Artificial Intelligence Methods Used in Microstrip Antennas

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Introduction

Recently, with the development of computer technologies, artificial intelligence has succeeded in changing the foundations of numerous industries and fields of work, including the design and optimization of antennas. The fact that artificial intelligence methods work effectively in complex, unsolved problems and perform classical calculations quickly and efficiently has led to a rapid rise in the literature. Classical optimization algorithms, one of the solution ways of artificial intelligence methods, can be applied to multidimensional problems and provide short-term and effective solutions from classical analytical approaches in antenna design.

The increasing use of microstrip antennas in satellite communication systems and their compatibility with the place they are used create an incentive for antenna designers to try original design methods in different geometries. In order to improve the disadvantages of microstrip antennas such as narrow bandwidth and low gain, new production methodologies are developed by making different studies on the physical and electrical parameters of antennas.

Approaches that do not require much calculation time by using artificial intelligence methods have enabled the realization of different microstrip antenna designs working with high efficiency in the literature.

Today, the increasing use of microstrip antennas in the electronic communication market makes it essential to use simpler and more effective methods for performance analysis. Many related technologies are needed to operate microstrip antennas with high efficiency in desired environments. Therefore, in recent studies in the literature, microstrip antenna designers prefer simple approaches that do not require much computation time. With the rapid developments in computer science, artificial intelligence methods inspired by nature and artificial intelligence-based techniques such as artificial neural networks and optimization algorithms, called heuristic algorithms, have become powerful alternative tools that produce more flexible and useful results.

There are parameters such as geometric shape, operating frequency, bandwidth, etc. of the microstrip antenna, which greatly affect the antenna performance. Microstrip antennas are designed in many ways for the place and purpose of use. Since most of the studies presented in the literature are easy to analyze and design, there are studies on known geometries such as rectangle, triangle and circle. However, since the dimensions of microstrip antennas with these known geometries are relatively large for high bandwidth applications, designs in other geometries are also carried out.

Antenna Designs Using Artificial Intelligence Methods

Jayasinghe et al.,(2015) a non-uniform aliasing method is applied together with the Genetic Algorithm, which shows significant improvements in the desired bandwidth of the proposed patch antenna design.

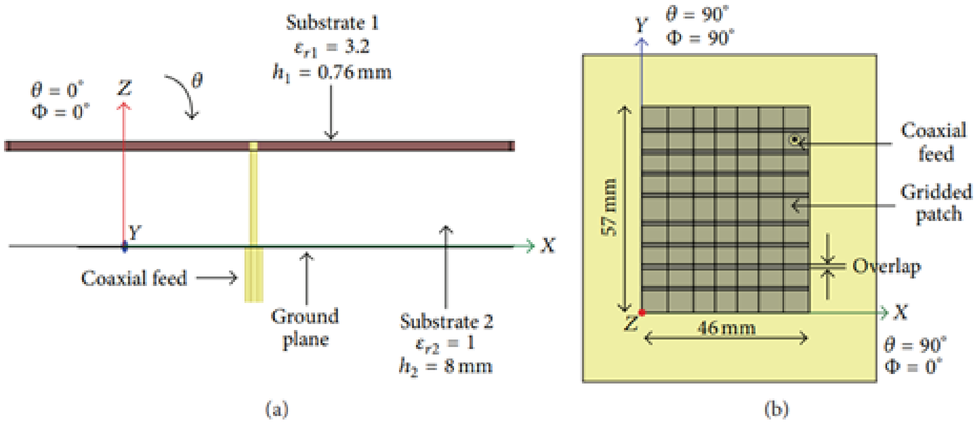

Figure 1. Antenna configuration. (a) Side view of the antenna. (b) 63-cell split patch

The fitness function for the genetic algorithm is identified as the sum of the reflection coefficient values taken in the frequency ranges. The desired problem solving frequencies for the microstrip antenna problem range from f_1 to f_4. The $L(f_i)$ parameter evaluates the reflection coefficient according to the desired frequency. The fitness function created for the antenna problem is defined in such a way that broadband solutions are preferred over the narrow bandwidth disadvantage solution with the least reflection coefficient values. N, total number of samples, and IF values shown in the equation represent frequency ranges.

