IUST Iran University of Science and Technology

Iranian Journal of Electrical and Electronic Engineering

Journal Homepage: ijeee.iust.ac.ir

Hyperbolic Detection of Ground Penetrating Radar for Buried Pipes Utilities Using Viola Jones

Nurul Syahirah Mohd Ideris*, Hasimah Ali**(C.A.), M S Zanar Azalan* and T S Tengku Amran ***

Abstract: GPR (Ground Penetrating Radar) is well-known as an effective non-invasive imaging approach for shallow nature underground discovery, like finding and locating submerged objects. Although GPR has achieved some success, it is difficult to automatically process GPR images because human experts must interpret GPR images of buried objects. This can happen due to the possibility of a variety of mediums or underground noises from the environment, especially rocks and roots of trees. Thus, detecting hyperbolic echo characteristics is critical. As a result, Viola Jones detection is used to determine whether the presence of a hyperbolic signature underground indicates a pipe or not. GPR can also be used in the public works department because it is a non-destructive tool. Workers, for example, should be aware of the pipe size that must be replaced when it leaks. The original GPR image already shows hyperbolic image distortion due to pipe refraction. The current method is unreliable due to its lack of flexibility. As a result, there is another method for resolving this issue. Thus, the image will be pre-processed to eliminate or reduce background noise in the GPR input image. The results of this project demonstrate that the Viola Jones algorithm can accurately detect hyperbolic patterns in GPR images.

Keywords: ground penetrating radar (GPR); image pre-processing; hyperbolic detection; Viola Jones.

1 Introduction

IN recent decades, GPR has been widely used in the investigation of explosives [1], archaeological work [2], and geological studies [3]. Because of its fast speed and low intrusion, it has become an effective non-destructive tool device in the construction industry for assessing structural health assessment.

GPR has also been used to inspect bar steel in the construction of concrete, locating and detecting below ground utility vents and cables that are inspecting roadways and pavements, and inspecting the structure of bridges [4]. GPR typically uses higher frequencies electromagnetic signal (EMW) development, which ranges from a 100 MHz to 1 GHz, for transmitting waves through the ground's surface with varying intensities. Radar techniques use the reflections of small bursts of electrical radiation transferred through the ground to record reflected pulses just like a function in time and the antenna pair placed along a survey line. The fundamental principle of GPR survey is centred on the transmission as well as dispersed in electromagnetic waves in the form of solid material.

The GPR method has numerous applications in a wide range of fields. Visualization provides accurate depth information about a suspected target. The depth information is critical for determining the location of buried structures, allowing the engineer and contractor to locate the utility location or specific area before beginning any projects. To measure reflected pulses as a function of time and antenna pair position along the

Iranian Journal of Electrical & Electronic Engineering, 2025.
Paper first received 18 Dec 2024 and accepted 01 Mar 2025.
* The author is with the Faculty of Electrical Engineering & Technology, Universiti Malaysia Perlis (UniMAP), 02600 Arau, Perlis, Malaysia.
** The authors are with the Centre of Excellence for Intelligent Robotics and Autonomous Systems (CIRAS), Universiti Malaysia Perlis (UniMAP), 02600 Arau, Perlis, Malaysia.
E-mails: hasimahali@unimap.edu.my
Corresponding Author: Hasimah Ali.
*** The authors are with the Department of Agensi Nuklear Malaysia, Bangi Selangor, Malaysia

survey line, GPR radar techniques use observations of small waves of electromagnetic energy transmitted to the ground [5]. The data are processed and visualized in a variety of ways, and the signals coming from the target objects are identified. Ground penetrating radar (GPR) is generally a modern geophysical device whose radar frequency ranges from 1 to several thousand MHz, which is considered too high to be a valuable ground penetrating radar.

