Buried Objects Detection and Segmentation Using a Semi-Automatic Technique Called Selected Peaks of Summing up Traces (SPST)

Israa J. Muhsin **Nabeel J. Tawfiq**
Physics department - College of science - Baghdad University

Received 9 February 2016 ; Accepted 9 March 2016

Abstract

Ground Penetrating Radar (GPR) is a nondestructive geophysical technique that uses electromagnetic waves to evaluate subsurface information. This research presents package software for GPR data analysis and image processing with an algorithm for semi-automatic object detection, displaying, filtering, edges detection, histogram equalization, segmentation such as quantization and Fuzzy C-means clustering (FCM). After applying preprocessing on the image, a new technique depends on taking the Selected Peaks of Summing up Traces (SPST) have been adopted to give the very good results of buried objects detection compares with other segmentation methods. MSE and RMSE criteria were used to perform the comparison between the results. The fundamentals of GPR and software are illustrated inside with data taken by (MALÅ GPR ProEx System) at the University of Baghdad campus -college of science.

Keywords: GPR, Object Detection, SPST, FCM.

كشف وتجزئة الاجسام المدفونة بتقنية شبه اتوماتيكية تدعى اختيار اثار ملخص القمم

اسراء جميل محسن **نبيل جميل توفيق**
قسم الفيزياء - كلية العلوم - جامعة بغداد

Buried Objects Detection and Segmentation Using a Semi-Automatic Technique Called Selected Peaks of Summing up Traces (SPST)

Israa J. Muhsin Nabeel J. Tawfiq

الخلاصة

رادار الاختراق الارضي هي تقنية جيوفيزيائية غير مدمرة التي تستخدم الموجات الكهرومغناطيسية لتخمين معلومات حول السطح. هذا البحث قدم حقيبة برمجية لتحليل بيانات رادار الاختراق الارضي مع معالجة صورية وخوارزمية شبه اتوماتيكية لكشف الجسم،العرض، كشف الحافات،تكميم المخطط البياني والتجزئة مثل التكمم ومعدل التعنقد الغير محدد. بعد تطبيق المعالجة الاولية على الصورة، تقنية جديدة تعتمد على اختيار اثار ملخص القمم تم تبنيها لتعطي نتائج جيدة جدا مقارنة مع طرق التجزئة الاخرى. معايير معدل مربع الخطأ وجذر معدل مربع الخطأ استخدمت لاتمام المقارنة بين النتائج. اساسيات رادار الاختراق الارضي وبرامجه المقدمة مع البيانات اخذت بجهاز (MALÅ GPR ProEx System) في مجمع جامعة بغداد- كلية العلوم.

الكلمات المفتاحية: رادار الاختراق الارضي، كشف الاجسام، اختيار اثار ملخص القمم، ومعدل التعنقد الغير محدد.

Introduction

Ground penetrating radar (GPR) is a range of electromagnetic techniques designed for search and locate the objects or interfaces buried under the earth's surface or found them between solid layers structure [1,2]. Recently, the Ground Penetrating Radar (GPR) is classified as one of the most important techniques in wide fields of scientific research. These researches include water detection underground, geology researches, civil engineering, oil detection studies, and archeology [3]. A typical GPR measurement is the amount of time it takes for electromagnetic waves to penetrate in the subsurface, reflect from impedance contrasts, and return to a receiver at the surface [4].The term of Ground penetrating radar (GPR) is related with the methods which use the Radio waves range from the electromagnetic radiations. The using range is about 1 to 1000 MHZ frequency, the function of the GPR is search and maps the structures of the buried objects in the ground. Primarily GPR was interest with the mapping structures and features in the ground, but now is consider being non-destructive way of non-metallic structures. The applications are limited by the imagination and obtainability of suitable instrumentation [5].

Buried object detection using GPR is not sufficient for analysis and interpretation, so many packages have been associated with the GPR device for preprocessing the received data, in this research a new package has been presented include many preprocessing edge detection, filtering, histogram equalization, digital converter (DC) removal as well as segmentation such Quantization and FCM, and a new technique consist of many steps to select the Peaks of Summing up Traces **(SPST**) has been illustrated.

