Embedded iron object detection using asynchronous full wave envelope detector technique in ground penetrating radar system

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ABSTRACT

The use of a ground penetrating radar (GPR) system that operates at low frequencies allows the detection of embedded objects underground from the earth's surface deeper than high frequency. However, the output signal generated from the system using pulse modulation (PM) technique and high-frequency carrier, has many high ripple signals consequently resulting in a blurry image. Nevertheless, this ripple signal can be minimized by reprocessing the signal using an envelope detector method. In this study, an envelope detection technique called ArJED© asynchronous full-wave (AFW) was used in the GPR system and was tested at a frequency range from 0.06 to 0.08 GHz. A dipole antenna has been used as an embedded object detection sensor of the GPR system. The detection system of embedded objects involves four depths starting with 2 cm depth, 5 cm, 7 cm, and 20 cm. A comparison of embedded object images before and after the application of the envelope detection technique was done and proved that the proposed envelope detection technique has produced a clearer radargram image of the GPR system.

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1. INTRODUCTION

To find an embedded object underground is not an easy task. It requires a lot of energy to dig or drill holes to find the object underground in the involved area. This method is unpleasant [1]–[3] because it can destroy the ground surface of the involved area. It also might affect the object underground because its position underground is unknown. Due to this concern and technology development, a ground penetrating radar (GPR) system was developed. This system is also known as the non-destructive technique (NDT) which can detect an embedded object underground with minimizing damage to the earth's surface area and the embedded object as discussed by Daniels [1], Pramudita *et al.* [4], Howlader and Sattar [5], Gopalakrishnan *et al.* [6], Thomas and Roy [7], Ziboon *et al.* [8], and Galajda *et al*. [9]. The minimization of damage to the ground surface area and embedded objects can occur because the GPR system uses electromagnetic wave radiation emitted from the system antenna which serves as an embedded object detector [10]–[12]. The electromagnetic waves emitted by the antenna of this system will be reflected and scattered when passing through mediums that have different permittivity values [13]. Therefore, this system is said to be able to detect embedded objects regardless of whether they are metal or non-metal [13]–[18]. However, the detection of embedded objects using this GPR system depends on the frequency range used by the system [19]. Low image resolution from the use of a low-frequency range will result in blur radargram image display produced by the system if using pulse modulation (PM) technique [3], [5], [20], [21].

The image displayed in Figure 1 shows how the propagation of electromagnetic waves when detecting embedded objects occurs. It can be seen here that the electromagnetic waves emitted by this GPR system will be refracted and reflected when passing through different mediums of permittivity values. This figure also shows the basic equipment of a GPR system that consists of one antenna which can function as a transmitter and a receiver. This is also known as a monostatic type of GPR system. In this type of GPR system, an alternating current generator and oscilloscope are used as tools for the transmitter system and receiver system that are connected directly to the antenna.

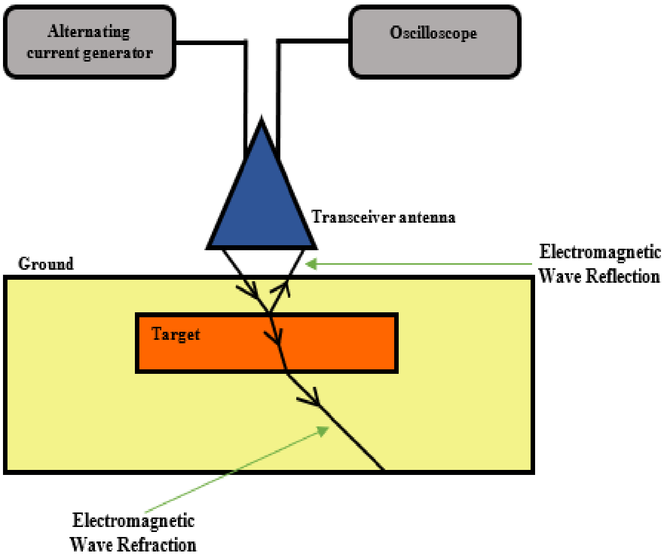

Figure 1. Electromagnetic waves propagation during embedded objects detection process by monostatic type of GPR system devices [22]

GPR system can be divided into three categories of domain operations. Those domain operations are time domain, frequency domain, and spatial domain. However, there are only two domain operations that are often attracting the interests of GPR system researchers which are the time domain and frequency domain. The spatial domain is given less attention because the data from this domain operation are difficult to be processed as it requires more than one data dimension. Referring to the GPR system categories shown in Figure 2, this study focuses on the time domain GPR system using PM. For information, this category has also been studied by several researchers such as Nishimoto *et al.* [23], Shou *et al.* [24], Soldovieri *et al.* [25], and Qiao *et al.* [26].