Identifying hyperbolic patterns in the received signal that result from the convolution of multiple impulse responses is a challenge in GPR [6]. Furthermore, it is widely accepted that the dielectric qualities of materials that act as insulators have an impact on the speed of electromagnetic waves (EM waves) moving through them at different refractive indices. Wave velocities and dielectric constants are related, which are 0.3 m/ns, 0.033 m/ns, (0.15-0.87) m/ns, (0.15-0.12) m/ns, 0.052 m/ns, and (0.10-0.087) m/ns in air, water, rocks, sand dry, clay wet, and concrete, respectively illustrates by [7].

These properties reveal important observations, such as that materials harden at a decreasing rate, while higher water content results in slower rates. In addition, material velocities can vary significantly. Because of these differences in average speeds, accurately predicting the depth of targets is particularly difficult. In addition, the selected antenna frequency affects hyperbolic range detection, because there is a trade-off between the depth range and the accuracy of the detected object. Higher antenna frequencies result in higher resolution, but they can only penetrate the material to a lesser depth than lower frequencies and vice versa [2].

As a non-destructive testing (NDT) device, Ground Penetrating Radar (GPR) radiates brief bursts of electromagnetic (EM) waves capable of entering development materials. These waves are at that point reflected by subsurface boundaries with contrasting electrical properties. In this way, a receiving wire gets the reflected EM waves, which are successfully utilized in respectful building reviews. Extra details regarding the study can be found in [8]. The key to translating GPR information for applications lies in utilizing progressed information handling strategies. Two essential techniques for translating conventional GPR information are signal-based and image-based methods. Signal-based approaches (A-scan information) point to relieving the impacts of background clamor and obstructions in heterogeneous media situations. Conversely, image-based methods utilizing B-scans information centre on preparing gotten waveforms through background expulsion and speed examination [9].

Additionally, an image-based algorithm was used to process the C-scan data, which is the result of the continuous 2D B-scan data. Although GPR imaging technology has been tuned to high levels of accuracy, the utility of GPR systems remains highly dependent on human clinical trials. The interpretation of GPR data is a challenge when building underground installations. For example, from a private infrastructure perspective, the network of invisible underground utilities in large cities is complex and artificial. Locating and mapping underground facilities in metropolitan areas is the most difficult and sophisticated research in ground-penetrating radar.

The Viola Jones approach was initially introduced in 2001. Has since gained popularity as a recognized algorithm, in the realm of computer vision particularly for tasks like object detection and facial recognition. This study aims to explore the factors that led to the development and widespread acceptance of this technology by highlighting its benefits and successful implementations across domains. A significant advantage of utilizing the Viola Jones method is its performance, which facilitates rapid object detection and identification [10]. The methods utilization of picture representation allows for computation of Haar like features, which play a crucial role in its operation. The swift processing capability, coupled with a series of boosted classifiers empowers the Viola Jones detector to swiftly process images making it suitable, for applications requiring analysis.

2 Methodology

A block diagram of the project is presented in Fig. 1. The proposed method commences with the acquisition of data from a GPR device. Next, comes image pre-processing, which includes morphological, thresholding, and image enhancement. After done with image pre-processing, it will proceed with GPR detection by using Viola Jones object detection. Before proceeding, the image must be trained by using Haar features algorithm to classified whether the image contained positive or negative image to make object detection more accurate.

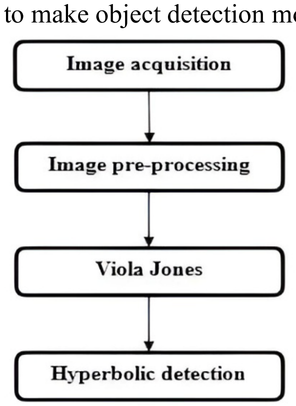

Fig 1. Block diagram of the project

It shows the flow and each step or method that needs to be done before achieving the result. The process starts with data acquisition from GPR and then continues to image pre-processing to analyze the image by using image filtering, image segmentation, opening and closing operations, and edge detection to check whether the image is ok or not to proceed to the next step. If yes, the image will show the shape of hyperbolic so it can be trained by the haar features, if not the process of image pre-processing will be repeated. In haar features, the image will be classified by positive and negative instances. If the image contains a positive instance it will proceed to Viola Jones hyperbolic detection.