Data Gathering and Programming

Several surveys have been conducted by ground penetrating radar system (MALÅ GPR ProEx System) in the campus of Baghdad University (Al-Jadria Location) as shown in figure 1. Two different antennas (250 and 500) MHz frequencies used on selected locations containing electrical cables, plastic and metal pipes with various diameters and buried at different depths, also, some regions having concrete or bricks buried (data with GPR system setting illustrated in Table (1). Data collected from (MALÅ GPR ProEx System) have RAMAC – RD3/RAD GPR data storage format, that data have been applied to the GPR_DP software, as Windows™ and Matlab™ based software.

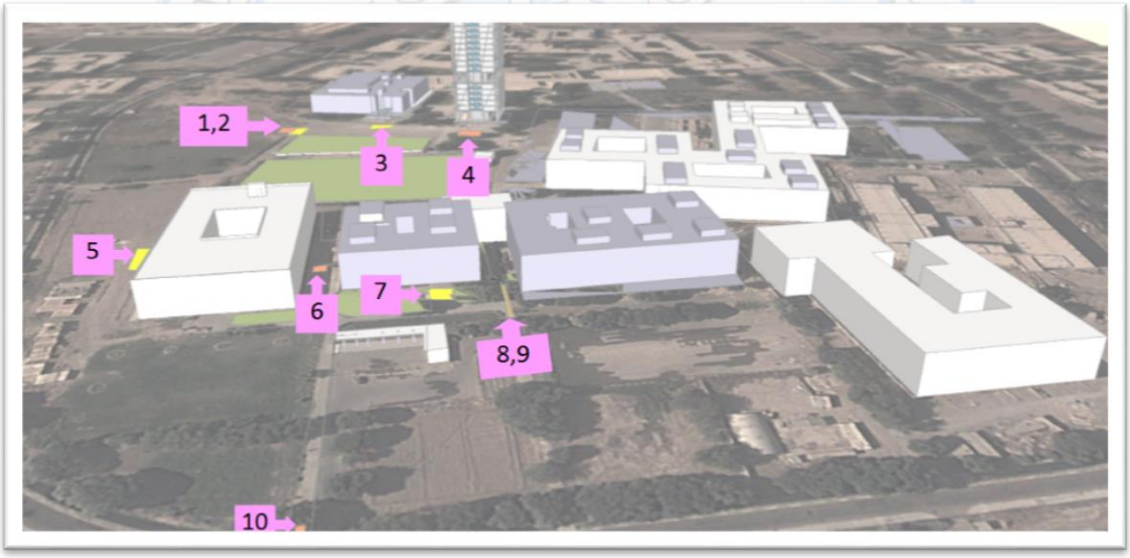


Figure 1: Satellite map view of surveying locations in Baghdad University, where: 1) site1, 2) site2, 3) site3, 4) site4, 5) site5, 6) site6, 7) site7, 8) site8, 9) site9, 10) site10.

Table 1: Data files with GPR system setting.

Radargram Image Group	The parameter setting of GPR system				
	Antenna Freq. (MHz)	Time Windows (ns)	Point Interval (m)	Sampling Freq. (MHz)	Velocity (m/ns)
Site1	250	192.8	0.05	2504.2	75
Site2	250	192.8	0.05	2504.2	75
Site3	250	204.4	0.05	2495.4	100
Site4	250	204.4	0.05	2495.4	100
Site5	250	204.4	0.05	2495.4	100
Site6	500	41.7	0.02	5559.4	75
Site7	500	41.7	0.02	5559.4	75
Site8	500	52.1	0.03	5065.2	100
Site9	500	52.1	0.03	5065.2	100
Site10	500	52.1	0.03	5065.2	100

Signal and Image Processing

A selected number of methods for signal and image processing in the *Spatial Domain* [The Term *Spatial Domain* refers to the signal or image plane itself] will be discussed in this section. Signal and image processing in the spatial domain, can be described as:

$$A'_{x,y} = T[A_{x,y}] \qquad \ldots(1)$$

Where : T: A filter applied to A, $A_{x,y}$: Amplitude of unprocessed data see figure (2), $A'_{x,y}$: Amplitude of processed data, x : Horizontal position of data (positions of measurement stations along mapped profile trace), y : Vertical position of data (depth to the reflectors sample)

$$I[x,y] \rightarrow \boldsymbol{I}[x,y] \qquad \ldots(2)$$

1. Signal processing in one-dimensional (effecting an individual trace or a-scan) and known characteristics are often utilized for signal enhancement, such as Zero-offset removal (DC removal) and Time-varying gain. Since the sampling gate of the receiver might exhibit some DC offset, an important process operation is to ensure that the mean value of the trace is near to zero. The DC offset is physical and associated to the construction and components of sampling rate.

