Journal of Artificial Intelligence and Data Science (JAIDA)
e-ISSN: 2791-8335
https://dergipark.org.tr/pub/jaida

Vol. 2, No. 2, pp. 87-93, 2022
Research Article

Diagonal L-Shaped Slotted Antenna Design for 2.4 GHz Wireless Applications with Machine Learning Based Reflection Coefficient Calculator GUI

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Abstract
In this study, a machine learning assisted microstrip antenna design for a 2.4 GHz Wi-Fi frequency band has been designed and numerically calculated. The proposed antenna design has been carried out using an electromagnetic field solver CST, different design parameters have been determined and because of parametric calculation, data suitable for machine learning algorithms have been obtained. According to the different values of 4 design parameters, 625 different antenna reflection coefficients at the 2.4 GHz frequency band were obtained in linear and decibel forms for the machine learning-based design. 4 different machine learning regression algorithms (linear regression, support vector regression, decision tree, and random forest) have been used to estimate the reflection coefficient at 2.4 GHz. The machine learning results have been examined, it has been achieved that the best prediction performance model had R2 value of 0.8 and a mean squared error value of 0.2 for the S11 in dB form, and R2 value of 0.98 and a mean squared error value of 0.02 for the linear S11. In addition, a PyQt based graphical user interface is presented, which can instantly estimate the reflection coefficient with different machine learning techniques depending on the design parameters of the proposed antenna.
Keywords: Microstrip Antennas; Antenna Design; Wi-Fi Technology; Machine Learning; Regression Algorithms; GUI Design.

1. Introduction

With technology development, the importance of wireless communication technology has increased significantly. Also, in recent years, the rapid developments in technology have also led to an increase in the variety of modern devices in which wireless communication technology has been used [1]. One of the most essential parts of these wireless systems is antennas. The increase in the variety of modern devices using wireless communication technology makes it necessary to design compact antennas [2]. In recent years, microstrip antennas have become more popular and are increasingly being used in many fields because they have characteristics such as light weight, ease of production, and low production cost. For this reason, microstrip antennas are often preferred in the field of wireless communication technology [3]. Microstrip patch antennas for home, office and industry are among the many bands used in mobile systems used in their applications; the ISM (Industrial, Scientific, and Medical) band, which covers the range of 2400-2485 MHz, is the most widely used. A wireless network developed by the Institute of Electrical and Electronics Engineers, IEEE, Wireless Local Area Network (WLAN) the general name of the standard is IEEE 802.11, and the WLAN standard operating in the ISM 2.4 GHz band is defined as IEEE 802.11b and IEEE 802.11g [4]. Microstrip antennas consist of the radiation layer, the dielectric layer, and the soil layer. The underlying soil layer is conductive, and it allows microstrip antennas to emit one-way radiation. The middle layer consists of a dielectric material and ideally, its dielectric constant must be less than 2.5. In dielectric material, the thickness varies from 0.05 mm to 6.35 mm. The thickness of this layer and the dielectric constant directly affect antenna parameters such as radiation values and bandwidth. To improve the performance of the antenna should be selected the low dielectric constant and a thick dielectric layer. The top layer is usually made of gold, silver, or copper it is the conductive layer for the antenna emitting radiation. Its thickness varies from 0.035 mm to 0.070 mm [5].

In recent years, machine learning has been used in many fields: automotive, medical, entertainment, marketing, speech recognition technologies, and much more [6]. Machine learning is a subset of artificial intelligence that aims to create a mathematical model using known input and output data [7]. Machine learning algorithms can be divided into 4 categories, each of which is designed for a different purpose. For example, supervised learning is intended to scale the scope of data and make predictions based on it. On the other hand, unsupervised algorithms organize and filter data to make sense. Machine learning algorithms are supervised learning, unsupervised learning, semi-supervised learning, and reinforcement learning. In the last decade, machine learning algorithms have been widely used to adapt not only antenna designs but also many microwave components more easily and

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Received: 04/08/2022; Accepted: 08/11/2022

increase performance [2, 8 - 11]. The electromagnetic field solver used in this process meets the need to produce the exact results, but these solvers cause a lot of time to spend on the antenna design process. Also, antenna designs developed using machine learning are expected to produce faster and more optimized results. Because, using the dataset obtained from the proposed antenna, thousands of results of the proposed antenna can be estimated. The same results can also be calculated using electromagnetic simulation programs, but this becomes difficult because it will take a very long time [6].