2.1 Image Acquisition

2.1.1 Material

As per the research conducted by Agensi Nuklear Malaysia (ANM) and the sandbox test bed for this project is designed to be 2.5 m in length, 1.5 m in width, and was fabricated by the Non-Destructive Test-Material Structure Integrity Group. To prevent metal objects from interfering with GPR operation and signal fidelity, this test bed was constructed completely of wood as shown in Fig. 2(a).

The soil medium is dry sand, much like in [9]. The selection of this soil medium was based on the observation of pipe conditions during the preliminary tests, as exemplified by the example of dry sand in Fig. 2(b). The pipe in this study has a dielectric constant that is different from the surrounding medium and is buried horizontally within the GPR antenna's effective depth range. The pipe's direction and the hyperbola on the GPR B-scan image should be perpendicular to the GPR's detection direction.

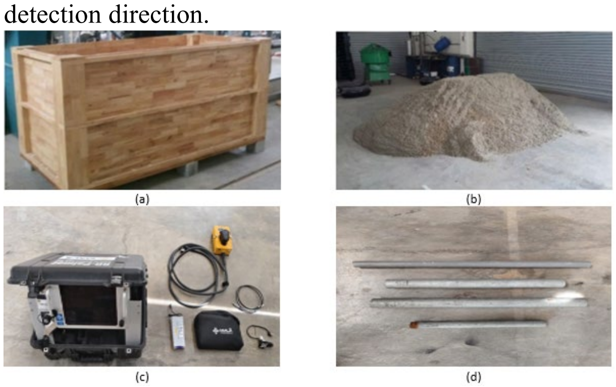

Fig 2. Material of experiment: (a)sandbox testbed (b)dry sand (c)GPR component (d)metal pipe

Fig. 2(c) illustrate the essential GPR components, which include an antenna, battery, control unit, wire battery, and portable PC. A shielded 800 MHz RAMAC/GPR antenna is used for GPR scanning and data acquisition. The GPR system's scanning process will be overseen by research personnel from the Non-Destructive Testing Division in ANM.

Metal pipes will be chosen as a pipe model in this work because metal pipes are frequently used for house utility pipes as shown in Fig. 2(d). The scenarios of buried utility pipe models will be investigated using GPR system.

2.1.2 Experimental setup

The pipe in this project will be buried horizontally and have a different permittivity from the surrounding medium within the effective depth range of the GPR antenna used. On the GPR B-scan images, the detecting direction of the GPR should be perpendicular to the pipe direction and hyperbolic curve.

This project consists of two experiments that were conducted using various-sized metal pipes as well as inside ground-planted metal pipes, Fig. 3(a) shows a single metal pipe has been buried with a brick meanwhile Fig. 3(b) shows three metal pipes with different diameters.

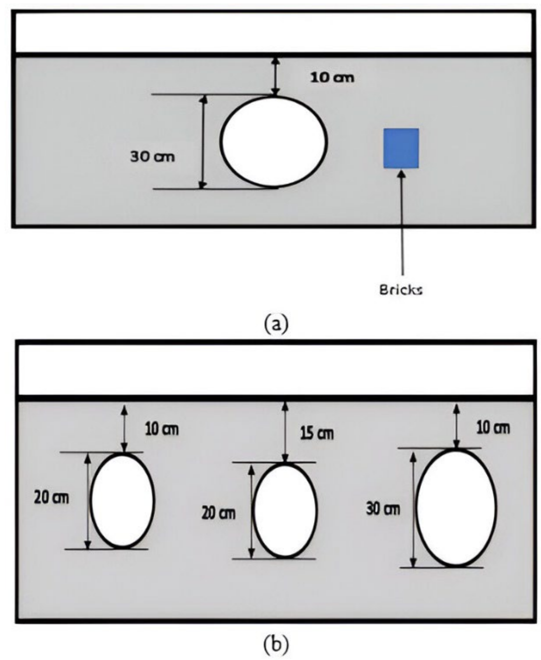

Fig 3. Experiment on buried: (a)single pipe with brick (b)three pipes

2.2 Image Pre-processing

Pre-processing can be achieved through two steps in this analysis, the correct slice for further analysis was considered in the first step. Once the appropriate slice is taken, it is pre-processed with different linear and non-linear filters to remove noise and other artifacts. The primary objective of pre-processing is to eliminate the clamour, balance the image brightness and clear the objects. Pre-processing image is the method used to boost image data before numerical processing.