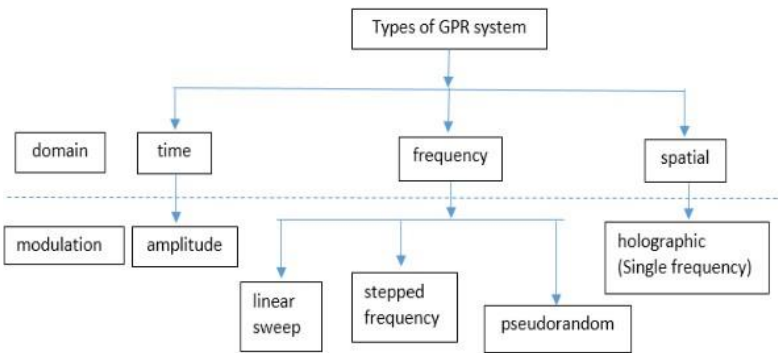

Figure 2. GPR system category [1]

2. DEVELOPMENT OF GPR SYSTEM SIMULATION

Referring to GPR systems that use low-frequency operation, the resulting radargram image display will be blurred. However, this can be solved by restructuring the radargram image obtained from the system output signal. In this study, the GPR was studied by simulation technique using computer simulation technology (CST) and MATLAB software. A low-frequency GPR system simulation model has been developed to obtain the system output signal which will then be rearranged in matrix form according to the order of the scanning position of the embedded object in the simulation model and processed using an envelope detector technique of ArJED©, a copyrighted software technique and it licensing under Universiti Tun Hussein Onn Malaysia (UTHM). The development of this software is to produce clearer radargrams images for GPR systems. This software works by processing GPR system equipment signals given and subsequently constructing radargrams images of the signal. This software was developed using a digital envelope detector method consisting of a detector asynchronous half-wave (AHW), asynchronous full-wave (AFW), and asynchronous real square law (ARSL) type envelopes. Figure 3 shows the flow chart of the GPR system output signal processing technique applied in this study which has been generated by the developed simulation model, while Figure 4 shows the block diagram of the ArJED© AFW, type envelope detector technique that has been used in this study.

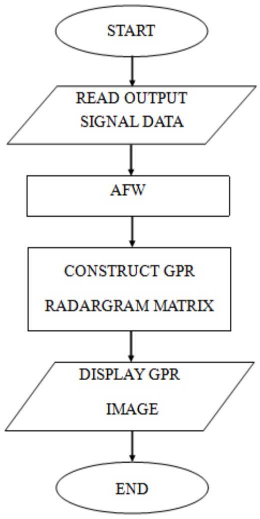

Figure 3. GPR system radargram image restructuring

Figure 4. ArJED© AFW envelope detector technique block diagram

2.1. Dipole antenna design in GPR system simulation

Before this GPR system is developed, a dipole antenna must be designed first using CST software. As described in the introduction section, the antenna is an important component in the development of a GPR system because the electromagnetic waves emitted by this component are sensed back by the component as a scanning procedure to detect the presence of embedded objects in the ground. The designed antenna must be compatible with the operating frequency to be used by the GPR system. The operating frequency selected to be used in this GPR system is from 0.06 to 0.08 GHz to achieve the suitability of the GPR system simulation antenna. With this frequency operation, the material selected for the simulation model of this dipole antenna is the perfect electric conductor (PEC). This dipole antenna has been designed using a cylindrical shape having a 200 cm length with a radius of 5 cm as shown in Figure 5.

2.2. GPR system simulation model development

Once the dipole antenna simulation model design made in CST software meets the required criteria, the addition of a background simulation model in the form of dry sand and embedded objects using iron material is designed to complete the GPR system simulation model. The addition of both simulation models in this GPR system can be referred to in Figure 6. This figure also shows the scanning direction of the GPR system in the simulation which involves 16 antenna positions for four different depths of the embedded object at the same frequency range of 0.06 to 0.08 GHz. Meanwhile, Tables 1 and 2 show the dimensions used in the development of the background and embedded object simulation models respectively.