$$A'_{x,y} = A_{x,y} - \frac{1}{N}\sum_{i=0}^{N-1} A_{x,y+i} \dots (3)$$

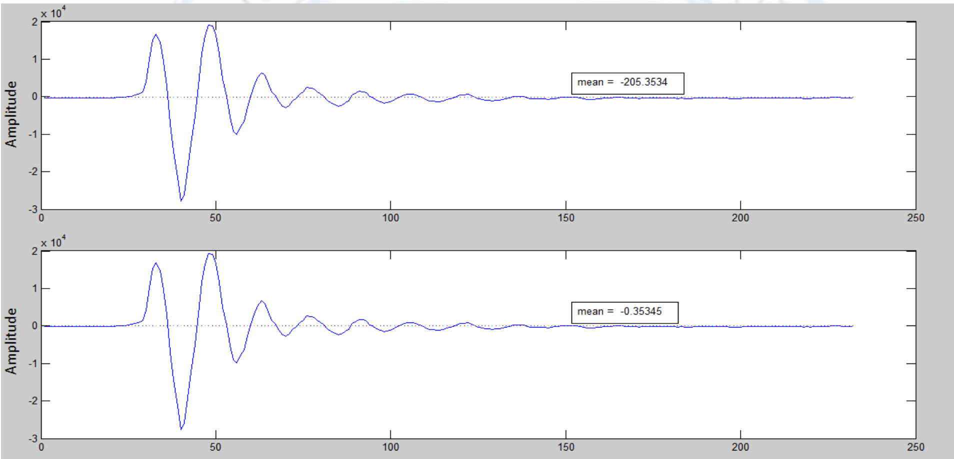


Figure 2: Plot of original and zero-offset removal processed signal.

This algorithm for Zero-Offset Removal assumes a symmetric distribution of amplitudes about the mean value and that the short-time mean value is constant. This assumption is generally true, but where time-varying gain is incorporated this assumption might be incorrect since time-varying gain tends to skew the distribution of amplitudes if a DC offset is present.

2. **Image processing in two-dimensional** (effecting a complete profile or b-scan), and similar to signal processing, known characteristics are utilized for image enhancement, such as: Edge detection; can be defined as the method of identifying and finding sharp discontinuities in an image. The discontinuities are rapid changes in intensity of the image pixels value. It is important way to appear the boundaries of objects in an image or any scene. There are many types of edge detection methods, each method designed to be detect certain shapes of edges. In this research the Sobel and Prewitt filters have been used which can be given as [6]:

Sobel operator: The function of Sobel operator is convolve the image with a mask, has integer valued filter in two direction horizontal and vertical respectively. The computation of this filter considers being simple. Therefore the gradient approximation is also simple, this filter is classified as high frequency variation in the image [6,7]

$$S_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}, \quad S_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

Prewitt filter: The Prewitt operator uses the same equations as the Sobel operator, where constant c = 1. Therefore, note that, unlike the Sobel operator, this operator does not place any emphasis on pixels that are closer to the center of the masks [6,7].

$$S_x = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}, \quad S_y = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix}$$

Time-Varying Gain

Time-Gain filter can be defined as a time-varying gain to compensate for amplitude loss due to spreading and attenuation. The trace is multiplied by a gain function combining linear and an exponential gain, with coefficients set by the user. It also has an Auto button which when pressed calculates and suggests filter coefficients [8]. For more information see figure (3), The mathematical expression of this filter can be illustrated bellow:

$$A'_{x,y} = A_{x,y}(\propto t_y + e^{\beta t_y}) \quad \ldots(4)$$

Where, α = linear gain, β = exponential gain, t_y = time of y.