In addition, the pixel value has been managed using the HSV filter [11]. The HSV filter transforms a colour image into a binary black and white image. The colour image is separated into three channels: colour (Hue), brightness (Value), and saturation (Saturation). Every one of these channels has a tolerance range. Every pixel (pixels) that are within this tolerance appear white in the black and white image. Any pixels that don't fit within this tolerance turn black. Hue describes the angle of a colour on the RGB colour wheel. Red is produced at 0°, green is produced at 120°, and blue is produced at 240°. Saturation regulates the amount of colour used. A colour that is 100% saturated is the purest that can be achieved, a colour that is 0% saturated is grayscale. The value of a colour determines how bright it is. Pure black is a colour with 0% brightness, while no black is present in a colour with 100% brightness. Because this dimension is often called brightness, the HSV colour model (used in P5.js) is also called HSB.

2.3 Viola Jones

The technique was first presented in the 2000 paper "Rapid Object Detection Using a Boosted Cascade of Simple Features" by Viola & Jones and is known as the Viola Jones algorithm after two computer vision researchers [12]. Even though Viola-Jones is an old framework, it is still very powerful, and real-time face detection has shown to be an especially noteworthy use case for it. This algorithm detects faces in real time with astonishing speed, but it is unbelievably slow to train. The algorithm is limited to working with grayscale images. Given an image, it analyses numerous smaller subregions and looks for distinct features in each one to locate a face. An image must verify numerous positions and scales since it may contain numerous faces of different sizes. Face detection in this algorithm was accomplished by Viola and Jones using Haar-like features. The same face detection technique will be applied to the hyperbolic image in this project. Some researchers have been implemented the same method for other objection detection like [13] and [14].

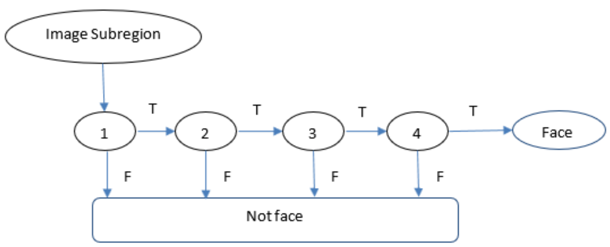

Fig 4. Cascade Classifier Illustration

The Cascade Filter is a strong feature that is formed into a binary classifier, and positive matches are passed on to the next feature [15]. Negative matches are rejected, and the computation is terminated as shown in Fig. 4. Following that, it will decrease the amount of computation time spent on false windows. Then, threshold values can be tweaked to improve accuracy. Lower detection thresholds result in higher detection rates and falser positives.

2.4 Histogram of Oriented Gradients (HOG)

The histogram of orientated gradients approach is a descriptor of features method applied in computer vision and image analysis to identify objects. It concentrates on an object's shape and counts the number of gradient directions in every local area. It also creates a visualization based on the intensity and position of the gradient. There is a constraint on the HOG, the moving window method paired with HOG can be costly to compute, especially for big pictures or applications that operate in real-time. Furthermore, HOG may not work effectively for objects with inconsistent gradient structures or those susceptible to non-linear modifications. However, other studies has shown that the Hog technique may prove more successful in particular situations, such as undersea item detection, where the surroundings present distinct problems [16].