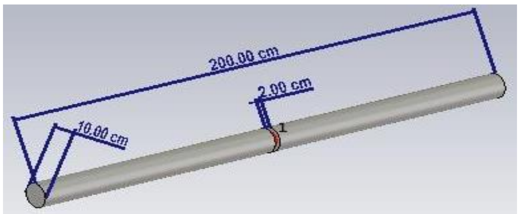

Figure 5. Dipole antenna designed in GPR system simulation development using CST software

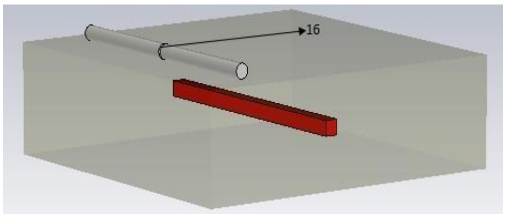

Figure 6. GPR system scanning direction

Table 1. Dimensions of the background simulation model (dry sand)

Parameter	Value	Unit
Length	250	cm
Width	250	cm
Height	73	cm

Table 2. Dimensions of the embedded objects simulation model (iron)

Parameter	Value	Unit
Length	200	cm
Width	20	cm
Height	20	cm

2.3. Radargram construction of the GPR system

In generating radargram images, data from the antenna output signal that has been simulated in a complete GPR system simulation model developed using CST software will be taken and exported into MATLAB software. Nevertheless, since the GPR system developed in this study operates in the frequency range of 0.06 to 0.08 GHz, the output signal generated by the simulation refers to a Gaussian pulse signal with a carrier frequency at 0.07 GHz. Based on this signal, the resulting radargram image of the system has become blurred which makes the detection of the embedded objects in the developed GPR system simulation model using the image becoming difficult. To overcome this problem, this study has used a signal processing method known as the ArJED© AFW envelope detector technique which can be referred to in Figure 4. Referring to the GPR system scanning technique, this study has applied the B-Scan type scanning technique which refers to the GPR scanning technique in a straight line.

3. RESULTS AND DISCUSSION

The obtained results from the designed GPR system simulation model in this study is discussed in more depth based on the radargram image of the GPR system produced. The comparison between the radargram image produced by the GPR system using the ArJED© AFW envelope detector technique as proposed in this study, with the radargram image produced without the envelope detector technique is discussed to verify the reliability of the AFW technique applied in the GPR system. This GPR system was designed to be simulated the scanning of underground iron object at four different depth which are 2 cm, 5 cm, 7 cm and 20 cm.

3.1. GPR system without AFW technique

The generation of radargram images resulting from the designed GPR system simulation model using CST software involves the extraction of the simulated output signal to be processed using MATLAB software. As a control simulation, a GPR system simulation was designed without the presence of embedded objects. The image obtained from this simulation will be used as a reference to figure out the pattern of the GPR image when the embedded object does not exist in the ground. The reference radargram image produced can be referred to in Figure 7(a), where several straight lines have appeared. Figures 7(b)-7(e) displays four radargram images produced in this study with the presence of the embedded objects in the GPR system simulation model at the depth of 2 cm, 5 cm, 7 cm, and 20 cm. Referring to these radargram images, the existence of the several straight lines as shown in Figure 7(a) seems to be distorted in these figures. The position of the embedded object cannot be determined based on these figures where the images seem to be very blurry due to the use of low frequency in the GPR system.

