

# A Review of Machine Learning Approach for Ground Penetrating Radar Applications

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**ABSTRACT** Machine learning (ML) is a branch of artificial intelligent in which algorithms learn relationships in data. ML can be applied in predictive sense or to investigate internal relationships of dataset. The ability to give promising results bring ML been applied in various application such as imaging, signals processing, data mining, and many more. In this paper, the ML approach for Ground Penetrating Radar application is reviewed. Nowadays, Ground Penetrating Radar have some issues of accuracy of localization and the image processing due to the noise and unwanted signal from the underground. Therefore, some of the smart learning technique is proposed especially to remove the clutter signals. A comparison of ML technique such as linear regression, logistic regression, KNN, support vector machine and etc for clutter issues is presented in this paper. The most suitable technique for in GPR applications in order to solve the clutter issues is proposed.

**KEYWORDS** Machine Learning, Ground Penetrating Radar, Algorithms.

## I. INTRODUCTION

Nowadays, ground penetrating radar (GPR) still facing some issues of clutter or unwanted signal and clearness of image process. For example, external issues have geological issues, external signal and clutter. Internal issues such as transmitting receiving signal and image process. Therefore, the aims of this paper are to review few Machine Learning technique that can be applied in GPR applications. Machine learning (ML) had widely used in many fields to make better outcome result and make our live more amazing. Machine learning techniques help a lot in a variety of application areas, such as medical, voice recognition, face recognition and computer vision [1-4]. Machine learning tries to construct algorithms and models that can learn to make decisions from the data. Machine learning algorithms generally categories to supervised learning and unsupervised learning [5]. Supervised Learning algorithms learn to classification or regression tasks from label data, while Unsupervised Learning algorithms focus on classifying the sample sets into different groups (i.e., clusters) with unlabeled data [6]. Therefore, Machine Learning can be applied in GPR system in order to remove the clutter signals to give a promising result.

The clutter and unwanted signal detected from surrounds brings big issues faced by GPR applications. The clutter brings accuracy issues to the object localization and detection in GPR. Therefore, a Machine Learning Technique with the algorithms can be apply for processing signal in accuracy and perform measurement should be improved to produce better output of GPR system. A different technique can be proposed and experimented to solve the clutter problems that faced.

Machine Learning with the help of the algorithms had been develop in the field. Therefore, a comparison of the Machine Learning algorithms for remove the clutter to produce better output image and accurate localization of the GPR system. The comparison algorithms that make for GPR system is linear regression, logistic regression, k-nearest neighbors (KNN) Algorithm, Naïve Bayes, Boosting Algorithm (EXP: ADABOOST & Gradient Boosting) and Support Vector Machine (SVM) Support Vector Regression (SVR). With the comparison of the algorithms the most suitable algorithms Machine Learning Technique that can implement for the GPR system.

## II. GROUND PENETRATING RADAR (GPR)

Ground Penetrating Radar (GPR) is a multidisciplinary Non-destructive Evaluation technique. Nowadays, Ground Penetrating radar (GPR) system had widely used in many fields to make the task become easier. GPR help a lot in a variety of application areas, such as security military [7-9] locating of the pipe and cable [10], concrete or building structure [11] [12] and etc. The theory of the modal GPR is detect the reflected signal and from the structure of subsurface. The Figure 1 shows example of the experiment modal GPR system on monostatic radar, the transmitter and receiver at the same place that is brown box show in the modal. The incident wave will transmit from the red box to underground and the scattered wave will be received at the Redbox also.



Figure 1. Experimental work for monostatic GPR

### A. Mono-static Radar

Mono-static radar is a single antenna that transmitting and receiving signal radar at a same place. The transmitting signal transmit signal and reflected signal can be detected by the same antenna. Mono-static radar had been use in the security [14] with the reconstruction algorithm for multi-monostatic radar. Monostatic radar can apply for most security field such as airport, customs or military. Also, some machine learning technique or deep learning technique with the smart algorithms can improve the detection accuracy for the security field. Next, bistatic radar the transmitter is placed at one site, and the receiver is placed at the second site. Figure 2 show the theoretical of different of monostatic and bistatic radar. To make the size of GPR as small as possible and the distance between transmitter and receiver is closer the lesser the clutter (unwanted signal or can be said as noise) that produce, the monostatic radar had been selected in this research. Microwave imaging achieved by inverting the linearized scattering integral operator for a reflection mode monostatic configuration. [15][16]

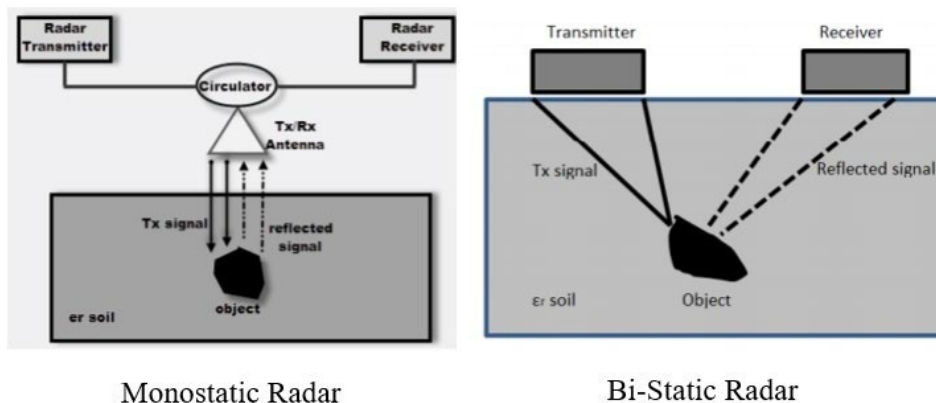


Figure 2. Different of Monostatic radar and Bistatic radar [17]