$$-\frac{\sum_{fi=f1}^{f2} L(fi) + \sum_{fi=f3}^{f4} L(fi)}{IF.N} \quad (1)$$

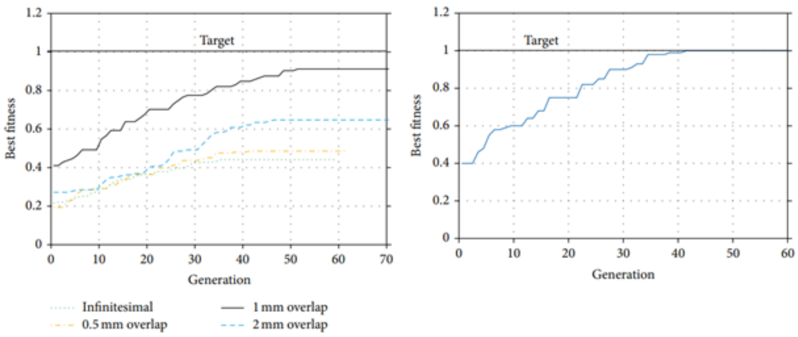

Figure 2. Best fit for generations. (a) For infinitesimal connections and smooth overlaps (b) For uneven overlaps.

The optimized design achieved using fixed overlap sizes shows quad-band performance covering GSM1800, GSM1900, LTE2300 and Bluetooth bands. In contrast, using non-uniform overlapping sizes has resulted in a pentaband design with a fractional band of 38% covering the GSM1800, GSM1900, UMTS, LTE2300 and Bluetooth bands in order to extra design flexibility.

In the study conducted by Gangopadhyaya et al., 2015, Differential Evolution algorithm was applied to optimize the resonance frequencies of the inline fed rectangular microstrip patch antenna, considering the geometric design parameters such as patch length, patch width and infeed line length as unknown variables. Simulations were made with Zeland IE3D software for different microwave frequencies (3 to 18 GHz) for optimized antennas.

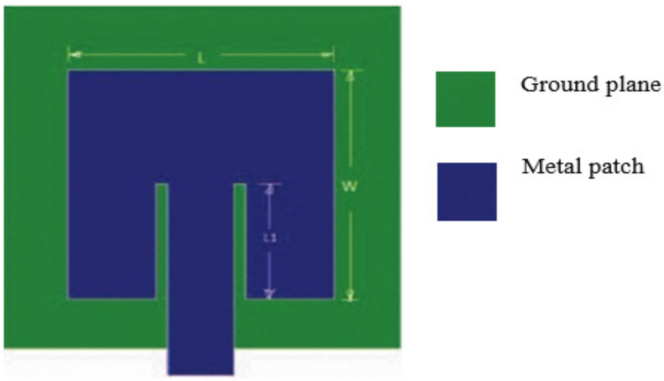

Figure 3. Microstrip Line Feed Rectangular Microstrip Antenna

The fitness function of the optimization algorithm is shown below. Here f_0 is the desired resonance frequency (3-18 GHz), L_r is the desired return loss, F_0 and L_0 are the optimized resonance frequency and return loss, respectively.

$$Fitness\ Function = |f_0 - F_0| + |L_r - L_0| \quad (2)$$

The obtained results show the effectiveness of the Differential Evolution Algorithm for the optimization of the infeed microstrip patch antenna. Figure 4 shows that the convergence speed of the algorithm from the best fit graph of DE is significant and effective. The DE algorithm appears to be a promising approach for antenna problems involving optimization and minimization.

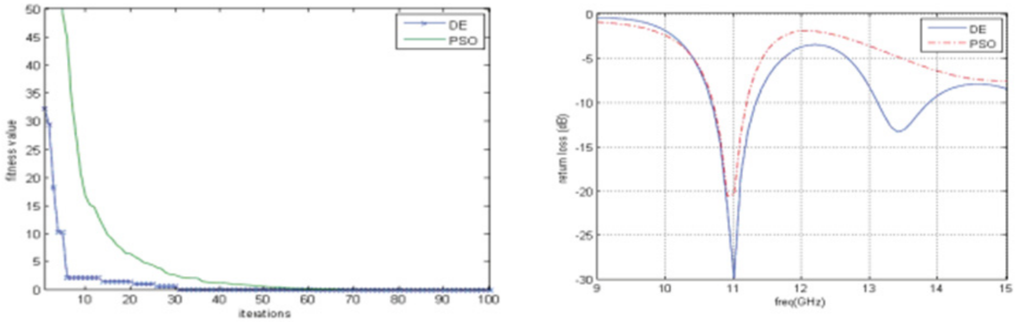

Figure 4. Comparison of differential algorithm and particle swarm algorithm used in optimization

In the study by Islam et al.,(2009), an inverted E-shaped microstrip patch antenna designed for the IMT-2000 band (2.1GHz) was designed to demonstrate an optimization technique using Particle Swarm Optimization (PSO) with Curve fitting. Curve fitting data was designed from Zealand IE3D software as in Figure 5 by varying different geometric parameters of the antenna.