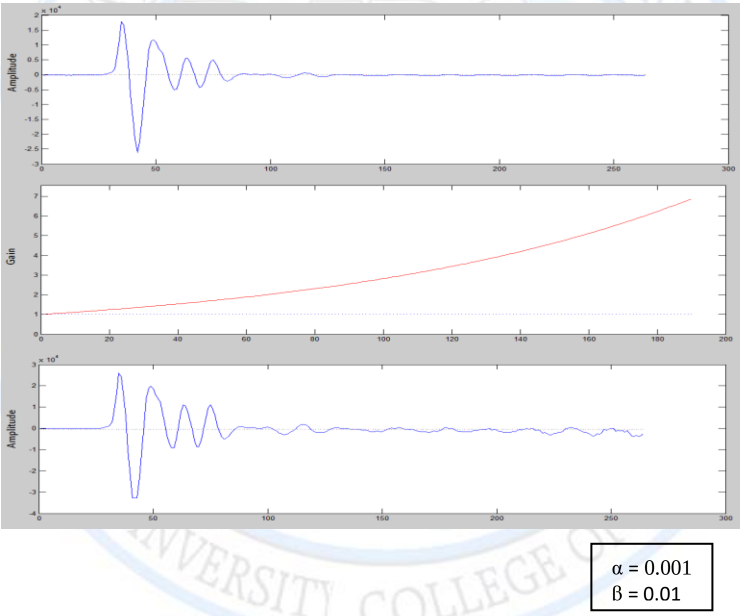


Figure 3: Plot of original signal, gain function and processed signal

The received signal is reduced in amplitude compared with the transmitted signal as a result of attenuation both of the medium of propagation and the spreading loss encountered in travelling from the transmitter to the observed target (reflector) and back to the receiver. In order to apply time-varying gain, to compensate for these losses, several conditions must be met. The trace should have an average near to zero, in order to not skew the distribution of amplitudes creating a large amount of DC offset. The noise levels at late times should be low, otherwise the noise at late times in the trace will be increased. The signal to noise ratio (SNR) is however constant, since both the signal and noise is increased in the same ratio.

Histogram Equalization

If f is an image with m_r and m_c row and column respectively of pixel gray scale ranging from 0 to G-1. G is the intensity levels values (256 gray scale). P is the normalize histogram of image f (mr, mc) which can be given as :

$$P_n = \frac{no.of\ pixels\ of\ intensity\ n}{total\ no.of\ pixels} \quad n=1,2,3,\ldots\ldots\ldots\ldots G-1$$

The histogram equalized of the image E can be given as :

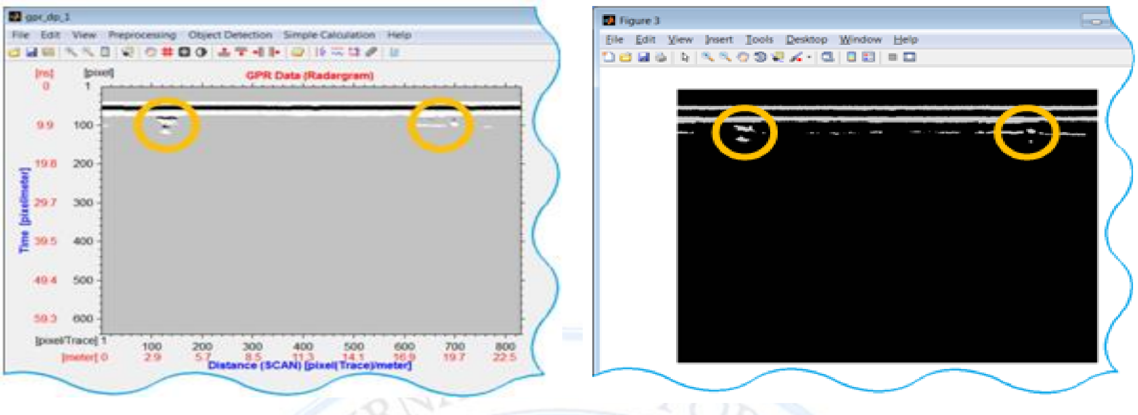
$$E_{i,j} = floor((G-1)\sum_{n=0}^{E_{i,j}} P_n) \quad \ldots(5)$$

Where, the floor () gives the nearest integer value. Is similar to transforming the pixel intensities, k, of f by the below relation [9] .

$$(k) = floor((G-1)\sum_{n=0}^{k} P_n) \quad \ldots(6)$$

Methodology

1. Object Detection using Segmentation Methods: The unique backscatters of the buried object detected from the radargram have been done using image segmentation. The other complex background due to non-target was recognized from the unique backscatter of the target using the gray scale Segmentation such as *Quantization* and *FCM* as shown in figure (4).



(a) (b)

Figure 4: Object Detection using GPR_DP applied on site10.rd3 by (a) *Quantization* Segmentation with threshold = 2, (b) *FCM* Segmentation.