### III. Machine Learning

Machine learning algorithms can solve the domain specific problems in various fields of engineering. Field of machine learning is a subset of artificial intelligence (AI) and deep learning. The term data science is a field using techniques from Artificial Intelligence (AI), machine learning (ML), deep learning and the input and the learning dataset with the software Machine Learning. In the last few years, approaches used to perform risk assessment can be observed to be changing as machine learning algorithms are beginning to aid and improve the findings from traditional risk assessment techniques.[18]. The Figure 3 below shows the Venn diagram of the relationship of Artificial Intelligence, Machine Learning and Deep Learning. The figure also stated the importance of the data of the experiment or research, for some Machine Learning algorithm need the big data for improving the output of experiment and computer science software to support Machine Learning.

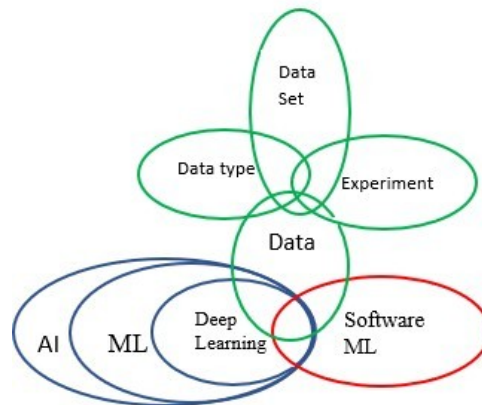


Figure 3. Venn diagram representing the components of AI adapted [18]

There are three key points of machine learning that can conclude in this research studies. First, has some underlying pattern to be learning to improve a better output or make the prediction of output more accurate. Second the program not easy definite so Machine Learning was required. Last, must have one or more input data and data to learning form. Machine learning can be said in form of AI that enables the system to learn from data rather than through explicit programming. Therefore, machine learning is not a simple process and need a lot of data for the system to analysis. [19]. The Figure 4 shows the regular flow of the Machine learning based on the research of GPR system. First, the database is collected from the GPR system. Then process to the Machine learning technique with the algorithms for classification purpose or regression with the smart Machine Learning technique it can study and do a decision. As the result, a better skill or result by the Machine Learning Technique. For our research GPR system can make an improvement of the accuracy with remove the clutter or unwanted signal

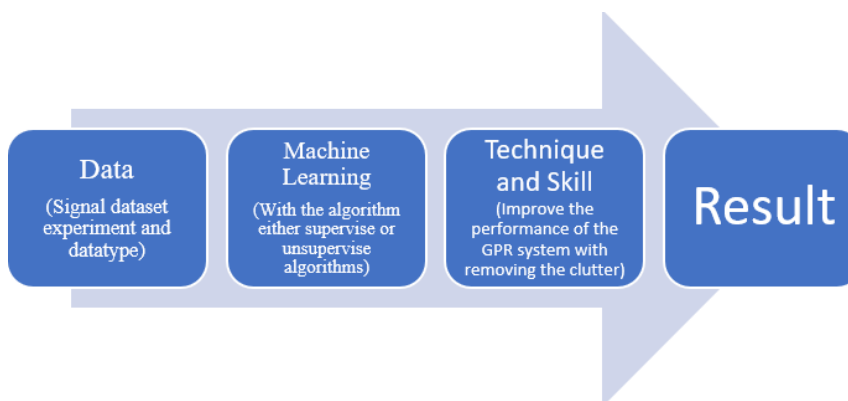


Figure 4. Flow Chart Machine learning based on project

### A. Simple Linear Regression

Linear regression is widely used in regression problems that perform well in image denoising and signal processing. Regression is used for the statistical analysis of the data for estimating the relationship of the dataset and can estimate positive linear or negative linear. Therefore, linear regression can predict the output variable from the input variable but without studying or learning the data and without making a decision by the inner mechanism [20]. Linear regression algorithms have been used for indoor localization with Wi-Fi and perform a good output [21]. Besides, linear regression can be used for assuming during the learning phase, because the samples can be converted to a strict binary label matrix (example:  $(x,y)$ ). Linear regression consists of a single parameter and a variable that have a linear relationship, the linear line with formula  $Y=mX+c$ ;  $m$  is the gradient,  $c$  is the point on the y-axis. [22] Therefore, with plotting we can know if it is positive or negative linear. Figure 5 shows the line of fit of one of the experiments.

The advantage of Linear Regression is easy to apply, also it is the easiest algorithm to interpret the output. It can also determine the relationship between the independent and the dependent variable of a linear relationship. The disadvantage of linear regression is not in the form of a complex description for a single variable. Therefore, the relationship of the description among the variables is also not complete. The disadvantage of simple linear regression is that it is a too simple algorithm, suitable for the normal GPR system but not suitable for our research project because it is not very accurate and not smart. Besides, to improve the accuracy of removing unwanted signals, smarter algorithms and self-learning algorithms are needed. Therefore, linear regression is not the first choice of algorithm for this research. In conclusion, simple linear regression is the "BEST FIT" line of the data suitable for numerical prediction.