3 Results and Discussion

3.1 Image Pre-processing

The first experiment has been conducted on pipe in the presence of tree branch image. It consists of one hyperbola signatures that represent the one metal pipes targets with the presence of tree branch as shown in Fig. 5(a). The second experiment conduct on three metal pipes. It consists of three hyperbola signatures that represent the three metal pipes targets as shown in Fig. 5(b). The original data has fewer details because it is difficult to analyse. As a result, the acquired image is first converted to grayscale for further investigation. The image will then be processed before being used in hyperbolic detection. There are 2 part of image pre—processing that the image will undergo. First part where the image will process for remove the background and the second part is to filter the image.

Image segmentation is a technique used for separating the image to obtain a clearer vision of the object in the image. Thresholding is an image segmentation technique in which the changes of pixels of an image to make it easier to analysed [17]. Thresholding is the process of converting a colour or grayscale image into a binary image, which is simply black and white. Most commonly, thresholding is used to select areas of interest in an image while ignoring the unwanted parts.

Fig. 5(c) and Fig. 5(d) shows the result thresholding method applied to a grayscale image to make the image clearly to analyzed for the next step. Binary thresholding is used for object detection if the background and objects differ by their brightness values. The image clearly can be differentiated between the colour of the object and the background. Even, the line in the image is the unwanted background and the object is the hyperbolic pattern. Image thresholding is most effective in images with high levels of contrast which is it can classify the background and the object.

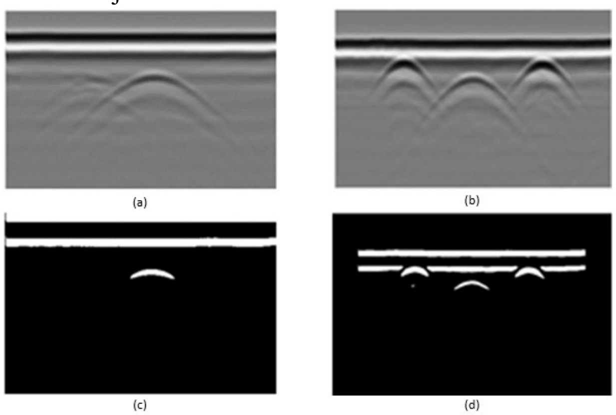

Fig 5. Image thresholding: (a)original image of single metal pipe with bricks (b)original image of three metal pipes (c)image thresholding on single pipe with bricks (d)image thresholding on three pipes

Fig. 6(a) and Fig. 6(b) shows the result after the morphological filter to detect the line horizontal in the image. In this project opening and closing operations have been used to utilize the hyperbolic region and the background region. In addition, the HSV filter is also applied to the image to set the saturation value. So that, the line can be detected more easily than the other object.

Using information from surrounding images, inpainting attempts to "guess" the lost information. This technique can be applied to object removal, old photo restoration, and construction work [18]. Although it is categorized as a branch of image restoration, inpainting is very different from other conventional restoration issues. When it comes to traditional problems (like motion blur or haze removal), the target region is not entirely unknown and, in most cases, information already exists in the region that needs to be repaired. Conversely, the area that needs to be inpainted only needs to be outside the known area of the image; there is nothing to be obtained inside the area.

This method can be used to remove these digitally. Fig. 6(c) and Fig. 6(d) shows the image of the result after background removal by using image inpainting. From the image, we can observe the line background of the image has been removed but still has a background leftover around the hyperbolic shape.

After that, the function of image filtering is among the most fundamental aspects in image processing, and it can greatly improve image quality and yield information that would otherwise be missed. The Gaussian smoothing operator is a 2-D convolution operator for 'blurring' images and removing detail and noise [19]. It is also can adjust sharpness and improve smoothness in both black-and-white and color images [20].

