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Research Article

Artificial Neural Network Model with Firefly Algorithm for Seljuk Star Shaped Microstrip Antenna

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Abstract

In this study, Seljuk Star microstrip antenna (SSMA) design based on the hybrid Artificial Neural Network model for frequency values in the range of 0.5-3.5 GHz has been performed. In the present study, a novel model is developed for training neural network by combining a back propagation (BP) and a meta-heuristic algorithm. The major disadvantage of back propagation in finding solutions is that it stuck local minima rather than global one. In this new hybrid training algorithm, local and global search made simultaneously. Initially, Firefly Algorithm (FA) was utilized to obtain weights of neural network due to the lower probability of entrapment into local minima thanks to long jump. Subsequently, this algorithm was combined with the local search capability of the BP algorithm and used to train the artificial neural network. Levenberg-Marquardt algorithm was preferred due to providing fast convergence and stability in training process of Artificial Neural Networks. In this paper, Seljuk Star microstrip antenna has been designed on DE104, double faced with 1.55mm dielectric and 35um conductor thickness, which has an electrical conductivity of 4.37 and a loss tangent of 0.002. HFSS antenna simulation program was used to design for 272 microstrip antennas. 90% of the data set was used as training and 10% as test data. The ANN with Firefly Algorithm results are more in agreement with the simulating results.

Keywords: Microstrip antenna, Seljuk Star, Artificial Neural Network, back propagation algorithm, metaheuristic algorithms

Selçuklu Yıldızı Şekilli Mikroşerit Anten İçin Ateş Böceği Algoritmalı Yapay Sinir Ağı Modeli

Öz

Bu çalışmada, 0.5-3.5 GHz aralığındaki frekans değerleri için hibrit Yapay Sinir Ağı modeline dayalı Selçuklu Yıldızı mikroşerit anten (SSMA) tasarımı gerçekleştirilmiştir. Bu çalışmada, bir geri yayılma (BP) ve meta-sezgisel algoritmayı birleştirerek sinir ağı eğitimi için yeni bir algoritma geliştirilmiştir. Geri yayılmanın çözüm bulmadaki en büyük dezavantajı, küresel minimumdan ziyade yerel minimuma sıkışmasıdır. Bu yeni hibrit eğitim algoritmasında, yerel ve global arama eş zamanlı olarak yapılmıştır. Başlangıçta, uzun atlama sayesinde yerel minimuma yakalanma olasılığının düşük olması nedeniyle sinir ağlarının ağırlıklarını elde etmek için Ateşböceği Algoritması (FA) kullanıldı. Daha sonra bu algoritma, BP algoritmasının yerel arama yeteneği ile birleştirildi ve yapay sinir ağını eğitmek için kullanıldı. Yapay Sinir Ağlarının eğitim sürecinde hızlı yakınsama ve kararlılık sağlaması nedeniyle Levenberg-Marquardt algoritması tercih edilmiştir. Bu çalışmada Selçuklu Yıldızı mikroşerit anteni, çift yüzlü 1.55mm dielektrik ve 35um iletken kalınlığında, 4.37 elektrik iletkenliğine ve 0.002 kayıp tanjantına sahip DE104 üzerine tasarlanmıştır. 272 mikroşerit anten tasarımı için HFSS anten simülasyon programı kullanılmıştır. Veri setinin %90'ı eğitim, %10'u test verisi olarak kullanılmıştır. Ateşböceği Algoritması ile YSA sonuçları simülasyon sonuçlarıyla daha uyumludur.

Anahtar Kelimeler: Mikroşerit anten, Selçuklu Yıldızı, Yapay Sinir Ağı, geri yayılım algoritması, metasezgisel algoritmalar.

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1. Introduction

With the advance of technologies in applications such as mobile electrical devices and wireless communication systems where size, weight, cost, performance, ease of installation and aerodynamic profile are constraints, microstrip antennas are needed to meet these requirements(Balanis, 2016). In the literature, most of the works for microstrip antenna have focused on familiar geometries such as rectangle, circle and triangle, due to their ease of analysis(Pandey, 2019). In order to overcome the narrow bandwidth, which is the major disadvantage of microstrip antennas, studies have been carried out on Seljuk Star microstrip antenna, a new patch shape in the literature(Uzer et al., 2016). Thus, in this paper we carried out a Seljuk Star microstrip antenna which is based on artificial neural network with optimization algorithm.