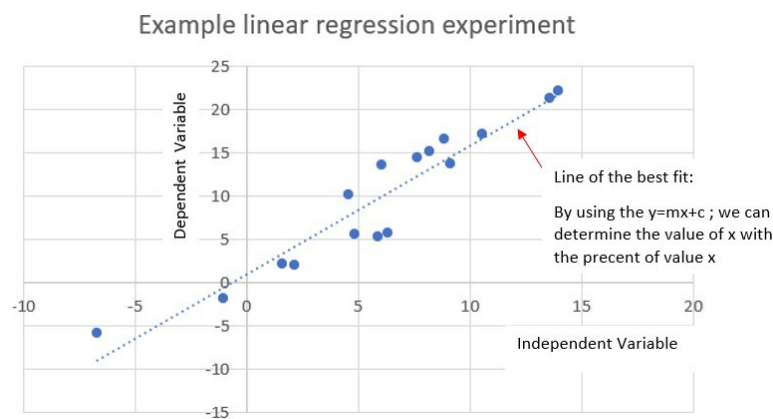


Figure 5. The example of the simple regression that the data after and before the experiment

### B. Logistic Regression

Logistic Regression is almost the same as linear regression, used for the regression purpose, the only difference is that logistic regression is more on predicting some condition whether it is "True" or "False", instead of predicting a condition like size. Logistic Regression is widely used for the estimation of discrete values (usually for binary; 0 and 1) from a set of independent variables. Therefore, Logistic Regression is widely used to predict the probability of a situation by fitting the data to a logit function. The regression shows in Figure 6. The difference between it and linear regression is that the data points are unarranged in line rows [23]. Furthermore, some researchers use Logistic Regression in many fields such as face image recognition by making the comparison using binarization [24], speech emotion recognition by classifying the modelling decision tree in the binary classification [25] and medical health in the detection of Ovarian Tumors using the classification of logistic regression algorithm formula [26]. For the previous studies, logistic regression is used for the Synthetic Aperture Radar (SAR) image with the change detection algorithm (CDA) for the output image classification of "1" which indicates change and "0" unchanged region [27].

The advantage of logistic regression is that it can predict the accurate distributions of the classes. Plus, it can be used to determine the appropriate predictor in coefficient size and the direction of association in positive or negative sites. The limitation of logistic regression is that it is only for discrete functions (cannot have decimal) prediction. Non-linear cannot be solved by logistic regression because it has a linear decision surface and it is very hard to find the linear separate data in the real scenario. Logistic regression is suitable for some of the GPR systems, but not suitable for our GPR research project because this is only suitable for adaptation for classification of a problem in the form of yes or no question and cannot remove the cluster or unwanted signal.



Figure 6. The example of the experiment of the logistic ‘o’ is no and ‘1’ is yes

### C. *k*-nearest neighbors (KNN) Algorithm

This algorithm can be used for classification of the data for data mining. The way it's an algorithm that stores all available cases and classifies any new cases by taking a majority vote of its *k* neighbors.[28][29] The Figure 7 shows the example of the basic KNN algorithm of classifying the red datapoint by looking at the nearest datapoints. Take the example of Figure 7, *k* we consider as 10, so the nearest datapoint is 3 blue datapoints, 5 orange datapoints and 2 gray datapoints. Since 5 orange datapoints is the most, so the final assignment of classification is orange. Therefore, with this theory, it can be applied for indoor localization by collecting the fingerprint [30] that can help in the forensic field. Also, the KNN algorithm is suitable for localization and landscape study [31]. KNN algorithm is also suitable for use in medicine, for example cancer (tumor). KNN is one of the nonparametric classification methods that has high accuracy and is easy to implement. Therefore, KNN has even been used to detect different stages of cancer [32].

KNN is called Lazy Learner (Instance based learning) because it does not learn anything. Therefore, KNN is much faster than other algorithms that require training such as SVM, Linear Regression. No training before predictions. So, a new data can be added seamlessly and will not affect the accuracy of the algorithm. Disadvantage is it does not learn anything during the training period, does not derive any function. KNN only stores the database and makes a real-time prediction without learning from the data. It does not work well with large datasets and high dimensions because a large number of dimensions is difficult for KNN to make a classification. KNN is a nice classification algorithm and theoretically can be applied for normal ground penetrating radar, but a smart algorithm was needed to self-study and make a decision from the data that was needed to remove the clutter, not a Lazy Learner.