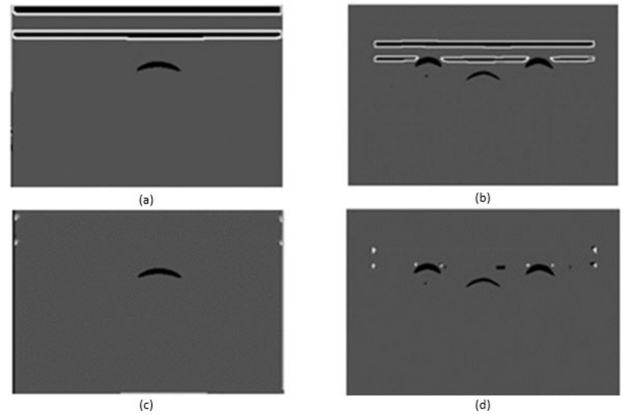

Fig 6. Image of background removal: (a)line horizontal detected on single pipe with scattering object image (b)line horizontal detected on three pipe image (c)line removal on single pipe with scattering object image (d)line removal on three pipes image

3.2 Viola Jones

Haar-like features are image features that are used in object recognition. Some universal properties of the human face are shared by all human faces, such as the eyes region being darker than its neighbor pixels and the nose region being brighter than the eye region [21]. Same goes to hyperbolic image which is the hyperbolic region has the darker region than the background.

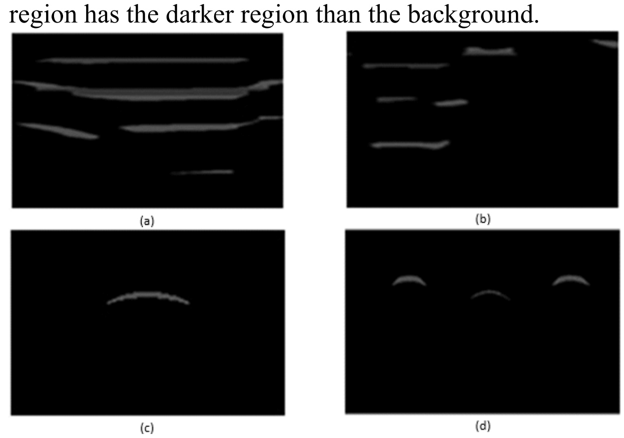

Fig 7. Image of haar feature: (a) and (b) sample of negative image (c) positive image of single pipe with scattering object (d) positive image of three pipes

After pre-processing method, the image will be trained by using haar-like feature technique by using machine learning based approach, in which a cascade function is trained using a sample that contains a lot of positive and negative images. Because of that, haar like feature has been used to supervised manifold learning effectively retrieves similar images from large databases [22]. Fig. 7(a) and Fig. 7(b) shows the sample of negative image that has been filter. Meanwhile, Fig. 7(c) and Fig. 7(d) shows a positive image is one containing an object that must be detected, a negative image is one not containing a need to find object.

3.3 Hyperbolic Detection

Fig. 8(a) shows hyperbolic pattern detected by using Viola Jones detection. The process begins by converting the input image into an integral image. An integral image, also known as a summed-area table, is a method for quickly and effectively calculating the sum of values in a rectangular subset of a pixel grid. The figure shows 1 hyperbolic pattern detected using the program showing the effectiveness of the algorithm. Meanwhile, Fig. 8(b) shows 3 out of 3 hyperbolic patterns detected using the program show the effectiveness of the algorithm. Thus, the conclusion is Viola-Jones Algorithm is better to use for face detection, but it can be trained for other purposes if there are enough positive and negative images to be trained.

The same results were obtained using the HOG in Fig. 8(c) and Fig. 8(d) which approach to determine whether the method is most suited for hyperbolic detection. From the result, both images should only detect the curve of the hyperbolic, but the results of the analysis detect unnecessary things such as the background and refraction from the hyperbolic However, the hog results show that the method is not appropriate for hyperbolic detection.