2. Object Detection using SPST Method: An approach to detecting buried objects using Software Package based on preprocessing methods, and then applied order statistics by Selected Peaks of Summing up Traces (**SPST**) have been described. Preprocessing methods to revelation anomaly buried objects detection using several styles such as:

<u>Style 1:</u> Applied directly to radargarm (none preprocessing).

<u>Style 2:</u> Detect edge of radargram using auto-threshold *Log* edge detection.

<u>Style 3:</u> Filtering radargram by vertical *Prewitt filter*, then *Dilate* (Morphological definition), inverting the color palette of image produced.

<u>Style 4:</u> Adjusting image intensities by histogram equalization, then detect edge of radargram using vertical *Sobel* edge detection with thresh.=0.2.

<u>Style 5:</u> Removed DC noise by *Zero-offset Removal*, compensate for reduced received signal in amplitude using *Time Varying Gain* (*TVG*) with alpha=0.001 and beta=0.003, then detecting edge of resultant using *Zero-cross* with thresh.=0.2, finally *Closed* (Morphological definition). Order statistics based on choosing the maximum variation on summing up the traces to detect horizontal distance and then selected peak variance of the chosen traces to determine vertical distance (depth), as illustrated in figure 5; detection depend on regions containing anomalies, plastic and metal pipes, electrical cables with various diameters, some regions having concrete or bricks buried as perspective view in figure 6. At first one of the preprocessing styles applied on site10.rd3 then object detection using **SPST**, as shown in figure 7. Two criteria fidelity have been used to achieve the comparison between the results such as mean square error and root mean square error which can be described in equation 7 and 8.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(\hat{Y}_i - Y_i)^2 \quad \ldots(7)$$

$$\mathrm{RMSE} = \sqrt{MSE(\hat{Y})} \quad \ldots(8)$$

Where $\hat{Y}$ vector of n production, and Y is the vector of the true values.

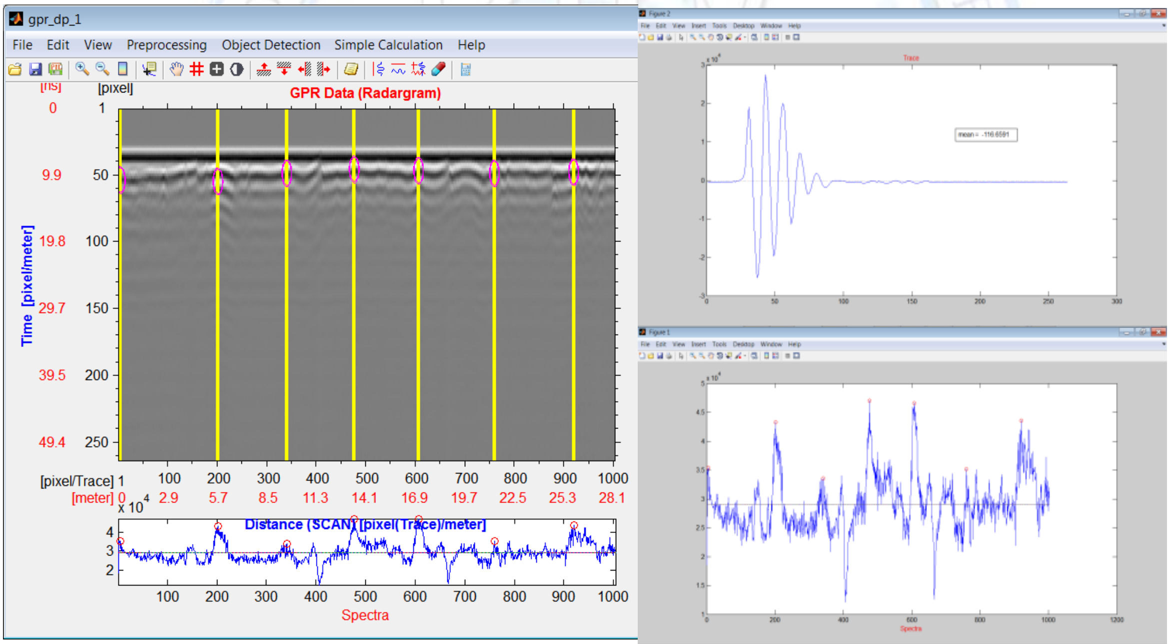


Figure 5: ***Left:*** **Objects Detection using SPST by GPR_DP on site2.rd3.** ***Right top:*** **Trace at 5.7m from start point (selected).** ***Right down:*** **the maximum variation on summing up the traces have been chosen to detect horizontal distance.**