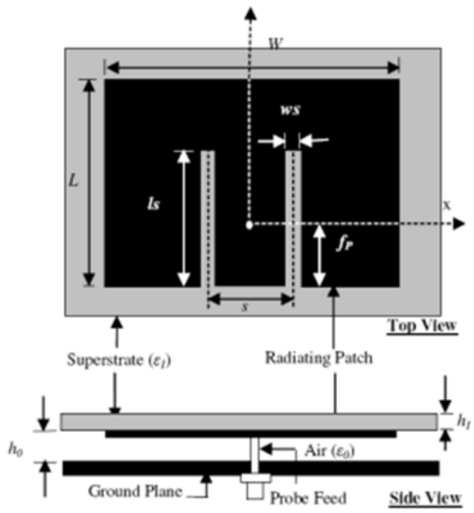

Figure 5. Inverted E-Shaped microstrip antenna geometry structure

$$F(x) = sqrt(M * 〖(fc - fctarget)〗^2 + N * 〖(BW - BWtarget)〗^2) \quad (3)$$

The fitness function used in the study is shown in the equation given above. M and N are constants used to control which parameter contributes more to the overall fitness function of each term. M and N values were chosen as 0.1 and 1, respectively. Optimization was carried out by completing 60 iterations with 36 particles. Patch length (L) and width (W), slit length (l_s) and width (w_s) were used as optimized parameters and it was aimed to reach the desired operating frequency and bandwidth.

Using the microstrip antenna parameters data, equations representing the relationship between different parameters of a microstrip antenna and obtaining the requested antenna properties are written. Graphmatica curve fitting software was used to generate the required curve to solve the problem. Particle Swarm Optimization software was developed and implemented in the MATLAB program, which is widely used in the literature. The antenna, which has been optimized at the desired ranges, has been simulated with the Zealand IE3D program. By comparing the conventional built antenna with the PSO optimized antenna based on curve fit, a significant improvement in bandwidth was observed. The observed bandwidth is increased by 15% for the inverted E-shaped microstrip patch antenna.

Gupta et al.,(2018) ,explored the potential of a nature-inspired soft computation technique known as adaptive bacterial foraging optimization (ABFO) for the optimization of the geometric parameters of a compact coplanar waveguide (CPW) fed microstrip patch antenna with imperfect ground structure.

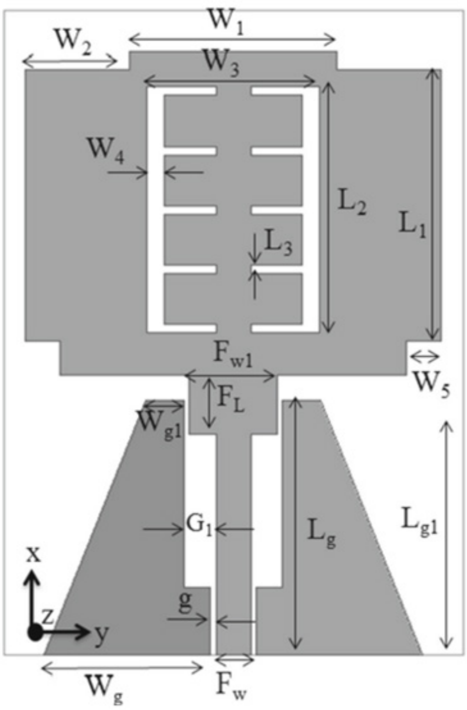

Figure 6. Geometry of CPW fed microstrip antenna with imperfect ground structure

The research study consists of three stages as the process carried out. In the first stage, the antenna was designed and analyzed for the desired parameters using the finite element based electromagnetic simulator Ansoft HFSS 15.0 as in Figure 6. Analytical equations of various design parameters related to other parameters to be optimized are modeled in MATLAB using curve fitting technique. Then, a joint cost function created by combining the individual fitness functions in the optimization algorithm used in the model was evaluated.

In the last part of the work, a variation of the BFO algorithm as the adaptive system named constrained ABFO is projected and designed to fit the limited constraints imposed by the projected antenna structure. The modified algorithm is effectively used joint optimization of certain design parameters to convert dual-band performance to broadband performance for high-speed point-to-point wireless services.