The paper is established in the following manner. The antenna model parameters and numerical calculation results of the proposed antenna are explained in Section 2 with the machine learning assisted design. The numerical results of the machine learning assisted design are given in Section 3. The concluding remarks are conducted in Section 4.

2. Methodology

2.1. Diagonal L-Shaped Slotted Antenna Design

The geometrical configuration of the proposed antenna in this study is given in Figure 1. The proposed antenna has a resonance frequency of 2.4 GHz. This frequency band is used as the Wi-Fi frequency band, according to IEEE 802.11 standards. To reduce the cost of the developed antenna design, FR-4 material has been selected as a substrate. The FR-4 material used has a thickness of 1.6 mm, a dielectric constant of 4.3, and a loss tangent of 0.02. Copper has been used with a thickness of 0.035 mm for the antenna radiation and ground layers. The geometric dimensions of the proposed antenna are given in Table 1.

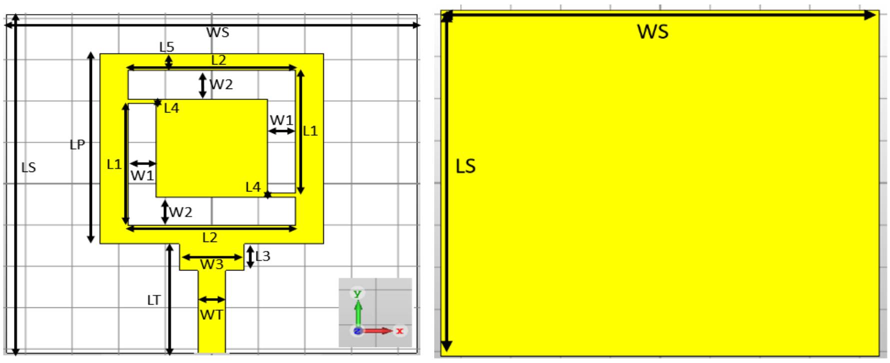


Figure 1. Front View and Back View of Proposed Antenna

Table 1. Dimensions of Proposed Antenna

LS	LP	LT	L1	L2
41 mm	23 mm	13.2 mm	14.8 mm	18 mm
L3	**L4**	**L5**	**WS**	**WP**
3.2 mm	0.5 mm	2 mm	44 mm	24 mm
WT	**W1**	**W2**	**W3**	
3 mm	3 mm	3.5 mm	7 mm	

The method of feeding microstrip antennas affects the performance of the antenna such as bandwidth, antenna gain, and antenna reflection coefficient. Basically, microstrip feeding, coaxial feeding, coplanar waveguide feeding, proximity-coupled feeding, and aperture-coupled feeding [12]. The antenna design developed is fed using the microstrip line feeding method. The design process of the proposed antenna is carried out using CST Studio Suite Electromagnetic Field Simulation Software. Also, important parameters of the antenna have been examined. The reflection coefficient result (S_{11}) of the proposed antenna design developed is given in Figure 2.