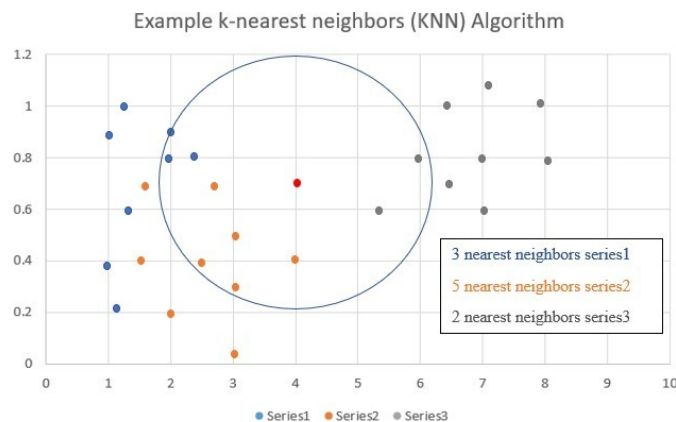
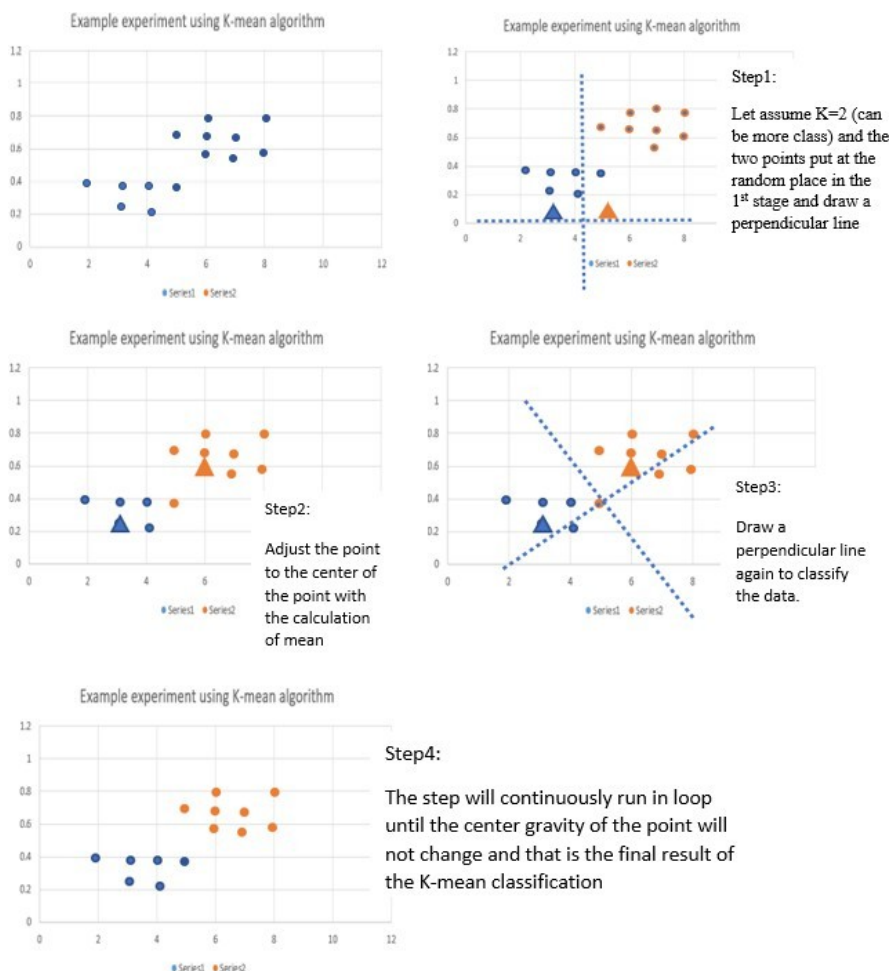


Figure 7. The example of the KNN algorithm classification

**D. K-mean**

K-mean wisely used in clustering data that based on the data grouped and it is an unsupervised algorithm [26]. The data sets are classified into specific number of cluster ( $k =$  number of point cluster) by homogenous and heterogeneous. The most important thing of K-mean picked the  $k$  value that called centroids, for each cluster. Each data point forms a cluster with the closest centroids. New centroids form based on the existing cluster members and the closest distance for each data point is determined [33]. The Figure 8 show the simple K-mean experiment step for the classification of the dataset. First, the number of the  $k$  was determined as the centroid (center gravity) of the datapoints to make the classification. Then, centroid was been adjusted to the center of the class dataset. This process will run continuously until the centroids is fixed [34]. Besides that, k-mean also can make a comparative analysis of hybrid clustering by classify the data [35]. Therefore, based on the theory of the k-mean it suitable for image segmentation [36] and face feature extraction [37]. K-mean clustering had improved the localization of the Antenna 8 RSSI measurement [38].

The advantage is easy to implement on identify unknow group of data from complex data sets. So, it is a simple manner algorithm. K-means support large number of datasets and computed much faster than the smaller dataset. L-mean suitable use for searcher intent because can easy classification of the problem and data. (Search intent is the answer behind of a searcher query on search engines). K-means cannot develop an optimal set of clusters and for effective results. So, before K-mean must decide on the clusters, means K-mean must decide the cluster before going through the K-mean algorithm can only perform in a numerical data. K-mean operate in assumption by cluster in spherical and each cluster equal number observation. Spherical assumptions have to be satisfied. The disadvantage can't work with clusters of unusual size, and it cannot handle noisy data and outlier. This is the biggest disadvantage. An algorithm that can handle noisy dataset is need but this algorithm cannot. K-mean is a good algorithm that can use for a lot of fields for example business because it makes a clustering interest of customers and promote it. The limitation of the spherical clusters and need to decide the cluster first before going through K-mean not so suitable for remove unwanted signal from GPR system because this algorithm hard to handle noisy data and outlier.



