EM SIGNATURE PREDICTION STUDIES USING MACHINE LEARNING

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Abstract *Stealth technology also termed Low Observable Technology (LO technology), is a sub-discipline of military tactics used to make aircraft, ships, submarines, missiles, satellites, and ground vehicles less visible (ideally invisible) to detectors. EM signatures are key parameters to detect Naval vessels. Generally, EM signatures are classified as Terrestrial and underwater signatures. RCS (Radar Cross Section) comes under the Terrestrial signature whereas Magnetics is an underwater signature. Radar cross section (RCS) is a stealth signature by which an object/target can be identified at longer ranges. Magnetic Signature is mostly exploited by Mines and Underwater vehicles for detection and detonation. The purpose of this paper is to predict the RCS signature and Magnetic Peaks by using Machine Learning algorithms and the data which is supplied to the Machine Learning algorithm is generated by using the RCS measurement tool.*
Key Words: *Stealth, Radar Cross Section, Magnetics, Prediction, Machine Learning.*

1.INTRODUCTION

We live in an electromagnetic (EM) wave environment, and radar system microwave frequencies comprise just a small portion of the EM spectrum. Regardless, light, radio, and microwave waves all obey the same physical principles. In the year 1900, the laws controlling the behaviour of EM waves were developed.

The EM waves that we are interested in are harmonic in both time and space, thus Maxwell's equations take on a certain form. The charge flux and pole flux stay at perpendicular to one another and also perpendicular to the direction of proliferation regardless of the source of radioactivity and replication. Both the charge flux and pole flux reach their extreme levels at the same time and location, and they also reach nil at the same time and place during their harmonic fluctuation.

When an EM wave impinges on a body, it causes oscillating charges and currents both within and on the body's surface. The generated charges and currents are restricted to the surface of a perfectly conducting substance, and at microwave frequencies, even a weakly conducting metal like steel approximates the behaviour of a perfect conductor. As a result, even if the body is a thin steel shell, there are no induced fields or charges within as long as the shell is closed [1].

EM signatures are classified as Terrestrial and underwater signatures. RCS is a Terrestrial signature whereas Magnetic signature is an underwater signature.

1.1 RCS Signature

A radar signature is information about a reflecting object's distinctive echo signals (target). It is the method for determining the type of object. RCS is important in object characterisation, particularly in military radar systems. RCS is highly reliant on the direction from which the radar illuminates the reflecting item. Characteristic variations are crucial in this case, which can also carry information regarding the target's elevation with respect to the radar. The usual method of obtaining the RCS signature is by the solution of Maxwell's equations, which is a physics-based technique. Methods of Moments, Microwave Optics, and Physical Optics are three of the most frequent numerical RCS prediction methods for any given three-dimensional object [2].

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The RCS prediction software programme, which is available at the workplace, may be used to predict the signature of an object. The object is first designed in CAD, and then simulation is performed on that CAD model. This technique is based on Physics.
In this study, RCS prediction is performed using a Machine Learning technique on basic designs such as FLATE PLATE, DIHEDRAL, and TRIHEDRAL, which may be extended to Naval vessels. The dataset needed to feed the machine learning model is created using the RCS prediction programme, which is available at work.
The entire algorithm is implemented in the MATLAB R2021a programming language. The Statistics and Machine Learning toolbox in MATLAB is used to discover the optimum method for the dataset.

2 PREPARATION OF DATASETS

A dataset is essential for solving any machine learning challenge. Some datasets are freely available on the internet, however this project dataset was developed from scratch. Simple forms such as Flat Plate, Dihedral, and Trihedral datasets are constructed for RCS prediction and stored in excel files. Machine learning datasets are made up of independent and dependent features. Before beginning the machine learning task, examine it for independent and dependent variables. The feature selection is critical in order to get more accuracy.
Independent variables such as frequency, length, and breadth are used to predict RCS signatures, whereas RCS at an angle is used as the dependent variable [3][4]. To obtain more accurate predictions, features can be further adjusted here. After gathering the three datasets for the three shapes, each dataset is loaded into the MATLAB regression learner application.