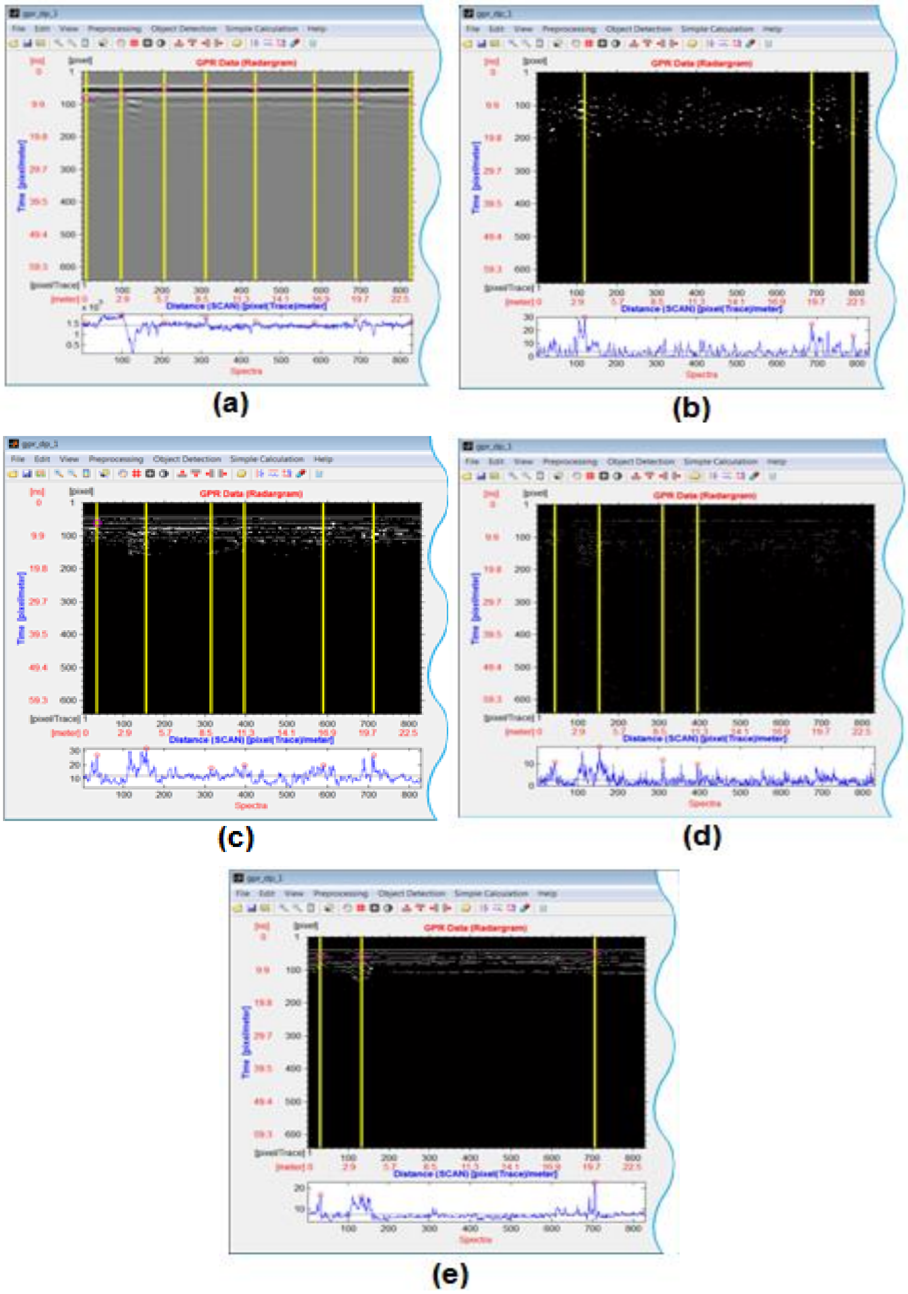


Figure 6: Object Detection using SPST by GPR_DP applied on site10.rd3 where : (a) Style_1 (None preprocessing) (b) Style_2 (c) Style_3 (d) Style_4 (e) Style_5.