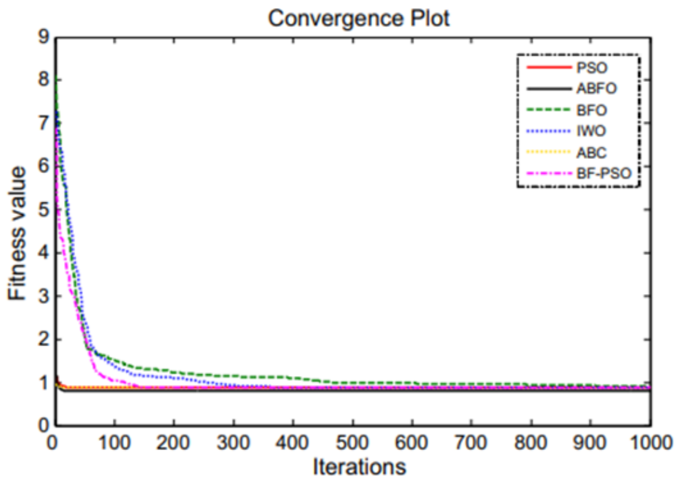

Figure 7. Convergence features comparing ABFO algorithm with other evolutionary algorithms

Design in bio-inspired algorithms using constrained ABFO, original bacterial foraging optimization (BFO), particle swarm optimization (PSO), hybrid bacterial collector particle swarm optimization (BF-PSO), weed optimization (IWO), and artificial bees. The performance of optimization colony (ABC) techniques is demonstrated. The dual-bandwidth of the designed microstrip antenna turns into wide-bandwidth performance (6.95 GHz–9.79 GHz) when the antenna structure with optimized parameters is simulated using an EM simulator.

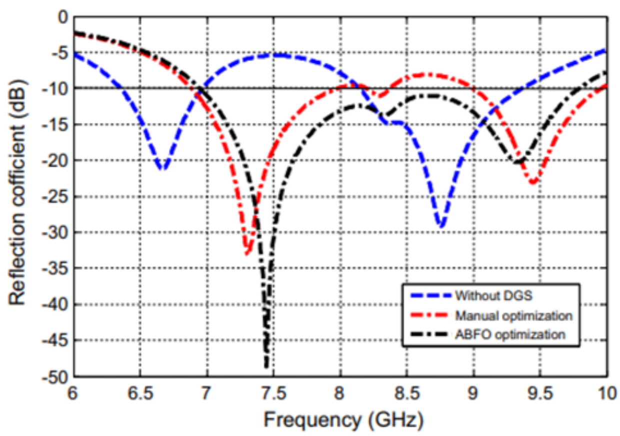

Figure 8. Reflection coefficient characteristics of the antenna optimized for ABFO

The ABFO optimized antenna was fabricated and tested as in Figure 8 to validate its experimental results, which are in close agreement with the simulated results. In conclusion, optimization using constrained ABFO has proven to be a competent approach to improve the performance of high-frequency antennas, especially where numerical modeling techniques are computationally expensive.

Gandopadhyaya et al. 2016, The resonance frequency of the probe fed Rectangular Microstrip Antenna (RMA) is optimized using the Cuckoo Search (CS) algorithm. Investigation was made for different microwave frequencies between 3 GHz and 18 GHz. Three variables of the microstrip antenna as patch length, patch width and position of the feed were used for optimization.

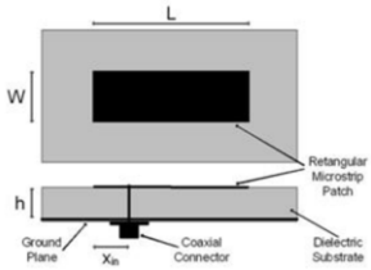

Figure 9. Rectangular microstrip antenna structure

Table 1. Rectangular Shaped Microstrip Antenna Parameter Constraints

Patch Length Upper Limit	$\lambda_0 / 2$
Patch Width Upper Limit	λ_0
Feed Position Upper Limit	Patch Length

Table 1 lists the limitations of the optimized parameters of the microstrip antenna. The following equation is used for the fitness function of the Cuckoo Search Algorithm.

$$Fitness\ Function = |f - f_r| + |Z_{real} - 50| + |Z_{im} - 0| \quad (4)$$

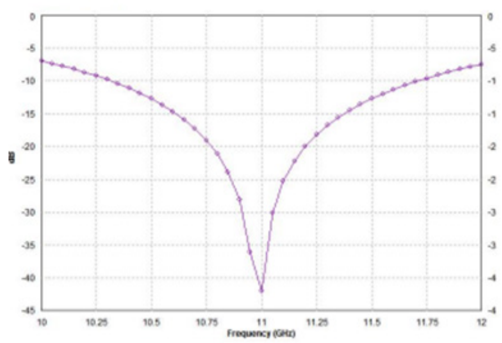

Figure 10. Return loss value at 11 GHz

Figure 10 shows the return loss of the antenna designed using the Cuckoo Search Algorithm at 11 GHz. Observations show that the cuckoo search algorithm is an efficient algorithm for optimal design. It was analyzed by optimizing the radius of the patch (a) and the height of the substrate (h) for a circular microstrip antenna to resonate at 5 GHz.