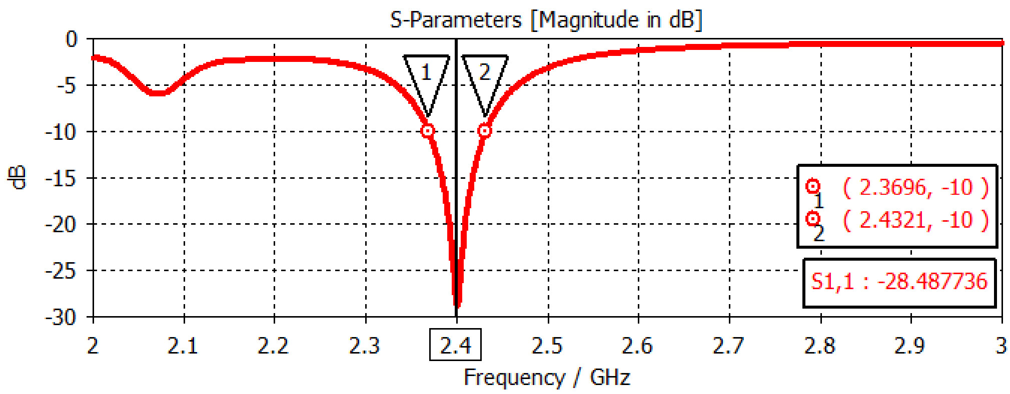


Figure 2. S_{11} Parameter of Proposed Antenna

2.2. Machine Learning Assisted Antenna Design

The following steps should be followed when performing machine learning-assisted optimization in antenna design. First, an antenna design should be developed. Then, using electromagnetic simulation programs, multiple number simulations of the antenna design developed by changing the different design parameters of the antenna should be performed. In this case, the electromagnetic characteristic of the antenna is obtained. Later, various machine learning algorithms should be developed for use in antenna optimization. Finally, the machine learning algorithms that have been developed are trained using the data that has been obtained [12]. As a result, the estimation of the antenna's performance can be performed without the need for electromagnetic simulation programs. Thus, antenna optimization can be achieved in less time.

Many machine learning algorithms are used in the field of antenna design, the most used algorithms are supervised algorithms [8]. In this study, more than one machine learning algorithm has been developed. These are linear regression, support vector regression, decision tree, and random forest. In addition, polynomial regression is added to the developed algorithms. The relationship between variables in the dataset may not always be linear. In such cases, it may be useful to apply to polynomial regression. So polynomial feature option has been added to the developed algorithms. At the training stage, more accurate prediction results can be obtained using the transformed dataset by selecting the desired polynomial degree. Also, an interface design has been developed using PyQt Designer to provide more comfortable use for the user about antenna optimization. The interface design shown in Figure 3 includes the following: 4 different machine learning algorithms, training can be done by adding the desired level of polynomial feature for the desired algorithm, and the training results for the desired algorithm can be displayed instantly at the desired polynomial degree and the reflection coefficient of the proposed antenna can be estimated for specific design parameters values.