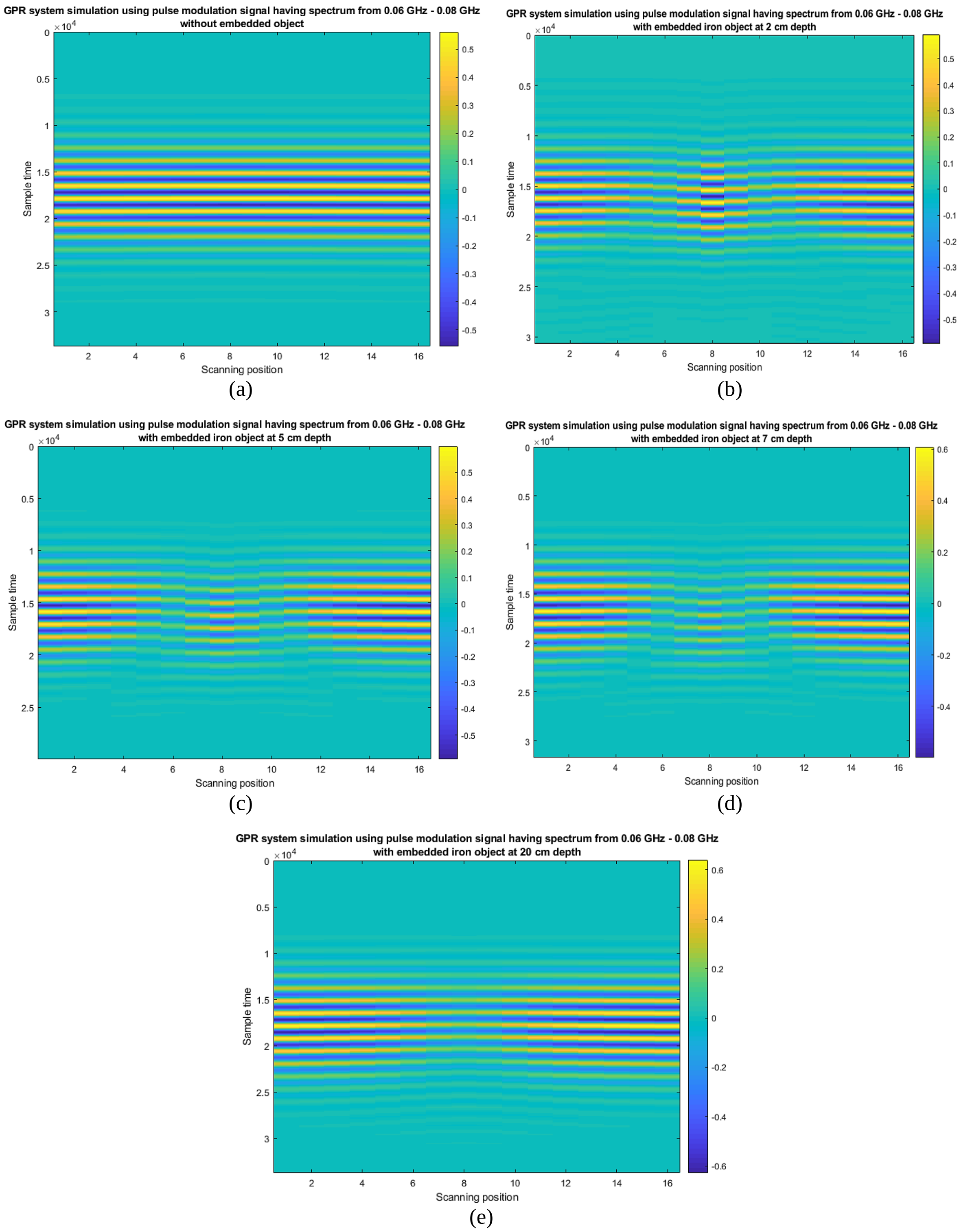

Figure 7. GPR system radargram image displays without AFW technique (a) no embedded object, (b) embedded iron object at 2 cm depth, (c) embedded iron object at 5 cm depth, (d) embedded iron object at 7 cm depth, and (e) embedded iron object at 20 cm depth

3.2. GPR system with AFW technique

Figure 8 displays a radargram image produced by the GPR system that has applied the ArJED© AFW envelope detector technique. By comparing the reference radargram image in Figure 8(a) with Figure 7(a), it shows a clear radargram image as an indication of the non-existence of an embedded object underground based on the yellow color straight line. Meanwhile, the radargram in Figures 8(b)-8(d) shows one yellow or blue area representing the embedded object clearly at the scanning positions 6 to 10. Based on Figure 8(e) the existence of an embedded object cannot be determined as there are no patches appear in the center of the image, however as comparing the image with Figure 8(a) it can be said that there is something underground as the yellow straight line has been distorted.