3 FLOWCHART

Flowchart for entire process is given below

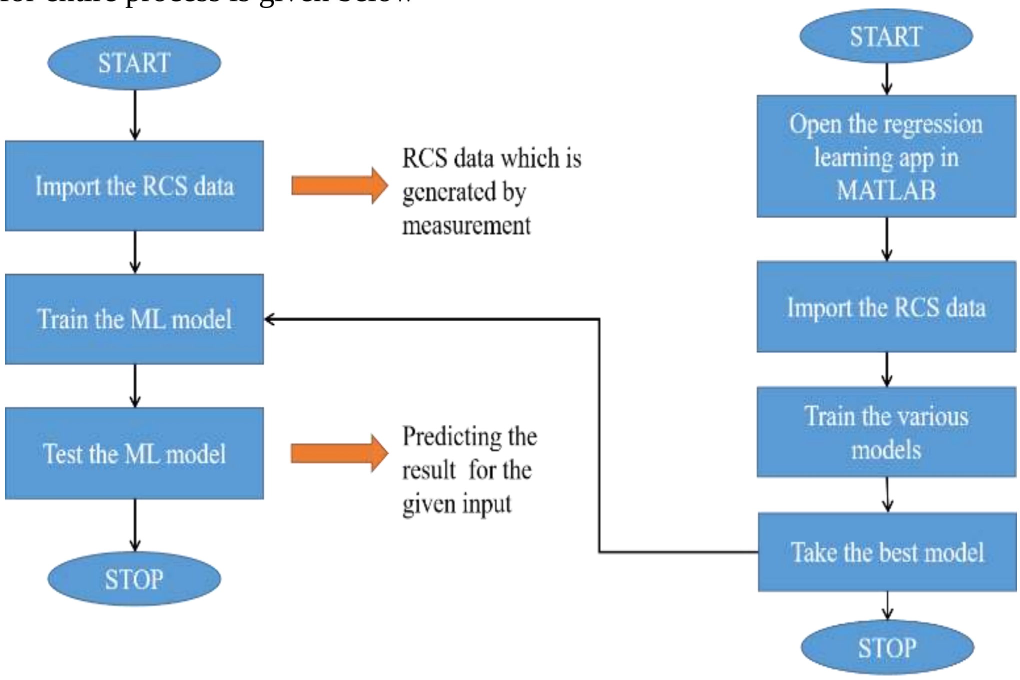

Fig 1: Flow Chart for Training and Testing

The flow chat overview is explained below

- In order to build the ML model open regression learning application in the MATLAB in that application we have to import the dataset this data is obtained or gathered from the prediction software which is available at the place of work.
- After importing the RCS dataset, Train various models in the regression learning application and find the best model for RCS prediction which is decided by the RMSE value. For the best model RMSE value is Low.
- After getting the best model, Import the model into MATLAB workspace as a function, further operations are done on that function to get the Predicted graph for unknown inputs.

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Repeat the process for different shapes (different datasets) such as Flat Plate, Dihedral and Trihedral. Train the various machine learning models in the Regression learner. Take the best model among them by analyzing the RMSE values of different available models.
For the flat plate dataset, the best Machine Learning model is Gaussian Process Regression (squared exponential), For Dihedral dataset, the best Machine Learning model is Gaussian Process Regression (Rational Quadratic) and for Trihedral dataset, the best Machine Learning model is Gaussian Process Regression (Rational Quadratic). These models are imported into Matlab workspace from the regression application.

4 RESULTS

To make use of Machine Learning algorithm, A GUI is created in the app designer which is available in the MATLAB.
In the GUI drop down box is arranged to select the shape. Numerical text boxes are arranged to enter the frequency in GHz, Length and Breadth in meters. After entering these values in the numerical text boxes, Compute button is enabled. On clicking that button Machine Learning computations will start to predict the RCS signature according to the inputs.

4.1 FLAT PLATE

If shape drop down is changed to Flat Plate, dihedral or trihedral according to the shape selected image is displayed. On selecting the Flat plate in drop down, Obtained GUI is shown in Fig 2.