**Figure 8. The experiment clustering with the simple K-mean theory**

### E. Naïve Bayes

Naïve Bayes wisely used in classification on assuming the presence of particular feature in class is either related to the presence of any other feature. The “Naïve” in Naïve Bayes means it make the assumption of a certain feature happen based on the independent of the other feature. “Bayes” is a name of a statistician Thomas Bayes, the “bayes” in Naïve Bayes is the theorem named after him. Therefore, the Naïve Bayes Algorithm is based on the Bayes Theorem on the conditional probability of the  $P(A|B)$  [39][40]. If the features are related to each other, Naive Bayes classifier still consider all of these properties independently by calculate probability of particular outcome. Naive Bayesian model can build and useful for big size of datasets. Let take an example of indoor localization by Naive Bayes classifier [41]. Naive Bayes classifier must follow two basic assumptions. First, all features must independent from each other. Second, each feature must have the same prominence. Besides that, Naïve Bayes can apply to the emotion recognition of the speech [42] and the face recognition using eigenface with Naïve Bayes algorithm by the theory of the probability of the Bayes theory [43].

The advantage Naive Bayes is suitable for solving multi-class prediction problems. If assumption is independence features holds true, it can perform better than other models and less training data required. Naive Bayes has advance on categorical input variables than numerical variables. The disadvantage is all the predictor in independent that less happening in real life. This will limit the uses of this algorithms. Due to the limitation this algorithm will be wrong estimation in some cases, so the output result can only take for reference cannot take very real result. ‘Zero-frequency problem’ effect zero probability to categorical variable whose category in the test data set wasn’t available in the training dataset. Therefore, Naïve Bayes Algorithm hard to get the expected result for our research that is remove the unwanted signal or clutter of the GPR system.

### F. Boosting Algorithm (EXP: ADABOOST & Gradient Boosting)

Boosting algorithms wisely used to make a prediction of a big load of data with high accuracy. Boosting is a learning algorithm that combines the prediction of some base estimators to improve robustness.

#### ADABOOST

AdaBoost can use for classification and regression problems. ADABOOST can apply with split termed as decision stumps works by weighting the samples. It helps to classify the sample weight that easy [44]. The Figure 9 shows the experiment of the classification of the dataset by ADABOOST Algorithm. The process is repeated as show in Figure 9 until the algorithm identifies the correctly classify the sample. ADABOOST algorithm can apply in human face localization with the convolutional neural network (CNN) [45]. For the radar signal recognition, ADABOOST algorithm had perform with stable recognition rate compare to SVM with Fast Correlation-Based Filter Solution (FCBF) [46].

It can apply on more than two classifications of the data called multiclassification algorithm. It will repeat the step until the data fully classify. Also, it can use for various regression classification models for the of build weak learners, which is very flexible. It has a low generalization error rate, high precision and also can be applied on most of the classifiers. Also, easy to use because no need to adjust parameters. The classification accuracy will affect by the imbalance of data. The training time taking is consuming because it will repeat the process one time once as show in the diagram. AdaBoost is a weak classifier or weak learners with a single split termed as decision stumps. AdaBoost has sensitive outlier cause difficult of classifying. ADABOOST algorithm being to noise interference.

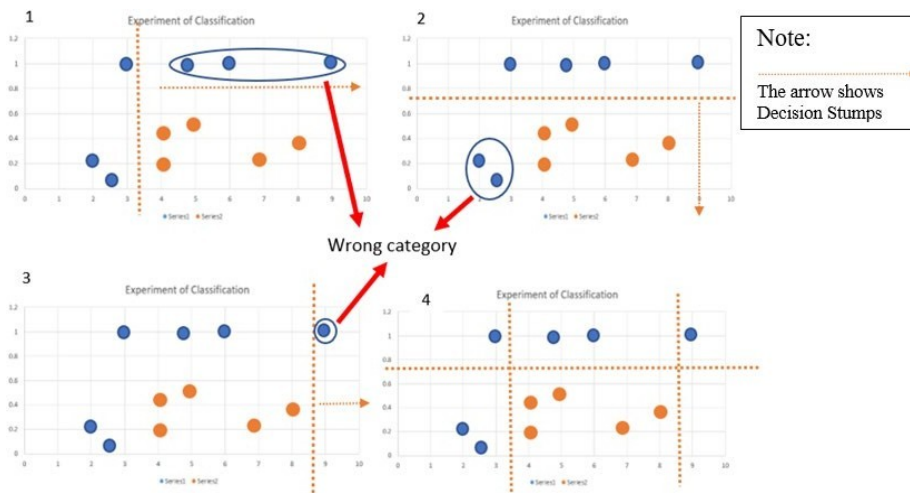


Figure 9. The Example of classification of the ADABOOST algorithms

### Gradient Boosting

Gradient boosting or gradient tree boosting wisely use for regression and classification problems. The theoretical of Gradient Boosting same as ADABOOST but the different is Gradient boost have larger decision tree. The main function of gradient boosting is minimizing a loss function by stirring in the reverse direction of the gradient [44]. The Figure 10 shows the experiment for the part of classification dataset by the Gradient Boosting algorithm and show that have larger decision tree and decision stumps than ADABOOST.

The best of the Gradient boosting is the accuracy of Gradient boosting is more accurate than AdaBoost, Gradient boosting more flexible to optimize loss function. The pre-processing not required because it can work great with categorical and numerical values as is. The disadvantage of gradient boosting has problem of overemphasize outlier and overfitting because it will always continue minimize the error so cause overemphasize. It less interpretative in nature more use on classifying business data, although this is easily addressed with various tools.

