COMPARISON OF ARTIFICIAL INTELLIGENCE MODELS TO PREDICT PHASES OF PATCH ARRAY ANTENNA

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Abstract - The present study introduces some artificial intelligence (AI) model for the lobe direction calculation of an antenna. Each model utilizes the direction of the lobe as input and the phases of antenna element as outputs. Thus, the lobe direction of the antenna is readily derived from the trained model's output, which is the phases of the antenna element. While, it's not easy to derive the phases of each antenna element from the desired lobe direction. For this purpose, Decision tree Regressor, chain SVM regressor and direct SVM regressor are three AI models used for simulation. 1280 lobe direction record for 8x1 array patch antenna were generated by changing the phases of the antenna element, and this set of data were utilized to train each model. The performance of the trained models is tested by estimating the Mean Absolute Error percentage (MAPE) for each. The obtained results are compared and direct SVM regressor model have the lowest MAPE value which provides its efficiency in lobe direction prediction.

Keywords - Artificial Intelligence, Lobe Direction, Microstrip patch array antenna, Machine Learning.

I. INTRODUCTION

Antenna is one of the main devices that are used in wireless communication. It receives and transmits signals. A plenty of application in our daily life depends on using antenna such as mobile phones, Wi-Fi routers, laptops, radios, TVs, cellular systems, satellite dishes and much more. Antenna has different type and shape designed according to the required characteristic [1]. In particular, microstrip patch antennas have been used popularly due to their conformal properties. One of the main antenna parameters is the radiation pattern. The radiation pattern of any array antenna depends on the amplitude and phase of the signal applied on each antenna element [2]. In case of patch array antenna, there is a direct link between each patch element. Therefore, it is strenuous to determine the amplitude and phase of each patch element to get the desired radiation pattern. Practically, it requires considerable time in order to synthesis different radiation pattern for the same antenna.

Not for long, artificial neural network has been applied to many research fields and applications. In particular, AI is used to solve some multioutput prediction cases and try to find best model fits each case. In [3] the supervised algorithm, support vector machine (SVR), was used to predict directivity, gain, radiation pattern and bandwidth of a rectangular microstrip patch antenna depending on some geometrical parameter as input. Moreover, the artificial neural network that uses radial basis functions as activation functions (RBFNN) was used to predict number of on and off elements of a planer array antenna in [4]. The convolution neural network (CNN) has been used to determine the phase of the excitation signal of the antenna element [5] also it is used to determine the directivity from the radiation pattern image [6]. In [7], decision tree machine learning model was used for multiband frequency selective surface synthesis using FSS structure that consist of array of patches. The used model was effective and accurate to complete the desired prediction. Moreover, the same method was effective to predict the azimuth and elevation angles of signals that hit on an antenna array in [8].Because of difficulties to determine the phase and amplitude of patch antenna element the researchers were motivated to developed the AI neural network which is most popular in this domain according to general-purpose nature, fast convergence rates, and new very large-scale integration (VLSI) implementations as in [9].

In this study, Decision tree Regressor, Chain SVM Regressor and Direct SVM Regressor were simulated to predict the phase of the excitation signal of antenna element. In section II, the design and antenna structure are described. Section III presents the data set analysis and derivation. The training of the three AI model presents in section IV. In section V, the outcome result of the models is compared in terms of RMSE. Finally, in section VI the conclusion is presented.

II. ANTENNA DESIGN AND STRUCTURE

Figure (1) describes the geometry of one patch element of the used antenna. Each patch element has same length and width (72 x 72 mm). The used substrate, upon which the antenna is affixed, is plexiglass with dielectric constant 3.4. the substrate was found to have dimensions of 54 mm in length and 55 mm in width.

The coaxial feeding point is at 0.45λ (55.1 mm) with respect to each patch.

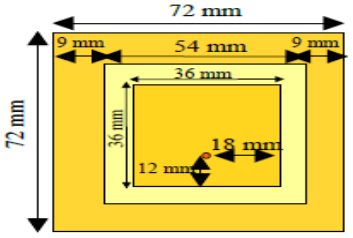


Figure 1: Geometry of single patch element.

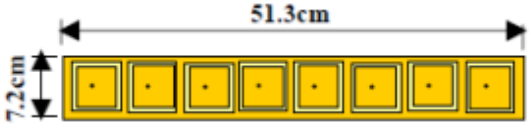


Figure 2: Structure of the simulated 8*1 patch array antenna.

Figure (2) above introduce the structure of the simulated antenna. The physical specifications of the 8*1 array antenna substrate were thoroughly examined and defined, revealing dimensions of 51.3 cm in length and 7.2 cm in width. The antenna itself stands at a height of 4 mm, and its structural integrity is maintained by a slender minimal thickness of just 0.5 mm. The antenna's dielectric properties were scrutinized, resulting in the establishment of key parameters: a relative permittivity εr=2.5 with an additional increment of 0.02 to account for any minor variations, and a loss tangent $tg\delta$=2* 10^{-2}. Furthermore, the central operating frequency for this antenna configuration was set at 2.45 GHz.
This patch array antenna was studied and designed to be used in data collecting.

III. EXTRACTION OF DATASET

The radiation pattern that presents the direction of the main lobe is detected by the variation of each phase on each excitation patch in the used antenna. The 8*1 patch array antenna described in section II was used to determine the dataset. Antenna array factor calculator is used to simulate the radiation pattern of the desired antenna array. It's an online software that takes configuration of antenna structure and give the radiation pattern. The used software gives the radiation pattern depending on the following equation [10]:

$$Rp = r(\theta, \emptyset) = \sum_{i=0}^{n} I_i e^{j(k\, x_i \sin\theta \cos\emptyset + \emptyset_i)}$$

Rp: radiation pattern value
n: number pf patch element
I: Amplitude
k: related to frequency and lambda where k= $2\pi/\lambda$
x: position of the patch
theta θ: position angle constant
phi $\emptyset$: phase of each patch

Based on the following equation and variable the data set was derived by the software. The variable factors were the radiation pattern and the phases else, each other factor was fixed to well analyses the variation.