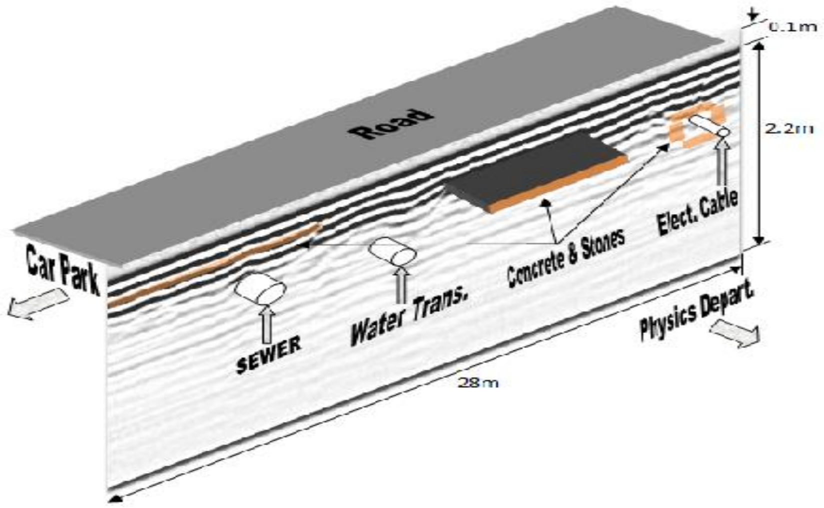


Figure 7: object detection using SPST by GPR-DP as perspective view on site2.

Results and Discussion

Ground penetrating radar (GPR) is a high resolution electromagnetic technique that is designed primary to investigate the shallow subsurface of the earth, building materials, roads and bridges. This research describe the building of an package using Graphical User Interfaces (GUI) of MATLAB R2014a, this package algorithm provide a valuable information to aid in detection and identification of subsurface features. The data have been adopted in this research were gathered using GPR survey. One site represent by Baghdad university campus has been used to collect these data. The results from GPR_DP to detect buried objects obtained firstly from segmentation using *Quantization* and *FCM* as shown in table 2, then SPST algorithm was applied directly on data without preprocessing, next, the SPST algorithm has been tested on results of applying preprocessing styles, the results with information about objects was buried in specific regions from maps have been tabulated in table 3. Two antennas with frequency 250 MHZ and 500 MHZ have been used to gather the reflected signals using GPR survey. Mean square error and root mean square error of applying different method and using the two type frequency can be shown in figure (8).

Table 2: Results from the application Quantization and FCM on the different data.

Radargram Data	No. of Objects in		
	Radargram	Quantization	FCM
Site1	1	0	1
Site2	4	2	2
Site3	1	2	3
Site4	1	0	3
Site5	2	1	1
Site6	3	2	4
Site7	1	3	3
Site8	4	7	7
Site9	3	5	3
Site10	5	2	2

Table 3: Results from the application SPST on the different styles.

Radargram Data	No. of Objects in					
	Radargram	Style_1	Style_2	Style_3	Style_4	Style_5
Site1	**1**	**6**	**4**	**1**	**4**	2
Site2	**4**	**7**	**4**	**2**	**5**	5
Site3	**1**	**7**	**5**	**1**	**1**	4
Site4	**1**	**6**	**3**	**0**	**2**	2
Site5	**2**	**6**	**4**	**1**	**2**	3
Site6	**3**	**5**	**3**	**5**	**1**	4
Site7	**1**	**5**	**3**	**1**	**1**	5
Site8	**4**	**7**	**5**	**2**	**2**	7
Site9	**3**	**6**	**4**	**2**	**1**	4
Site10	**5**	**8**	**6**	**3**	**4**	3