The increasing use of microstrip antennas in the electronic communications market requires the use of simpler methods for performance analysis. This is why microstrip antenna designers prefer simple approaches that do not require a lot of computing time. Artificial Neural Networks (ANN) have become modeling tools that are accepted in solving complex problems in different disciplines and frequently used in artificial intelligence applications. ANN have recently attracted interest as a rapid and compatible tool for EM / Microwave modeling, simulations and optimization and are frequently used in microstrip antenna design. ANN were used to calculate the resonant frequency of microstrip antennas with frequently used patch shapes.(Guney, Sarikaya, & Propagation, 2007; Sagiroglu, Güney, & Letters, 1997; Thakare & Singhal, 2009) In addition, there are studies using ANN trained with optimization algorithm to determine microstrip antenna parameters(Kaur & Rattan, 2015; Kumar, Ashwath, Kumar, & Malmathanraj, 2010; Vilović, Burum, & Brailo, 2013).In this study, ANN model with optimization algorithms have been used for computing parameters of the Seljuk Star shaped microstrip antenna. HFSS Software designed the proposed antenna based on finite element method (FEM) to acquired resonant frequency, return loss, bandwidth, input impedance and voltage standing wave ratio for ANN training and test.

In this work, we adopt multilayer perceptron (MLP) with Firefly Algorithm (FA) model for parameters of microstrip antenna. MLP was able to bring the nonlinear input-output mapping closer to the simulation results. Updating the weights based on the Levenberg-Marquardt backpropagation algorithm can accommodate local minimum values. Therefore, we utilized the FA global optimization algorithm to better train the weights in MLP. The error value of the Artificial Neural network is calculated using Mean Squared Error (MSE) as the performance indicator.

2. Material and Method

The simulation, modelling and collaboration of ANN is observed in Fig1. In the first step, Seljuk Star microstrip antenna is designed and dataset of training and testing of ANN is generated. In the second step, data set as 13 inputs and 5 outputs data was presented to the multi-layer network after preprocessing. In the third step, the weight and bias values in the multilayer network have been optimized using the Firefly algorithm. Before the training of the Artificial Neural Network, the Mean Squared Error (MSE) was used as the cost function with the optimization algorithm. Then, the neural network was retrained with the Levenberg-Marquardt backpropagation algorithm that finds local minimums. In the last step, the performance of the trained model is examined in the test data set.

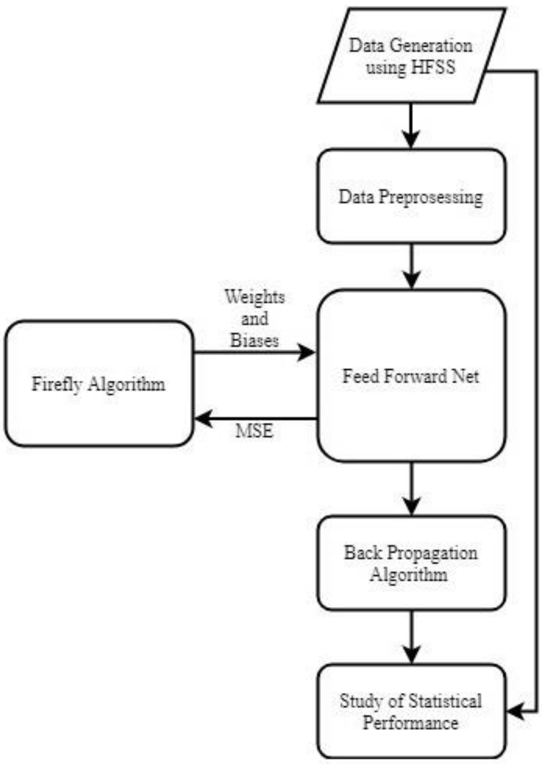

Figure 1. A flowchart that overviews the study.

2.1. Data Generation and Preprocessing

So that generate a database for modelling the ANN training and test, simulations of 272 SSMAs with various geometrical and electrical parameters are carried out using HFSS Software based on finite element method (FEM).

The geometry of the considered SSMA is given in Fig. 1. The Seljuk Star microstrip antenna made up for Seljuk Star shaped patch with radius r_{ss} over a ground plane with a substrate thickness h and having dielectric constant ε_r.The typical architecture of Seljuk Star microstrip antenna consist of three layers including patch, dielectric substrate and ground plane.