Firefly Algorithm, one of the metaheuristic optimization algorithms, was used as the optimization algorithm. Optimization was made using the MATLAB R2009b program and the results obtained helped to simulate the antenna model using CST Studio Suite 2011 (Sahoo et al., 2015). The firefly algorithm was run with 10 fireflies in 100 iterations. The fitness function used is shown below.

$$\text{Fitness Function} = |F_{desired} - F_{calculated}| \tag{5}$$

Firefly Algorithm Convergence Graph is shown in Figure 11.

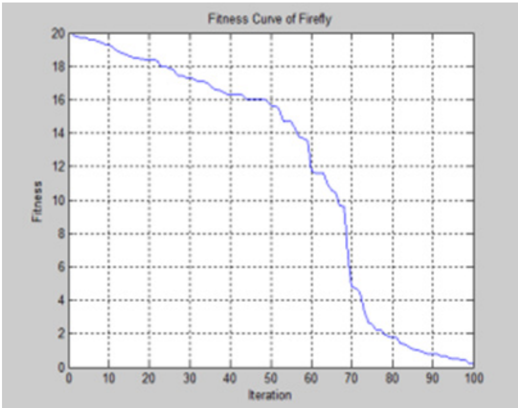

Figure 11. Firefly algorithm convergence graph

In the obtained S parameter graph, the return loss of -26.365567 dB at 5.004 GHz was obtained as in Figure 12.

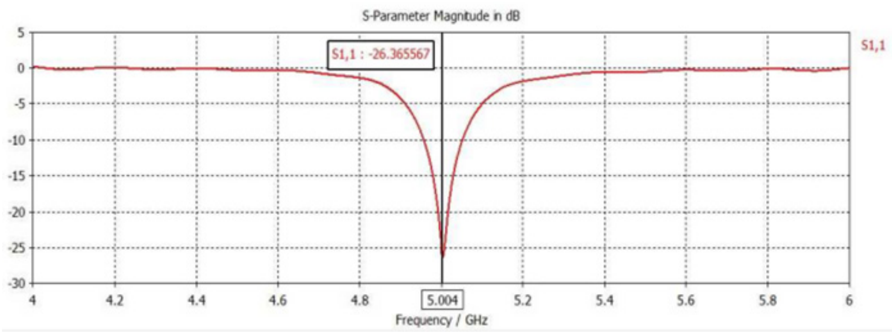

Figure 12. Return Loss Graph obtained in the simulation

Dastranj, (2017) In the literature, a problem approach is presented to optimize microstrip antenna parameters using invasive weed optimization (IWO), a global optimization algorithm used in antenna problems. It provides a general approach to designing printed ultra-wideband (UWB) antennas. Variable geometric parameters of the microstrip antenna were chosen as optimization variables to obtain input impedance and good radiation characteristics together with wide bandwidth.

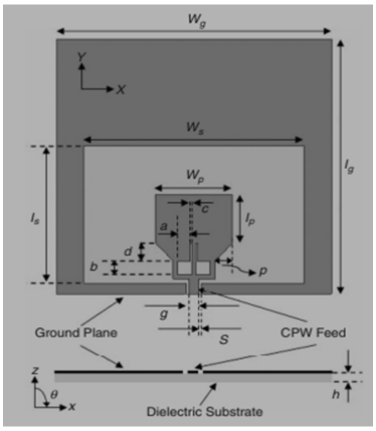

Figure 13. Antenna geometry to be optimized

Table 2: Boundary Conditions of Antenna Parameters to be Optimized

Antenna Parameters	Search Boundary Conditions
a	$0.03\lambda_0 < a < 0.08\lambda_0$
b	$0.03\lambda_0 < b < 0.15\lambda_0$
c	$0.004\lambda_0 < c < 0.02\lambda_0$
d	$0.03\lambda_0 < d < 0.2\lambda_0$
p	$0.03\lambda_0 < p < 0.1\ \lambda_0$
lp	$0.1\lambda_0 < lp < 0.35\ \lambda_0$
wp	$0.2\lambda_0 < wp < 0.6\ \lambda_0$
ls	$0.5\lambda_0 < ls < 0.75\ \lambda_0$
ws	$0.75\lambda_0 < ws < 1.08\ \lambda_0$