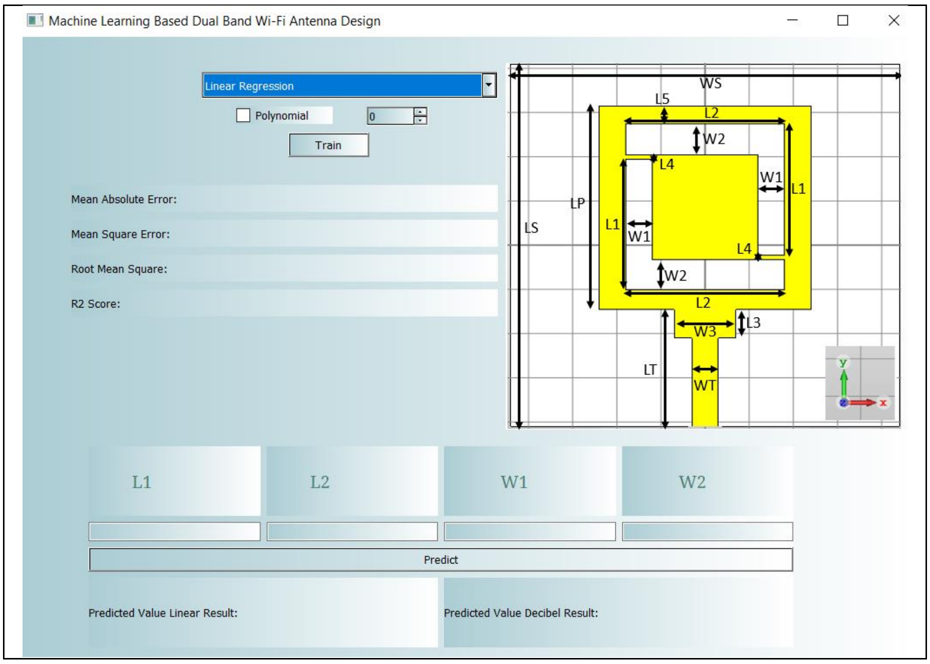


Figure 3. Graphical User Interface (GUI) Design with PyQt Designer

As a result, in this study, machine learning-assisted optimization has been achieved by above the steps mentioned. The steps followed in this study are shown in Figure 4. The prediction performance of the developed machine learning algorithms has been examined and the algorithm with the best prediction has been selected. The tables of these results are given in the next section. The design parameters used to obtain the electromagnetic characteristic of the proposed antenna and their rates of change are given in detail in Table 2.

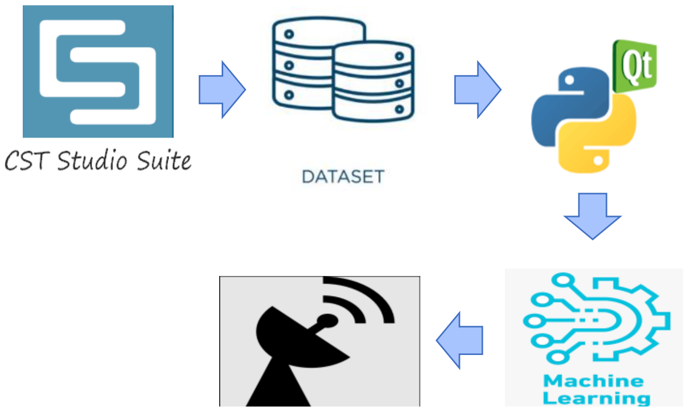


Figure 4. Work Follow-up Chart of Study

Table 2. Antenna Design Parameters for Dataset

Parameter	Change Rate (in mm)	Step Size (in mm)	Number of Samples
L1	[13.8 - 15.8]	0.5	5
L2	[11 - 15]	1	5
W1	[1 - 5]	1	5
W2	[2.5 - 4.5]	0.5	5
	Total Data:	625	

4. Results

Linear regression, support vector regression, decision tree, and random forest algorithms have been developed in a python environment to provide antenna optimization in this project. The prediction results of these algorithms are given in the following tables. The results of the reflection coefficient of the proposed antenna have been taken in linear and decibels forms. Table 3 shows the prediction results for linear regression according to decibel and liner results of the reflection coefficient. Tables 4, 5, and 6 show the prediction results for support vector regression, decision tree, and random forest algorithms in the same order for the decibel and linear reflection coefficient.

Table 3. Results of Linear Regression Algorithm for

a) dB dataset

Mean Absolute Error	0.604
Mean Squared Error	0.670
Root Mean Squared Error	0.818
R Square Value	0.330

b) Linear dataset

Mean Absolute Error	0.545
Mean Squared Error	0.457
Root Mean Squared Error	0.676
R Square Value	0.543

Table 4. Results of SVR Algorithm for

a) dB dataset

Mean Absolute Error	0.373
Mean Squared Error	0.529
Root Mean Squared Error	0.727
R Square Value	0.471

b) Linear dataset

Mean Absolute Error	0.29
Mean Squared Error	0.199
Root Mean Squared Error	0.446
R Square Value	0.80

Table 5. Results of Decision Tree Algorithm for

a) dB dataset

Mean Absolute Error	0.170
Mean Squared Error	0.155
Root Mean Squared Error	0.394
R Square Value	0.845

b) Linear dataset

Mean Absolute Error	0.064
Mean Squared Error	0.005
Root Mean Squared Error	0.075
R Square Value	0.97