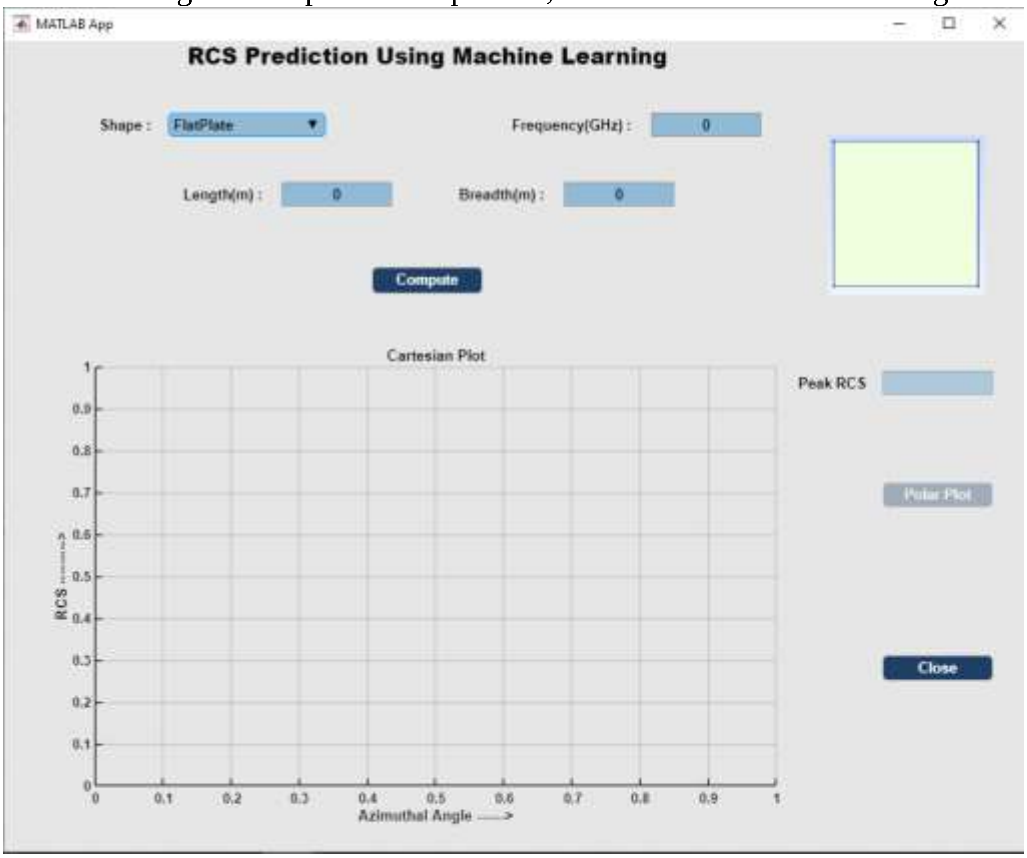

Fig 2 GUI is created in app designer for the RCS Prediction

Axis block is arranged such that predicted graph is displayed. In order to see the Polar Plot, a button on Right side is enabled. On clicking that button RCS signature is displayed in the polar coordinate system.
Frequency is taken as 9.4 GHz, length and breadth of a Flat Plate is taken as 1 meter. On computing these values RCS signature is obtained which is shown in Fig 3. This signature is obtained based on the Machine learning approach.
Computing the Flat Plate of 1m X 1m at a frequency 9.4GHz in the software tool, On computing RCS signature is obtained which is shown in Fig 4 which is physics based approach.