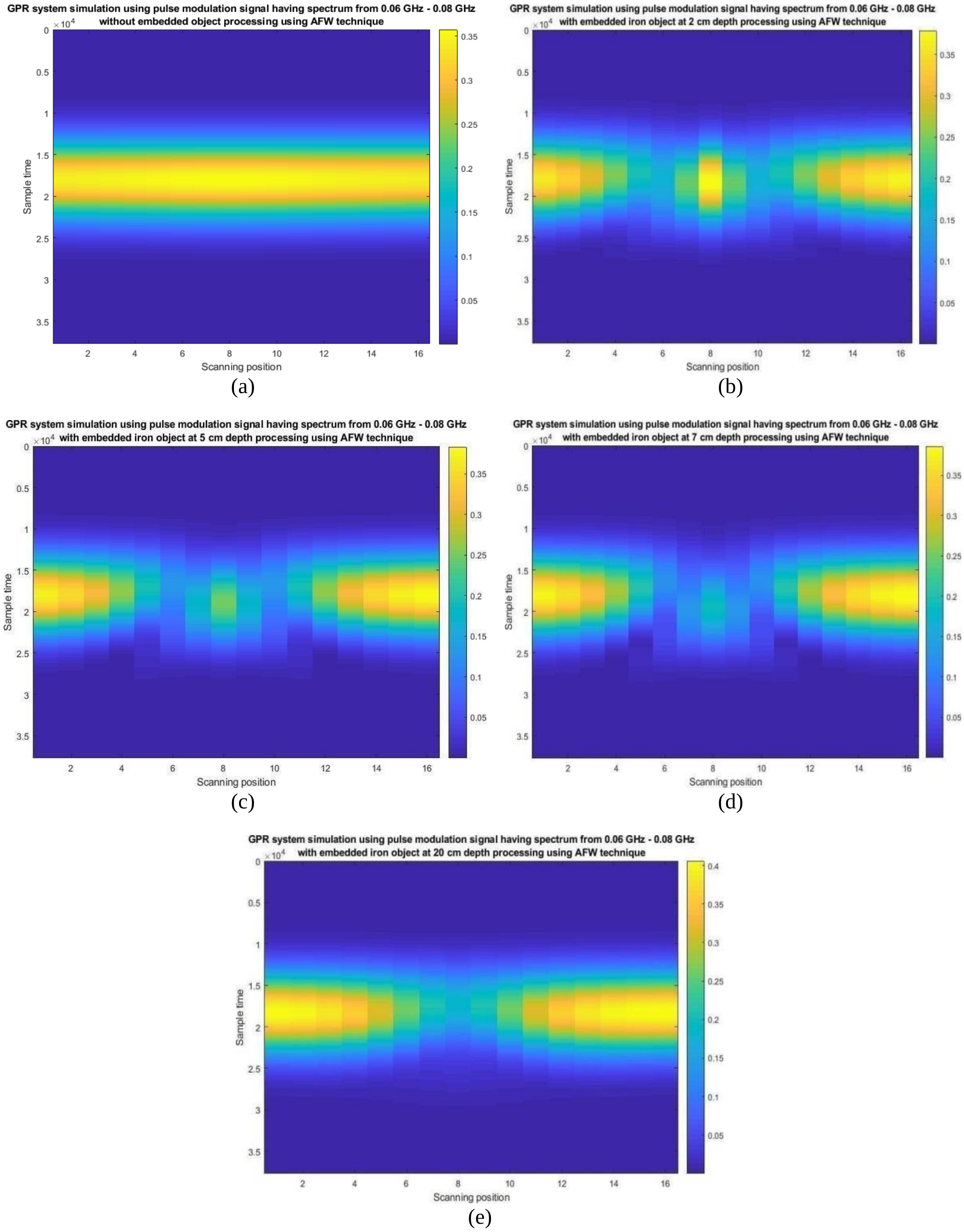

Figure 8. Radargram image display of GPR system after AFW technique application (a) no embedded object, (b) embedded iron object at 2 cm depth, (c) embedded iron object at 5 cm depth, (d) embedded ironobject at 7 cm depth, and (e) embedded iron object at 20 cm depth

Table 3 shows the result of the object detection system in this study which involves the development of a designed GPR system simulation model with and without using the ArJED© AFW envelope detector technique. Referring to this table, the detection of an embedded object in the developed GPR system simulation without using the ArJED© AFW technique is impossible. However, when the AFW technique is applied in the GPR system, the existence of the embedded objects has been successfully performed in the simulation model involving the position of objects at the depths of 2 cm, 5 cm, and 7 cm. While, in detecting the presence of the embeddedobject at the depth of 20 cm, the GPR system simulation is not able to detect it.

Table 3. Radargram image differences before and after the application of the ArJED© AFW technique

Embedded object depth, cm	Before AFW technique	After AFW technique
2	X	/
5	X	/
7	X	/
20	X	X

4. CONCLUSION

The use of the ArJED© AFW envelope detector technique has been successfully applied in this GPR system. Based on the GPR radargram image produced in this study, the GPR system developed using operating frequency from 0.06 GHz until 0.08 GHz was able to detect the presence of iron objects from 2 cm up to 7 cm depth. The position of the embedded object can be identified more clearly through high color indications and pattern changes on the resulting radargram image display. On the other hand, the existence of the embedded object at a depth of 20 cm cannot be ascertained because the pattern on the GPR radargram image does not produce an object pattern in the image. However, the radargram displays an empty space in the center of the image that can be expected to be an embedded object.

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