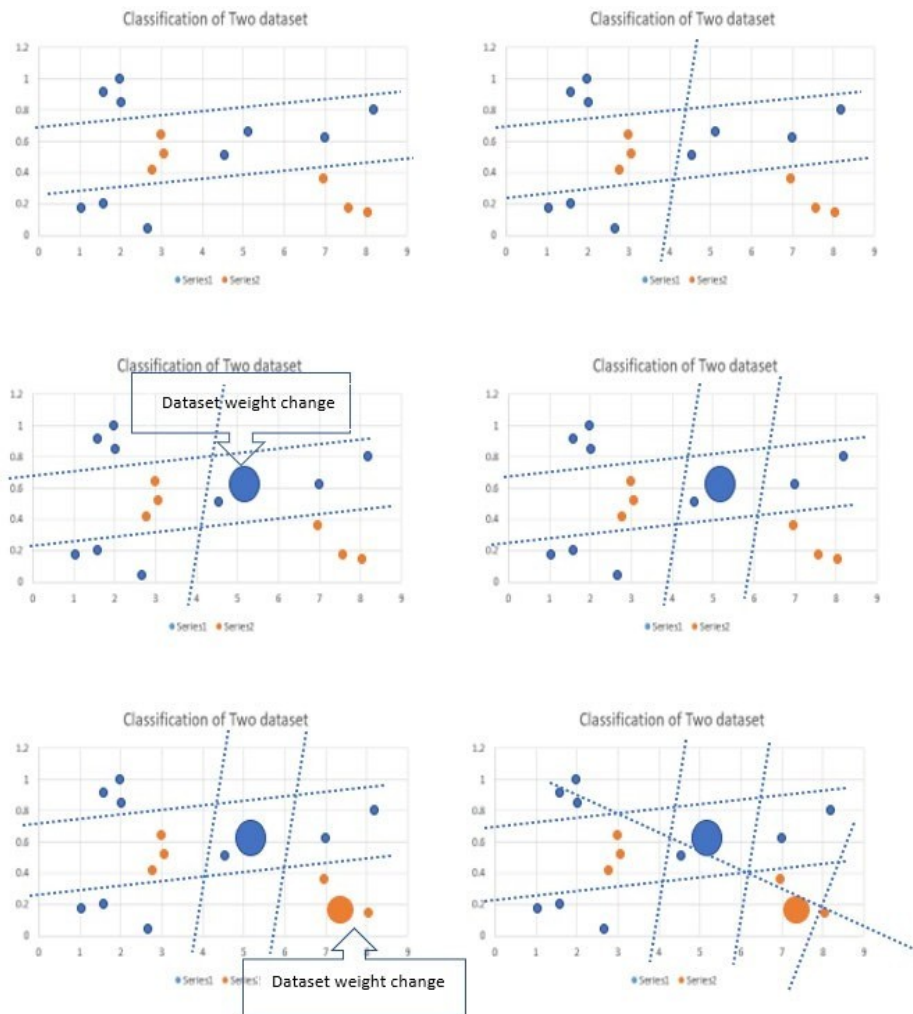


Figure 10. The Example of the classification experiment Gradient Boosting for the dataset

AdaBoost and Gradient Boost is a weak learner of classification and regression and it has some limitation. Therefore, this both algorithms hard to help us to learn and make a decision to remove the clutter of the GPR system

**G. Support Vector Machine(SVM) & Support Vector Regression(SVR)**

Support Vector Algorithm is a nonlinear generalization of the Generalized Portrait had been developed in Russia in the sixties2 by Vapnik and Lerner 1963, Vapnik and Chervonenkis 1964 (VC theory is Vapnik and Chervonenkis). After that, the framework of statistical learning theory which has been developed over the last three decades by Vapnik and Chervonenkis (1974) and Vapnik (1982, 1995). As the last, VC theory is a learning machines which enable them to generalize well to unseen data.[47].

Support Vector Regression (SVR) is built from the concept of Support Vector Machine (SVM). SVM is a supervised learning algorithm that can learn from label data. SVM learning is one of the Machine Learning Technique, compared to the others Machine Learning, SVM is very powerful at recognizing subtle patterns in complex datasets. SVM widely used in recognize handwriting [48], recognize fraudulent credit cards [49], recognize voice or speech recognition [50], also recognize face [51] and soon. SVM was carried out on non-linear problems that studied by others researcher using method of neural networks for GPR [52]. Therefore, a lot of comparison of the other non-linear detection technique have been carry out to determine feasibility. Research shows that SVM can perform good with neural networks by nonlinear problems investigated.[53]

Support vector machine (SVM) can be stated as Machine learning (ML) with maximization (support) of separating margin (vector). Machine learning is a model that can self-learning from previous data to predict future data, and the key process of the self-learning can be define as once of the artificial intelligences (AI). The supervised learning is a technique that build a modal based on the learning from known data. SVM learning is one of the Machine Learning techniques that can use for Machine Learning for classification and regression data [54]. Therefore, SVM modal is a powerful method for building a classifier. The main function is making a decision boundary between two classes for the prediction of the feature vectors. This decision boundary is known as hyperplane. Based on the formula Table 1, the margin was founded and can classified the data set as the Figure 11. The figure shows the classification of the two datasets by the SVM technique in linear form.[40]

TABLE 1  
 The basic theory of formula of SVM [54]

The training dataset: $(x_1, y_1), \dots, (x_n, y_n) ; x_i \in R^d ; y_i \in (-1, +1)$ $x_i$ : feature of vector $y_i$ : class label (negative is the lower part line, positive is higher part line) the dataset from the first $(x_1, y_1)$ to $(x_n, y_n)$
The optimal of hyperplane: $ax^T + b = 0$ $a$ : weight vector (Gradient) $x$ : input feature vector $b$ : bias
The training set: $ax_i^T + b \geq +1$ $ax_i^T + b \leq -1$