The variation of lobe direction depends mainly on the amplitude and phase of the signal on each excitation. In this data set, amplitude is constant (I=1) for the eight-excitation signal. The lobe direction varies as phases of signals change. The input (main lobe direction) is presented in unit of degree ranging between -90 and 90 degrees. Additionally, the intensity of the lobe in the radiation pattern was expressed in dB; however, the output (phases) ranging from 0 to 180 degrees.

The data set consists of 1280 record. Each record consists of 1 input (direction of lobe) in degree and 8 outputs (phases) in degree. The phases vary in linear mode where the difference between each 2 consecutive excitation is equal.

Before the simulation starts, some parameters must be defined in the used software. Assign frequency at 2.45 GHz. According to the designed antenna the number of elements will be 8. The inter-element distance is 55.1025 mm. the position of each excitation will be assigned automatically. The amplitude is constant equal 1. Then in each case change the phases in linear mode to get the lobe direction with the maximum amplitude.

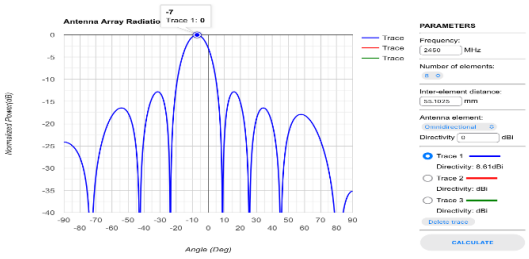


Figure 3: Radiation pattern for one record example.

Figure (3) shows the radiation pattern of a specific record. In this case, the difference between phases is 20 degrees where the phases of the excitation signals are (0, 20, 40, 60, 80, 100, 120,140) respectively. The following radiation pattern shows one main lobe at 0 db. The lobe direction is at -7°.
Three different machine learning model are used in section IV to train and simulate the following dataset.

IV. ARTIFICIAL INTELLIGENCE MODELLING AND TRAINING

Three different machine learning models are chosen to train the dataset. It's necessary to precise the type and the number of input and output of the model. In this case study, data set is divided into 1 input which is the

direction of main lobe and 8 outputs the phases of excitation signal of each patch. Decision tree Regressor, Chain SVM Regressor and Direct SVM regressor models are used. These models considered a multioutput regression model.

Decision tree regressor works by splitting the dataset into smaller subset and start validate and calculate values to reach nearest possible predicted value. In the following case study, the model use k- fold cross validation method to split the data. Then, after consecutive split, tree will be built and prediction starts from the first node reaching the last node leaf which will be the predicted value.

On the other hand, Support vector machine model (SVM) is a supervised machine learning model that deals good with a small and complex data set. This model is divided into two types direct and chain SVM model. The direct approach to multioutput regression involves dividing the regression problem into a separate problem for each target variable to be predicted. While the chain SVM model develop a sequence of dependent models to match the number of numerical values to be predicted.

k-fold cross-validation method is used to evaluate the multioutput regression models. This method uses to split training data into k folds where k is a selected number. For each split the model also change the validation set and calculate the error metric. Finally, the result will be the average of error metric depending on number of folds used.

The three models applied for the test problem use 5 and 10-fold cross-validation with three repeats. Moreover, mean absolute error percentage (MAPE) was used to compare the model efficiency. These models where simulated using python code using PyCharm software. The results of the simulation presented in section V.

V. RESULTS AND DISCUSSION

Table (1) shows the simulation result of decision tree regressor, Chain SVM and Direct SVM regressor model. MAE is the mean absolute error. To be more accurate, this value was also calculated in terms of percentage to compare well the values.

Machine learning models	MAE	Number of splits in repeated k-fold	MAPE (%)
Decision Tree Regressor	134.818 143.226	10 5	25.1% 20.43%
Chain SVM Regressor	208.424 212.814	10 5	15.7% 18.1%
Direct SVM Regressor	156.995 156.842	10 5	12.78% 12.61%

Table 1: Comparison of different machine learning model in terms of MAPE (%).

Running the example evaluates the performance of the decision tree model for multioutput regression on the test problem. At 10-folds the MAPE was 25.1% while at 5-folds it was more effective with 20.43% error. However, the simulation of the chain SVM model gives less MAPE values. It was 15.7% at 10-folds and 18.1% at 5-folds. The percentage of error decreases more in Direct SVM model. It was 12.785 at 10-folds and 12.61% at 5-folds.

By comparing percentage of error (MAPE), Direct SVM model have the less error percentage. Unfortunately, this model proves its efficiency in predicting the convenient phases for each antenna patch to get the desired radiation pattern.

V. CONCLUSION

By conclusion, artificial intelligence really shows its effectiveness in solving conflict problems and calculations. As in literature review, it was used to support communication systems as antenna in different ways. Moreover, in our case it was used to predict the phases of the 8-element patch antenna from the radiation pattern. It helps to go in inverse direction where most virtual antenna simulation software can give the radiation pattern from the phases, these software work in one direction. This work shows the efficiency of direct SVM regressor model to predict the desired values by the less error of MAPE value 12.61%. For future work, this value can be improved and be more efficient by using the deep neural network algorithms.

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