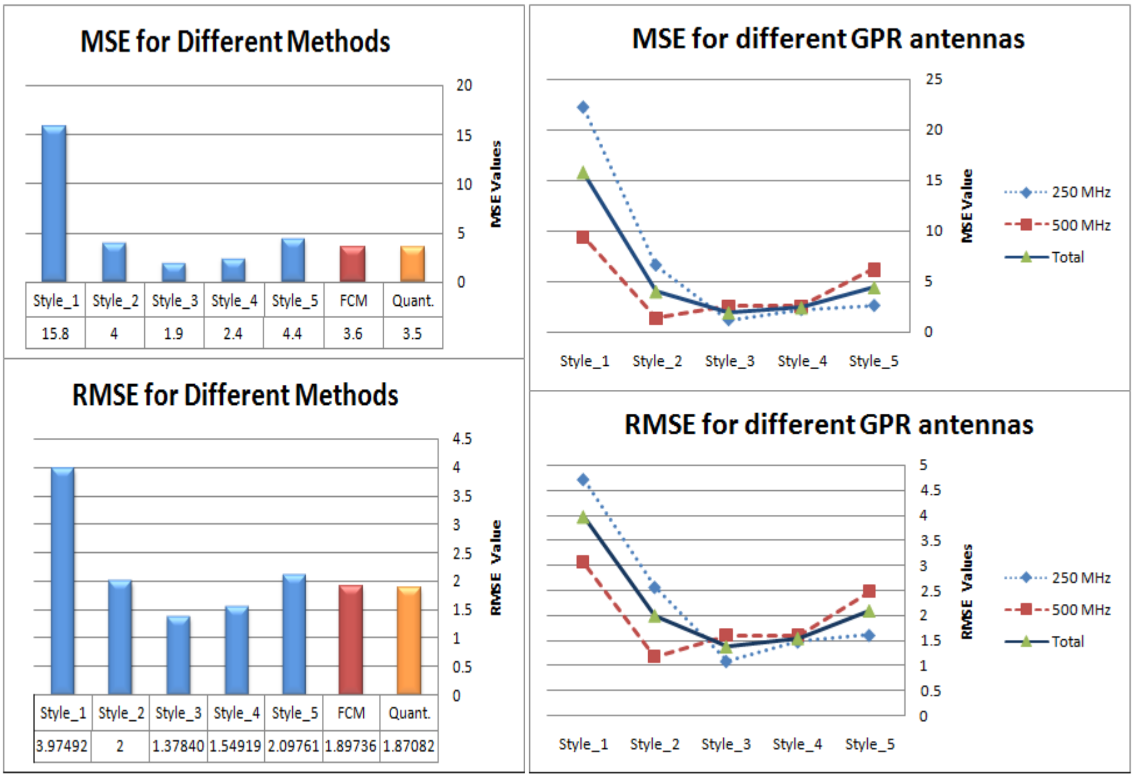


Figure 8 : The statistical properties of the obtained results using different styles and different antenna

Conclusions

The algorithm has been built in this paper was widely used for semi-automatic object detection, displaying, filtering, edges detection, histogram equalization, segmentation and detection of objects hidden beneath the surface. The following points are considered to be the most important conclusions, that have been obtained from this research:

1. In general the results from GPR_DP to detect buried objects obtained from SPST algorithm was better than using *Quantization* and *FCM* segmentation. as shown in tables (2)&(3).

2. The computation of MSE and RMSE show similarity between FCM and Quantization, but different result have been obtained by SPST segmentation using different styles as shown in figure 6.

3. In using SPST technique, different result have been noticed using different antenna frequency (250 MHz, 500MHz) spatially in 1,2,5 styles and no effect of frequency on style 3 and 4 as shown in figure (6).

4. During the GPR surveying it's important that the fields must be as dry as it could be because of the distortion effect of the water to the reflected part of the radio wave that transmitted from the GPR antenna which forms the output image.

References

1.Knight, R., 2001, Ground penetrating radar for environmental applications: Earth and Planetary Science, 29, 229–255.

2.Daniels, D. J., 2004, Ground Penetrating Radar, 2nd Edition, IEEE Press.

3.Jol, H. M., Ed.,2009 "Ground Penetrating Radar: Theory and Applications", 1st Edition, Elsevier Science, Amsterdam.

4.Renee Rose Francese " Spectral Analysis Of Thinning Beds Using Ground Penetrating RADAR', Submitted to the Office of Graduate Studies of Texas A&M University in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE,2012

5.Annan, A.P., 2001. Ground penetrating radar—workshop notes. Sensors & Software Inc., 1091 Brevik Place - Mississauga, Ontario - L4W 3R7, Canada.

6.G.T. Shrivakshan, "A Comparison of various Edge Detection Techniques used in Image Processing", IJCSI International Journal of Computer Science Issues, Vol. 9, Issue 5, No 1, September 2012, ISSN (Online): 1694-0814.

7.D. A. Noon 1996. Stepped-Frequency Radar Design and Signal Processing Enhances Ground Penetrating Radar Performance, Ph.D. thesis, Department of Electrical & Computer Engineering, University of Queensland, Australia.

8. Radexplorer "easy and effective GPR processing software" Mala Geoscience USA,Inc.

9.R. C. Gonzalez and R. E.Woods , 2008, Digital Image Processing, Third Edition.