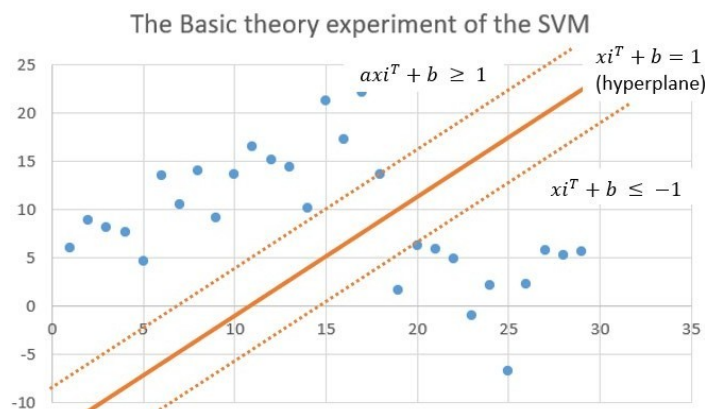


Figure 11: Margin of the modal SVM [54]

The support vector regression (SVR) is using the theory of the support vector to solve regression problem. Therefore, the main objective of this algorithm is to generalize the optimal bounds for the purpose of regression, this has some relationship between the theory of the hyperplane in the case of classification. Let take an example commonly use of application of the kernel functions to map the original input variable into high-dimension feature that non-linear to the solution. Given the set of data  $\sum N \{ (X_i, Y_i) \}$ ; an SVM regression model relates the output variable and the input variables as:  $Y = f(X) = W * \phi(X) + b$ ;  $\phi(X)$  corresponding to feature mapped from original input with kernel function; W and B coefficient estimated that follow the optimization process below:

$\|W\|^2$  is known as regularized term; C is penalty parameter to determine the flexibility of the model. The Equation 1 is the empirical error and is measured by the  $\epsilon$ -intensity loss function Equation 2. Defines of  $\epsilon$  tube shown in Figure 12.

$$\text{Minimize} = \frac{1}{2} \|W\|^2 + c \frac{1}{N} \sum_{i=1}^N L_{\epsilon}(Y_i, f(X_i)) \quad \text{Equation 1}$$

$$L_{\epsilon}(Y_i, f(X_i)) = \begin{cases} 0 & |Y_i - f(X_i)| \leq \epsilon \\ |Y_i - f(X_i)| - \epsilon & \text{otherwise} \end{cases} \quad \text{Equation 2}$$

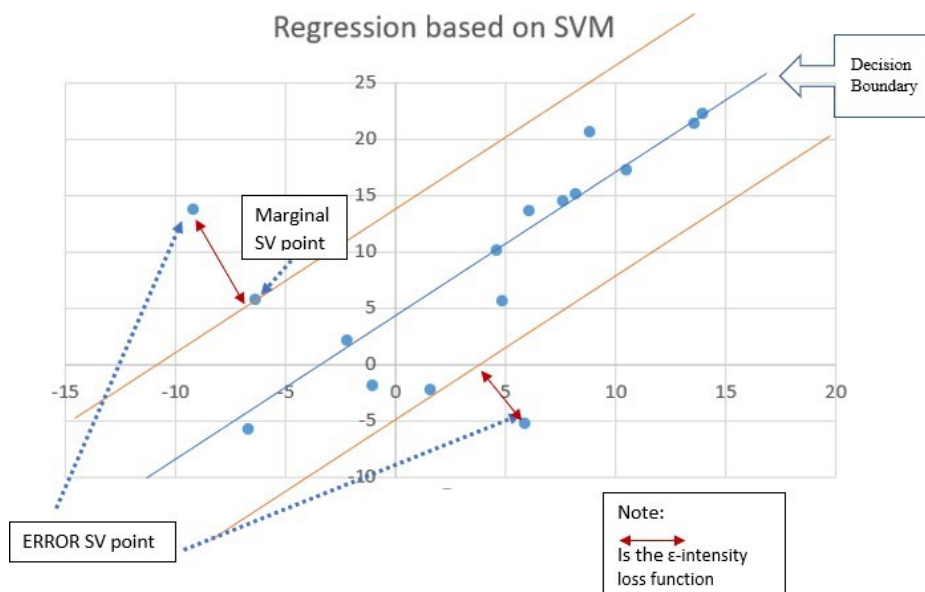


Figure 12: The parameters of the support vector regression [56]

#### IV. Machine Learning of SVR for GPR system

The generation or construction of image based on interpretation and signal recognition will be applied. The ability to remove unwanted signal (remove clutter) with advanced technique can produce a better and high quality of image and minimize the localization error. Most of the analysis will be conducted at this stage. Therefore, Machine Learning technique will be applied at this stage. Based on the Figure 13 the unwanted signal that produce by GPR in imaging nowadays and the prediction of the SVM to the unwanted signal.