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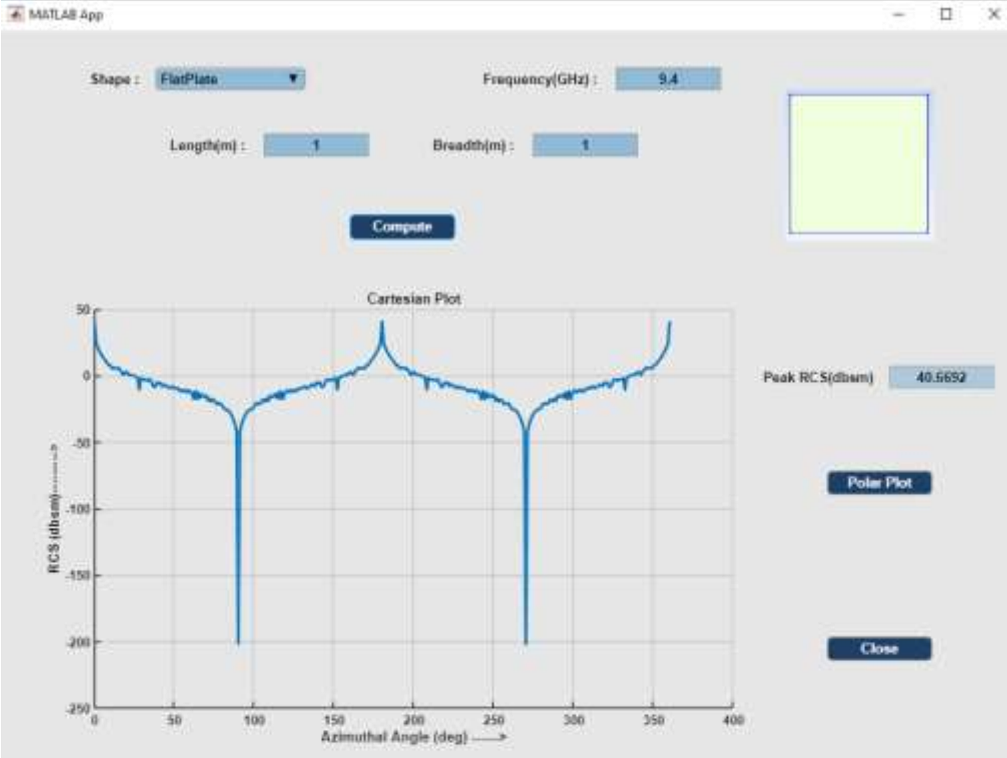

Fig 3 Machine Learning Prediction of RCS for FLAT PLATE with length = 1m and breadth = 1m at a frequency of 9.4GHz

Below figure shows the RCS prediction in the software which is available in the work place.

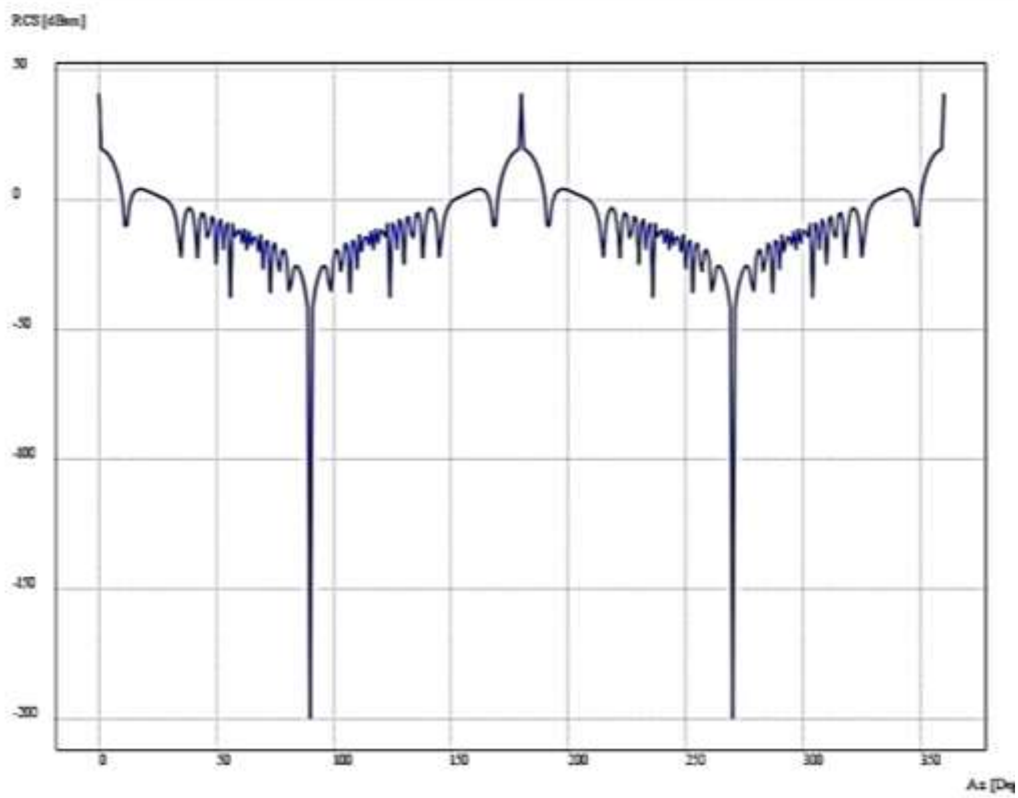

Fig 4 Software based Prediction of RCS for FLAT PLATE with length = 1m and breadth = 1m at a frequency of 9.4GHz