Table 6. Results of Random Forest Algorithm for

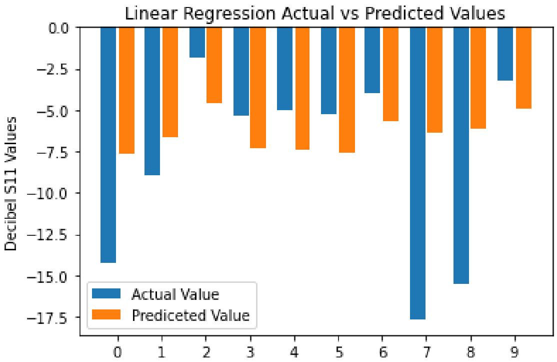
a) dB dataset

Mean Absolute Error	0.242
Mean Squared Error	0.197
Root Mean Squared Error	0.444
R Square Value	0.803

b) Linear dataset

Mean Absolute Error	0.099
Mean Squared Error	0.017
Root Mean Squared Error	0.131
R Square Value	0.983

The prediction results of the reflection coefficients (linear and dB forms) of the proposed antenna design are presented in this section. Linear (Figure 5), Support Vector (Figure 6), Decision Tree (Figure 7), and Random Forest (Figure 8) regression techniques have been implemented, respectively. Using 10 test data, prediction performance difference graphs of machine learning algorithms are presented in figures.



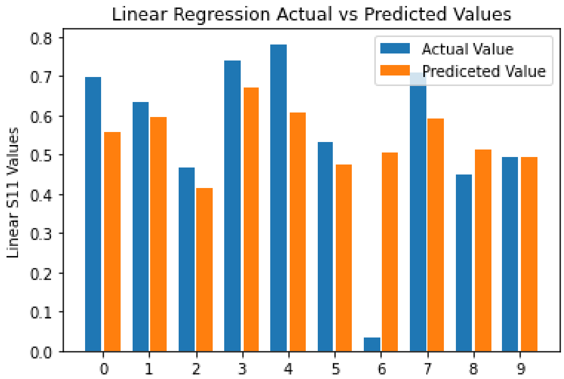


Figure 5. Actual / Predicted Values for dB and Linear Dataset in Linear Regression Algorithm

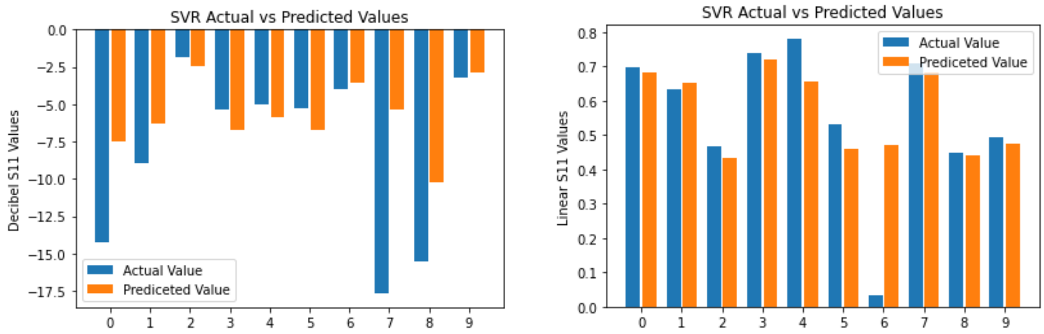


Figure 6. Actual / Predicted Values for dB and Linear Dataset in Support Vector Regression Algorithm

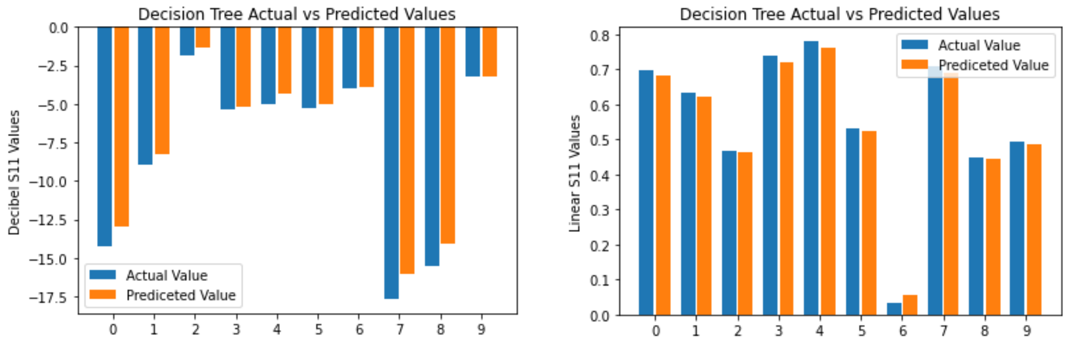


Figure 7. Actual / Predicted Values for dB and Linear Dataset in Decision Tree Algorithm