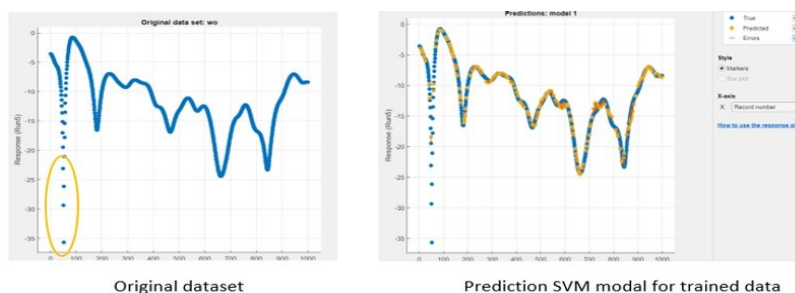


Figure 13 Example of unwanted signal that need to remove and the SVM modal after training the dataset from GPR system

Table 2  
 The RMSE validation, MSE validation, MAE validation of modal SVM after training

GPR (times)	RMSE (root mean square error)	R-square	MSE (mean square error)	MAE (mean absolute error)
Run1	0.22675	1	0.0051415	0.17688
Run2	0.199	1	0.0396	0.14373
Run3	0.36628	0.99	0.134116	0.3272
Run4	0.87249	0.97	0.76124	0.59508
Run5	0.61171	0.99	0.37419	0.41083
Run6	0.71902	0.98	0.51699	0.48233
Run7	0.22961	1	0.05272	0.1781
Run8	0.19211	1	0.036906	0.1406
Run9	0.35998	1	0.12958	0.32127
mean	0.419661		0.232973	0.308447

Support Vector Regression (SVR) as the Machine Learning algorithms also define as “smart algorithm” in analysis data, classification of problems and regression challenge. The Table 2 shows the training result of the SVM based on the GPR system run. Overall, the SVM modal obtain a good result, root mean square is about 0.419661 is less than 0.5. Therefore, with the self-analysis of the Machine Learning technique the clutter can be remove and produce better image. First step, the literature on microwave imaging from the GPR system is produced. Secondly, we need to measure the scattering data with buried object and without buried object to make a comparison. In this research the image of the buried object under the Machine Learning technique can produce quality of image same as unburied object. Next, the transformation was converted to time domain. After that the focusing part of our project that is remove clutter. With the ML technique with “smart” algorithm SVR associated self-learning that analysis data and regression technique. The last the buried object image that produce is clear as the unburied image. Figure 14 show the flow of image construction of Machine Learning with SVR to classify the clutter and remove it.

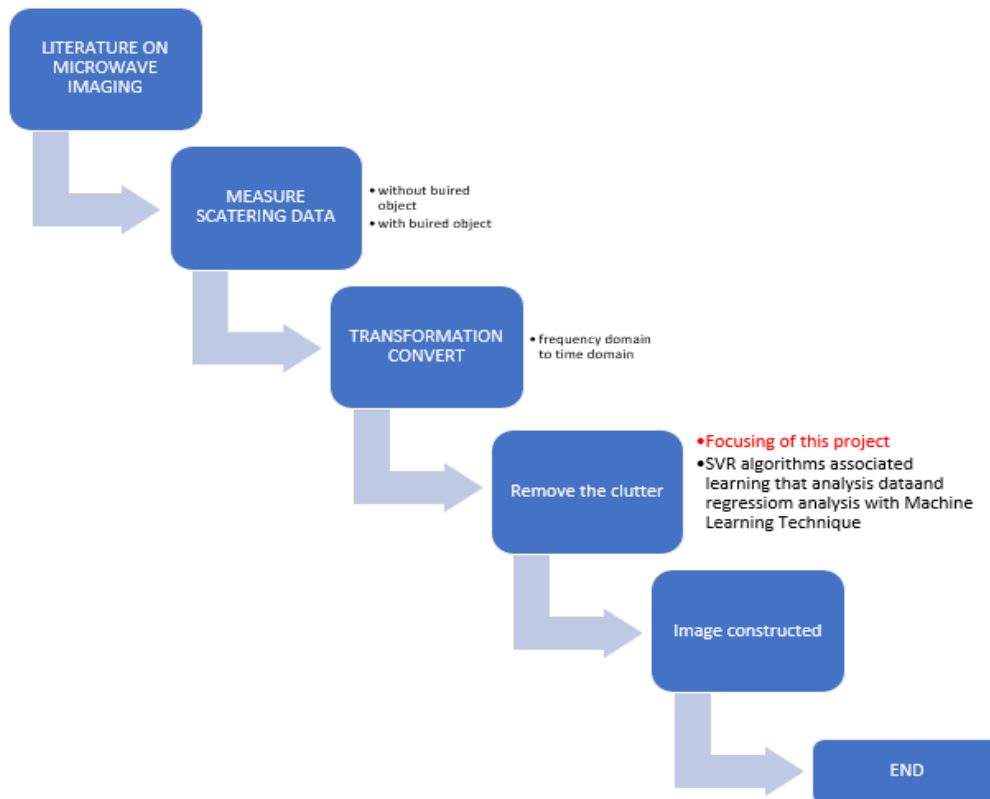


Figure 14 Flow of microwave imaging construction

## V. Conclusion

As a conclusion, by implementation of the Machine Learning (ML) technique to the Ground Penetrating Radar (GPR) system, the issue of the clutter that face by GPR system can be improve. Based on the comparison, Support Vector Regression was implement and this technique can give a better output to the image process and accuracy detection of the buried object. The “smart” self-learning technique is the key of the improvement output of the GPR system, but it is not a simple process and need a lot of data for the system to analysis. In this project the Machine Learning with SVR algorithm need to run in continuous-value to make sure that the output value process in continuously for the accuracy of detection of GPR system. Also, Machine Learning with SVR will help on minimize error and maximizes the margin.

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