COMPARING FLAT PLATE RESULTS

Comparing the Peak RCS results which are obtained from the software and machine learning GUI tool.

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Peak RCS is taken as analyzing parameter in order to compare the results of both the reduction curves. In Software tool firstly Flat Plate CAD model should be drawn such that simulation will be held on that CAD model. But in the Machine learning GUI tool just entering the parameters is sufficient to predict the RCS signature.

Table 1 Comparison of Software and Machine Learning results for Flat Plat

Flat plate	Peak RCS in dBsm	Peak RCS in sm
Software Result	40.918	12353.78
Machine Learning Result	40.6692	11646.62
%Error	0.6%	5.7%

From the above table Software and Machine Learning GUI tool results of Flat Plate are compared at a frequency of 9.4GHz and dimensions of the Flat Plate is 1m x 1m. the error in both software and machine learning is 0.6% dBsm (decibels square meter) or 5.7% sm (Square meter)

4.2 DIHEDRAL

If shape drop down is changed to another shape such as dihedral or trihedral according to the shape selected image is displayed. Dihedral results are displayed below

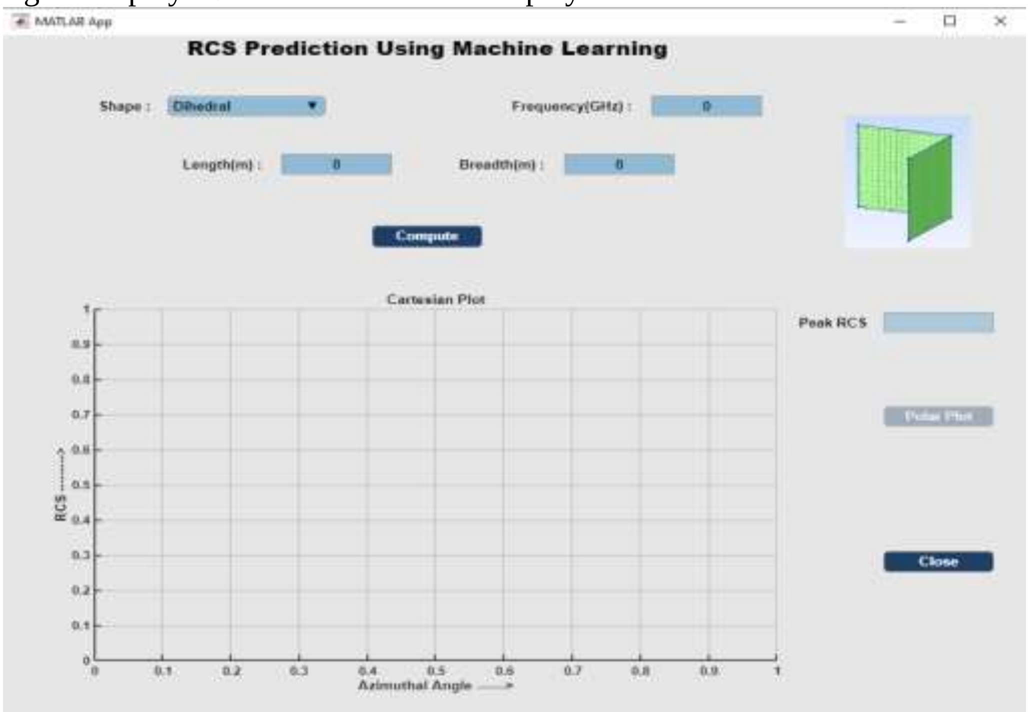

Fig 5 GUI where Shape is changed to Dihedral

Frequency is taken as 9.4 GHz, length and breadth of a Dihedral is taken as 1 meter. On computing these values RCS signature is obtained which is shown in Fig 6. This signature is obtained based on the Machine learning approach. Computing the dihedral of 1m X 1m at a frequency 9.4GHz in the software tool, On computing RCS signature is obtained which is shown in Fig 7which is physics based approach