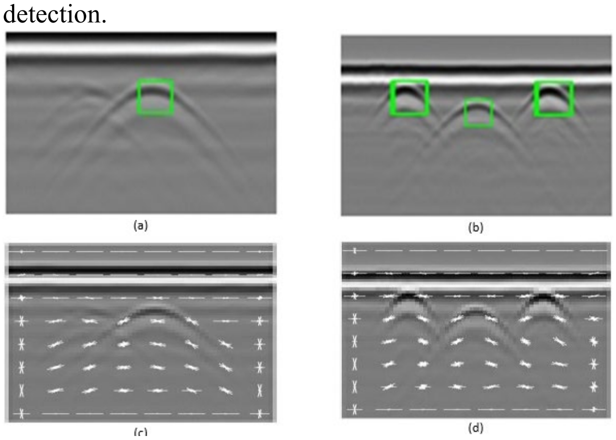

Fig 8. Image of hyperbolic detection: (a) hyperbolic detection on single pipe with scattering object (b) hyperbolic detection on three pipes (c) result using HOG method on single pipe with scattering object (d) result using HOG method on three pipes

4 Conclusions

In conclusion, all experiments conducted have different requirements for each data even using the same process on other images. This is because each data has a different pixel value, different contour color, and intensity to achieve the objective. All the images collected need to be analyzed before done for the next step. Therefore, we need to use an algorithm appropriate to get effective results. Besides, we need to know the way for the way to place an intensity value making the appropriateness of the data before proceeding to the next process. In addition, some of the images need an extra process like edge detection for smoothing and sharpening the structure. We can conclude that, Viola-Jones is effective at recognizing items with a distinct and constant appearance. It employs Haar-like features to record variations between bright and black regions, as well as an order of classifications for rapid rejection of non-object regions. Next, AdaBoost is used to train classifiers, which focus on the most useful characteristics and improve the accuracy of detection with time. The algorithm's flexibility in handling various sizes and appearance variations can be very helpful in GPR, as the depth of objects and the geological environment can have a significant impact on subsurface features' fluctuations for future works.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Nurul Syahirah Mohd Ideris: Methodology, Software, Data curation, Visualization, Investigation, Original Draft preparation. **Hasimah Ali**: Conceptualization, Supervision, Final approval. **M S Zanar Azalan**: Ideas, Supervision. **T S Tengku Amran**: Data collection, Experimental setup.

Acknowledgment

The authors acknowledge the financial support provided by the Centre of Excellence for Intelligent Robotics and Autonomous Systems (CIRAS), Universiti Malaysia Perlis (UniMAP).

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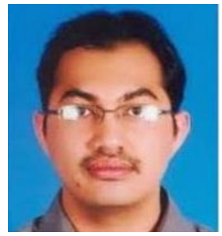
Biographies

Nurul Syahirah Mohd Ideris is a Master of Science student at the University of Malaysia Perlis, specializing in Mechatronic Engineering. She earned her bachelor's degree in the same field from the University of Malaysia Perlis. Presently, she is actively involved with the Ground Penetrating Radar Research Group within the Faculty of Electrical Engineering Technology at the University of Malaysia Perlis.

Hasimah Ali is currently an Associate Professor at Mechatronic Department, Faculty of Electrical Engineering & Technology (FKTE), University Malaysia Perlis (UniMAP). She also responsible as Program Chairperson of Postgraduate Study at Mechatronic Department, FKTE, UniMAP. She received her PhD in Mechatronic Engineering from UniMAP (2015), MSc in Mechatronic Engineering from IIUM and BEng in Mechatronic Engineering from IIUM. Her research interests are signal and image processing especially in ground penetrating radar, machine learning, AI, robotics gripper and IoT . Besides, she is the Head of Ground Penetrating Radar Research Group.



M S Zanar Azalan is a senior lecturer at Faculty of Electrical Engineering Technology, UniMAP. He received his PhD in Mechatronic Engineering from UniMAP (2019). His research mainly on signal and image processing, ground penetrating radar, brain computer interface and AI. He is responsible for Manager Division in Electrical and Measurement, Head of Brain Computer Interface Research Group.

T S Tengku Amran is a research officer at Agensi Nuklear Malaysia under Department of Nondestructive Test (NDT). She completed her MSc in Solid State Physics from University Sains Malaysia and BEng in Engineering Physics from University Sains Malaysia. Her research area mainly on ground penetrating radar and NDT investigation. She is the Head of MoU agreement on GPR between Agensi Nuklear Malaysia-UniMAP including supervising the GPR RAMAC/MALA.