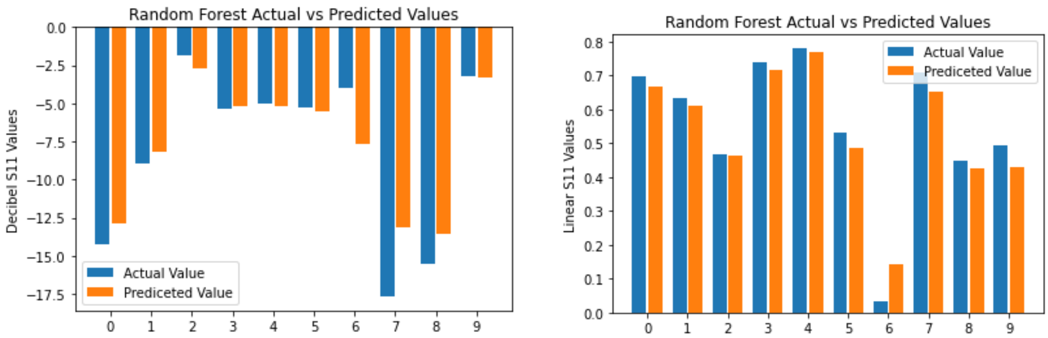


Figure 8. Actual / Predicted Values for dB and Linear Dataset in Random Forest Algorithm

5. Conclusion

In this study, firstly, a microstrip antenna design with a resonant frequency of 2.4 GHz has been realized that can be used in Wi-Fi applications. The proposed antenna design has been fed using the microstrip line feeding method. FR-4 has been used as the dielectric material and copper has been used as the radiating surface. The simulation stages have been carried out in the CST Studio Suite. Secondly, the electromagnetic characteristic of the antenna developed using CST is obtained. Therefore, by changing 4 different design parameters, a dataset consisting of 625 samples showing the change of antenna reflection coefficient has been obtained. The dataset has been divided into 0.2 test and 0.8 training. Thirdly, the Machine Learning algorithm, which is necessary for estimating the performance data of the antenna, has been developed in the Python environment with 4 different machine learning algorithms, Linear Regression, Support Vector Regression, Decision Tree, and Random Forest. The prediction results of these algorithms have been examined and the prediction algorithm that gives the best result has been selected. That algorithm is the Random Forest machine learning algorithm. As shown in table 6.b, random forest algorithm has highest R^2 value with 0.983. Also, it has lowest error values with MAE is 0.099, MSE is 0.017 and RMS is 0.131. The results have been examined by running the developed algorithm. It has been observed that the obtained results have an acceptable level of predictive performance. Also, it has been observed that the accuracy of the algorithm increases when the dataset recorded as linear is used in the prediction algorithm.

Antenna optimization will be achieved in quickly, using the obtained machine learning algorithm without the need for long-time simulation stages. Finally, an interface design has been performed using PyQt Designer. Thus, this graphical user interface design and prediction results of the antenna reflection coefficient can be performed using all the algorithms that have been developed.

Acknowledgements

This study has been carried out using the laboratory facilities of İzmir Katip Çelebi University Smart Factory Systems Application and Research Center (AFSUAM). An earlier version of this paper was presented at the ICADA 2022 Conference and was published in its Proceedings (Title of the conference paper: "Diagonal L-Shaped Slotted Antenna Design for 2.4 GHz Wireless Applications with Machine Learning Based Reflection Coefficient Calculator GUI")

Declaration of Interest

The authors declare that there is no conflict of interest.

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