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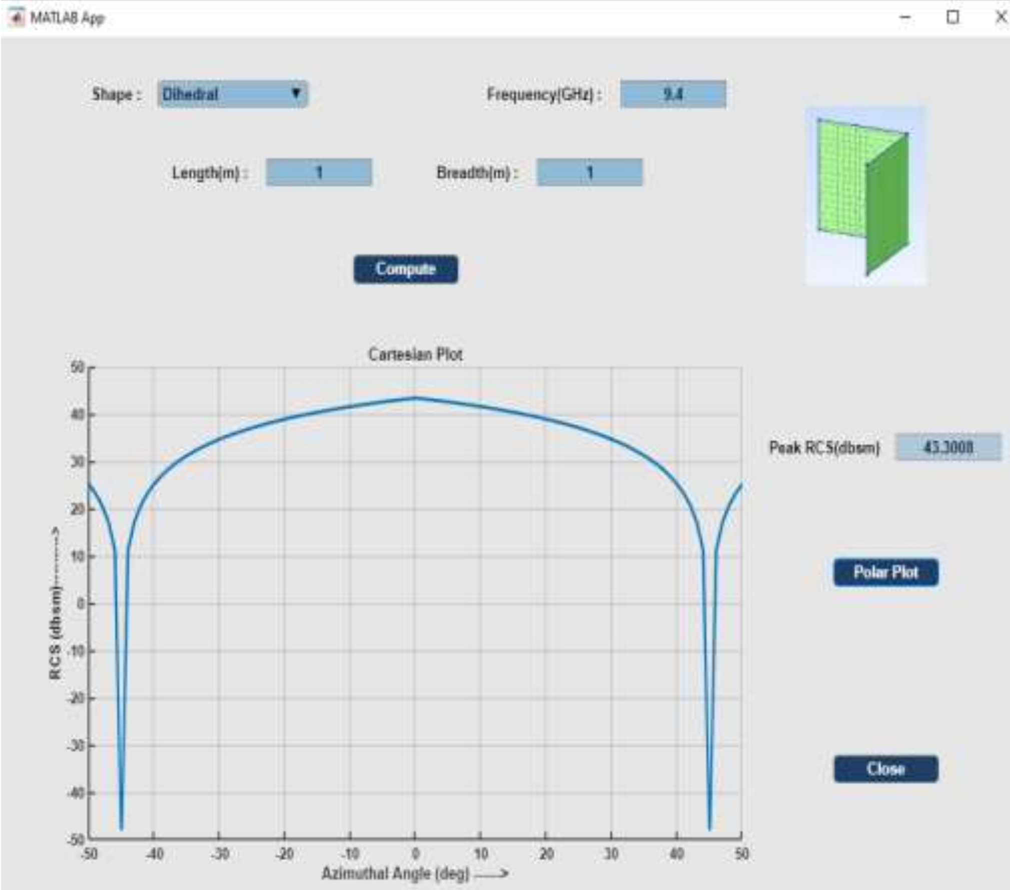

Fig 6 Machine Learning Prediction of RCS for Dihedral with length = 1m and breadth = 1m at a frequency of 9.4 GHz.