The fitness function used for the Invasive Weed Optimization algorithm is expressed by the equation below. E_1 is the relative error of the desired S11 value, E_2 is the difference between the obtained and the desired gain. W is the weight coefficient, m is the number of sample frequencies.

$$\text{Fitness Function} = \frac{1}{m} \sum_{j=1}^{m} [W[E_1+E_2]] \quad (6)$$

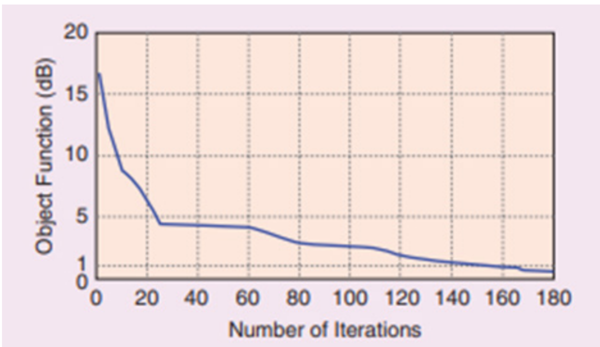

Figure 14. IWO convergence graph

In Figure 14, the IWO algorithm has been successfully used and demonstrated for the optimization of the compact CPW supported printed antenna in the 1.6–11.2 GHz frequency range. Some of the geometric dimensions of the antenna were chosen as the optimization parameters to be used in the algorithm. Then, the bandwidth, input impedance and antenna gain for the designed microstrip antenna are optimized according to the specifications required by the designer. Antenna geometric dimensions are optimized using the fitness function related to the resonant frequency of an antenna with optimum weighting coefficients to obtain the desired electromagnetic properties over the entire frequency range. At the same time, a small size of 50 mm × 50 mm was obtained by applying constraints to the optimization parameters. The measured results were found to be in good agreement with the full-wave simulations, which proved the validity of the presented optimization technique.

The designed antenna was compared with several previously proposed designs and the comparison results showed that the optimized antenna outperformed other designs.

In the study conducted by Yelken et al., (2020), a Seljuk Star microstrip antenna (SSMA) was designed based on the hybrid Artificial Neural Network model for frequency values in the 0.5-3.5 GHz range. Seljuk Star microstrip antenna is designed on DE104 as double-sided, 1.55mm dielectric and 35um conductor thickness, electrical conductivity 4.37 and loss tangent 0.002. Firefly optimization algorithm is used to update weight values for training in Hybrid Neural Network structure. 272 Seljuk Star microstrip antennas were designed with HFSS software and 90% of this data was introduced to the Artificial Neural Network as training and 10% as testing. In Figure 15, Seljuk Star Shaped Microstrip Antenna structure is seen.

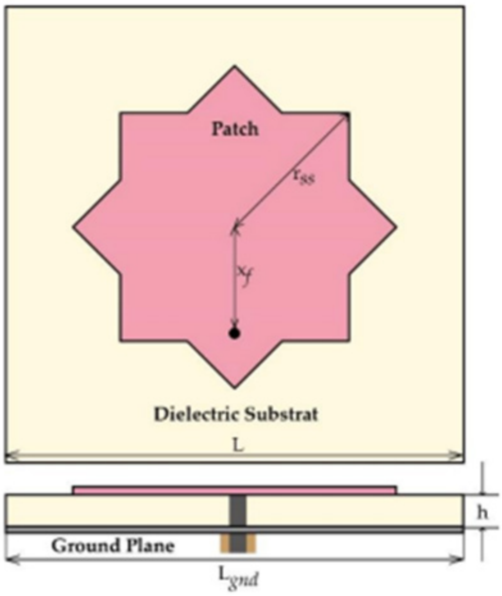

Figure 15. Seljuk Star shaped microstrip antenna structure

In this study, Firefly optimization algorithm was used in Artificial Neural Network training. Mean Square Error (MSE) was used as the cost function of the optimization algorithm.

$$MSE = \frac{1}{n}\sum_{i=1}^{n} (y - \hat{y})^2 \quad (7)$$

The dielectric coefficient 〖(ε_r), substrate thickness (h), X_f, Y_f, patch radius(r) values of the Seljuk Star shaped microstrip antenna were tried to be trained with the trained Artificial Neural Network. Resonant frequency and Bandwidth are defined as output parameters. It has been seen that the result of the Artificial Neural Network trained with the optimization algorithm is in harmony with the simulation results.

