bed simulation was conducted at the real site.

Chapter 4: This chapter includes all the processing results, analysis and discussions of this research. It's includes analysis of preliminary dataset and real site dataset. The signal reflection, dielectric properties and type were compared and studied to help derive the material underneath without destructing the area. Condition of the type of soil was considered because it can affect the signal reflection (Bongiovanni *et al.*, 2011).

Chapter 5: This chapter concludes the study done based on the results and analysis in Chapter 4. It is important to prove the objectives are achieved. Other than that, recommendations are also included for future study to provide improvements in the years to come.

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