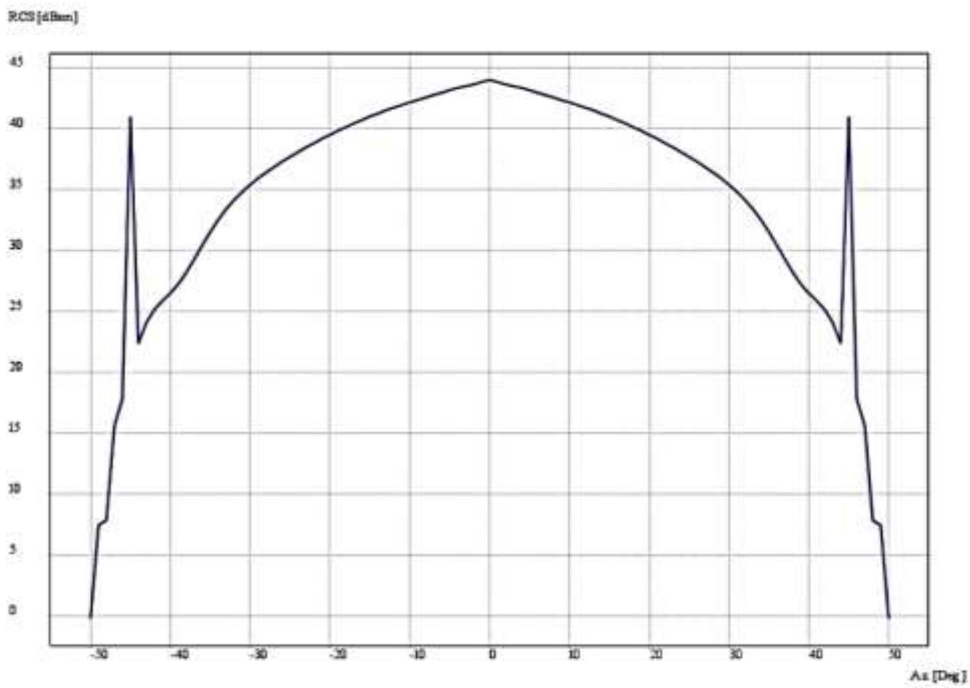

Fig 7 Software based Prediction of RCS for Dihedral with length = 1m and breadth = 1m at a frequency of 9.4GHz

COMPARING DIHEDRAL RESULTS

Table 2 Comparison of Software and Machine Learning results for Dihedral

Dihedral	Peak RCS in dBsm	Peak RCS in sm
Software Result	43.955	24859.93

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Machine Learning Result	43.3008	21383.559
%Error	1.4%	13.98%

From the above table Software and Machine Learning GUI tool results of Dihedral are compared at a frequency of 9.4GHz and dimensions of the Dihedral is 1m x 1m. the error in both software and machine learning is 1.4% dBsm (decibels square meter) or 13.98% sm (Square meter)

4.3 SQUARE TRIHEDRAL

If the shape is changed to Square Trihedral then Frequency and length (side length of trihedral) is enabled. After entering the required values compute button is enabled. On clicking compute button Machine Learning Computations will start. After computations are finished then graph is displayed on the axis.

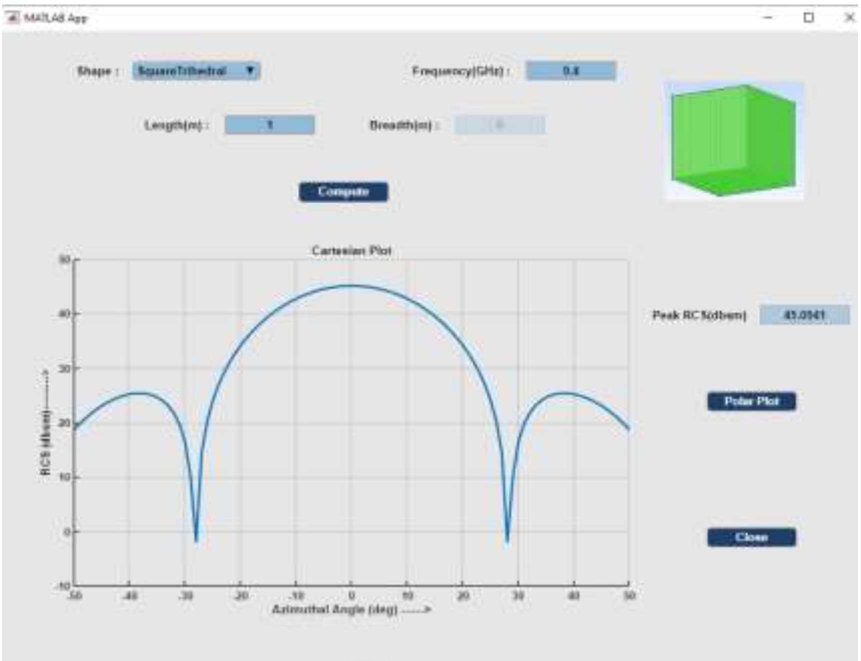

Fig 8 Machine Learning Prediction of RCS for Square Trihedral with side length of 1m at a frequency of 9.4 GHz