In order to determine the operating frequency of A-shaped patch antennas (APA), two machine learning methods, namely multilayer perceptron (MLP) and K-nearest neighbors (KNN) algorithm models, were used in UHF band applications(Pal,2017).

Firstly, datasets were obtained from 144 antenna simulations with the help of HyperLynx® 3D EM electromagnetic simulator using moment method (MoM) technique. The models entered with 124 APA parameters were trained and their accuracy was tested with 20 APAs. In MLP and KNN models, mean absolute error (MAE) values were calculated for different numbers of hidden layer neurons and different neighborhood values, respectively. Figure 16 shows the A-Shaped Microstrip Antenna Geometry.

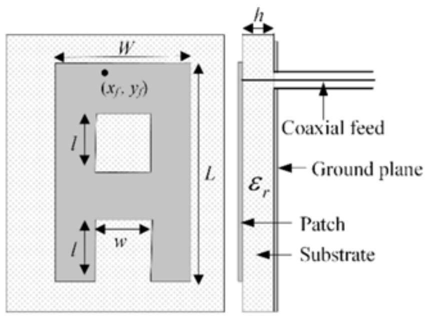

Figure 16. A-Shaped microstrip antenna geometry

The performances of MLP and KNN models were compared during the training and testing process. The lowest MAEs were obtained with 6 hidden layer neurons for MLP and 2 neighborhood values for KNN. These results show that APAs can be successfully applied to computational operating frequencies.

Considering the line ratios obtained between the MLP and KNN models, the MLP model achieves the best performance for the training and testing process. For MLP and KNN training, the working frequencies MAE determined in terms of the problem were obtained as 0.025 and 0.067, respectively. The proposed models were then tested and MAE values of 0.038 for MLP and 0.072 for KNN were achieved. It is seen from the results obtained that MLP and KNN model approaches have short processing time and easy modeling for convenience, and that they give more suitable data for the operating frequency of APAs without using complex mathematical expressions and long simulation processes.

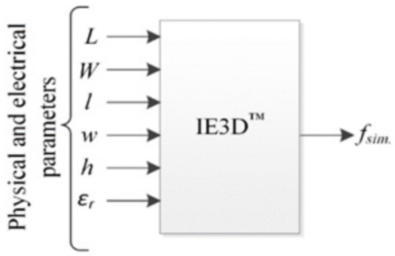

Figure 17. Simulation process

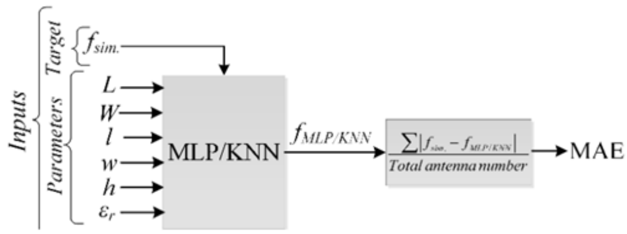

Figure 18. Machine learning process

Figure 17 shows the Simulation process and Figure 18 shows the Machine Learning process. In the study by Akdağlı et al., a method-based artificial neural network (ANN) was first applied to calculate the resonance frequency of the circular ring compact microstrip antenna (ARCMA) created by loading a circular slot in the center of the patch antenna. A multilayer perceptron model based on feedforward backpropagation ANN was used and the created model was separately trained with 8 different learning algorithms to obtain the best results regarding the resonance frequency of ARCMAs in dominant mode.

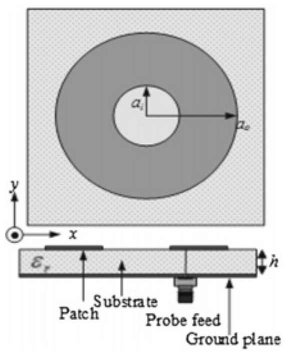

Figure 19. Circular ring compact microstrip antenna structure

Ring inner and outer radius, substrate dielectric coefficient and thickness, and antenna operating frequency were tried to be estimated in ANN training. The resonance frequencies of 80 ARCMAs with various sizes and electrical parameters were simulated with IE3DTM, a numerical electromagnetic calculation tool based on the torque method. Then, an ANN model was created with the simulation data, and 70 ARCMAs were used for training and the remaining 10 ARCMAs for testing. When the performances of 8 learning algorithms were compared with each other, the best result was obtained with the Levenberg-Marquardt algorithm. Figure 20 shows the ANN structure.