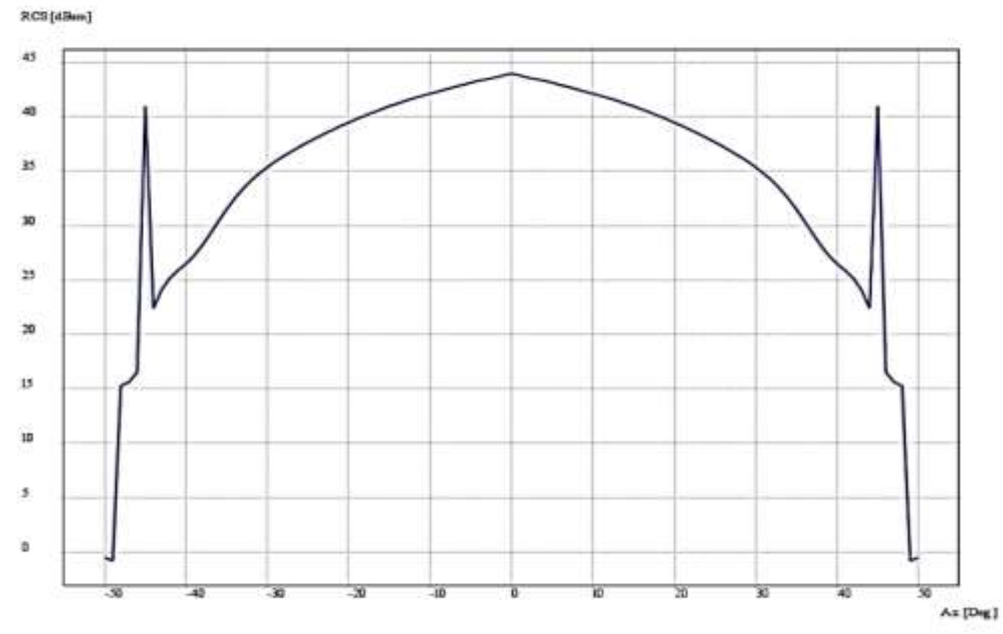

Fig 9 Software based Prediction of RCS for Square Trihedral with length = 1m at a frequency of 9.4GHz

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COMPARING SQUARE PLATE TRIHEDRAL RESULTS

Table 3 Comparison of Software and Machine Learning results for Square Plate Trihedral

Square Trihedral	Peak RCS in dBsm	Peak RCS in sm
Software Result	45.55	35892.19
Machine Learning Result	45.09	32284.94
%Error	1%	10%

From the above table Software and Machine Learning GUI tool results of Square Plate Trihedral are compared at a frequency of 9.4GHz and Side length of the Square Plate Trihedral is 1m. The error in both software and machine learning is 1% dBsm (decibels square meter) or 10% sm (Square meter).

5 CONCLUSION AND FUTURE SCOPE

The Project work "RCS SIGNATURE PREDICTION STUDIES USING MACHINE LEARNING" deals with signature prediction of simple objects using Machine Learning. Which can be further extended to Naval vessels and also another terrestrial and underwater signatures. This paper mainly focuses on RCS signature. Here RCS signature of simple objects is predicted using Machine Learning approach. Traditional way of predicting the signature is based on physics which is termed as physics based prediction but in this paper signature is predicted using Machine Learning.

For the RCS signature prediction, the simple objects such as flat plate, dihedral and trihedral data are taken. A GUI is designed in the app designer tool which is available in the MATLAB. From the GUI, user can select the shape, frequency and dimensions, correspondingly the tool will generate the RCS signature. It is a proof of concept that it can be further extended to the Naval vessels for the prediction of RCS signature and this concept is also applicable for the other type of signatures.

This project can be extended to other type of signatures such as magnetic signature and IR signature. To predict the exact signature of different EM signatures. Dataset is extended to increasing the accuracy or decreasing the RMSE (Root Mean Square Error) of the model. Increasing the independent features can also increase the accuracy.

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