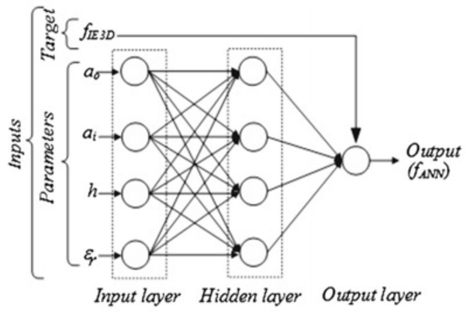

Figure 20. ANN structure

The results obtained in this study show that learning ANN model with LM algorithm can be successfully used to calculate the resonant frequency of ARCMAs without using any complex methods.

In this study, a unique ANN model is proposed for equilateral triangle microstrip antenna (ETMSA) designs used in suspended air as well as glass epoxy suspended surfaces. The two configuration runs used in the study, ETMSA and ETMSA, are discussed in suspended air produced on a glass epoxy substrate (er = 4.3, h = 0.16 cm, tan d = 0.02) suspended above the ground plane using a finite air gap Deshmukh et al., 2018). As the first step to be used in training the ANN model, the ANN network was trained using datasets containing data such as substrate thickness, resonance frequency in terms of working wavelength, simulated patch side length and half wavelength value. Training data sets were taken in the frequency range of 800-6000 MHz in every 400 MHz frequency range. Also, using this trained ANN model, the side length of the ETMSA was estimated for different substrate thicknesses over the 600-6000 MHz frequency spectrum. Figure 21 shows (a) Top and (b) Side Views of the Equilateral Triangle Microstrip Antenna. The ANN model created is given in Figure 2.

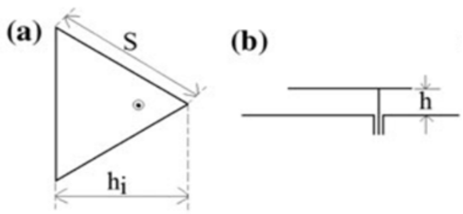

Figure 21. Equilateral triangular microstrip antenna (a) Top View and (b) Side View

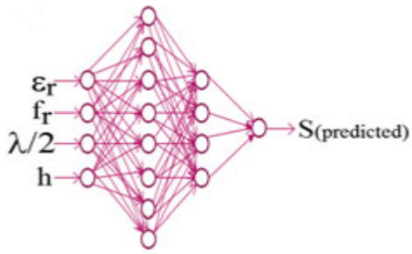

Figure 22. Created ANN model

When simulated using the obtained length, it gives almost the same resonance frequency for ETMSA with less than 2% error for both air and suspended dielectric substrate. Therefore, the proposed ANN model will be helpful in estimating the edge length of ETMSA in air as well as the preferred suspended dielectric configurations in broadband high-gain variations of ETMSA designs.

It offers a deep neural network to re-express the design parameters of an internally fed rectangular microstrip patch antenna. A multilayer perceptron-based deep neural network is proposed to estimate the antenna's resonance frequency and gain values. Rectangular MSA structure and Deep Learning Model Block Diagram in Figure 23 are given in Figure 24(Pal et al..,2019).

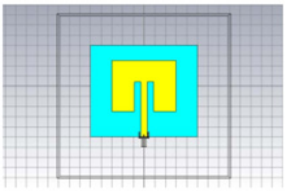

Figure 23. Rectangle shaped MSA structure

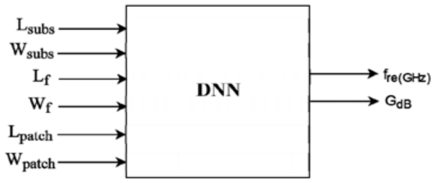

Figure 24. Deep learning model block diagram

Rectangular microstrip patch antenna, dielectric substrate dimensions (L_{subs}, W_{subs}), feedline size (L_f, W_f) and patch geometry dimensions (L_{patch}, W_{patch}), length (L) and width (W) parameters are given as input to the model. Resonance Frequency (freqGHz) and gain (GdB) are estimated as output of the model. Root mean error (RMSE) and mean absolute error (MAE) were used as performance measures of the network. Compared to results simulated by CST, mean absolute percent error (MAPE) values were less than 1.30% and 1.56%, respectively. Therefore, it is proposed that the created artificial intelligence model can efficiently predict the resonance frequency and antenna gain of any size microstrip patch antenna with high accuracy. It is stated that in future studies, with a larger data set to be obtained from microstrip patch antennas, the performance of the network model can be made much more suitable for the problem in the future.

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