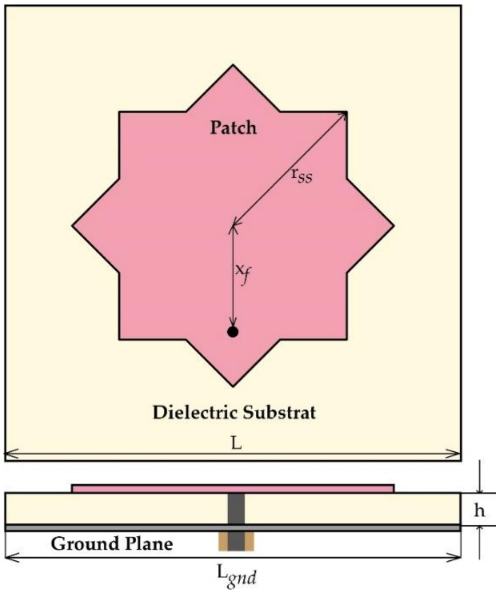

Figure 2. Geometry of Seljuk Star Microstrip Antenna

The Minimum-Maximum (Min-Max) normalization technique was used in conjunction with learning methods. Input and output values were normalized between -1 and 1.

$$X' = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (1)$$

2.2. Multi-Layer Feed Forward Neural Network

Artificial Neural Network is an artificial intelligence method that is inspired by the neural networks system specific to living things. This method is an effective method for predicting data, especially in microstrip antenna applications. Multilayer neural networks, which have a structure in which many neurons with nonlinear activation functions are interconnected in an architecturally hierarchical manner, are a special form of Artificial Neural Networks. In the feedforward neural network, cells are arranged in layers, and the outputs of cells in one layer are input to the next layer by weights. The input layer transmits the information it receives from external environments to the cells in the intermediate (hidden) layer without making any changes. Network output is determined by processing information at intermediate and output layers. With this structure, feed forward networks perform a nonlinear static function. It has been shown that a feedforward 3-layer artificial neural network can approximate any continuous function with the desired accuracy provided there are enough cells in the middle layer. Back propagation learning algorithm, which is the most known algorithm, is used effectively in the training of such artificial neural networks. In Figure 3, the multilayer neural network structure consisting of hidden layers is shown.

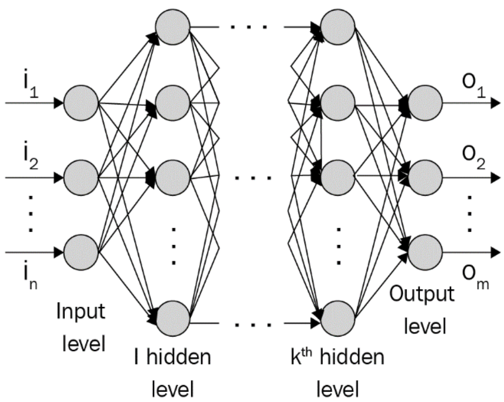

Figure 3 Multi Layer Feed Forward Network

A neural network without the activation function will behave like a linear regression with limited learning power. Therefore, various activation functions are used in studies with ANN in the literature. As the activation function used in the study, the transfer function of hidden and output layers is the hyperbolic tangent sigmoid transfer function as follows:

$$f(x) = tansig(x) = \frac{2}{(1+exp(-2*x))} - 1 \tag{2}$$

In this study, ANN with two hidden layers is modelled. The number of hidden layer neurons was tested in the range of [5: 15] and it was observed that the optimum performance was obtained with n = 10,7 respectively. MLP networks are feed forward networks trained with the Levenberg-Marquardt optimization algorithm back propagation algorithm. There are completely 272 parameter of microstrip antenna. During the ANN training phase, 28 of 272 data were used for testing, and the accuracy of the model created was investigated. For this reason, 28 data belonging to the HFSS data set were tested and the results obtained were analyzed.

2.3. Firefly Algorithm

Firefly Algorithm (FA) proposed and developed as most successful nature-inspired algorithms by Xin She Yang simulates the behaviour of flashing of fireflies and their movement. In the social behavior of fireflies, the attractiveness of each firefly is determined by its brightness and they try to move towards brightness. The brightness of each firefly rely on the fitness value of that firefly. The pseudo code of FA algorithm is listed in Fig. 4.

Start
Define objective function f(x), where x = $(x_1, x_2 \dots, x_d)$
Generate an initial population of fireflies
Formulate the light intensity *I*
Define the absorption coefficient γ
While (t < Max_Generation)
    For *i* = 1 to n (all n fireflies)
        For *j* = 1 to n (all n fireflies)
            If ($I_J > I_\mathrm{i}$)**,** move firefly *i* towards firefly *j*
            End if
            Evaluate new solutions and update light intensity
        End for *j*
    End for *i*
    Rank the fireflies and find the current best
    End while
End

Figure 4 Pseudo-code for Firefly Algorithm

In this paper, the movement between any pair of two fireflies x_i and x_j can be calculated as Eq. (2) as recommended by Yang.

$$x_i^{t+1} = x_i^t + \beta_0 \mathrm{e}^{-\gamma r_{ij}^2}\left(x_j^t - x_i^t\right) + \alpha\epsilon_i^t \tag{3}$$

Where r_{ij}= mutual distance between x_i and x_j; β = attractiveness when r_{ij}= 0; γ = light absorption coefficient; α_t= step size parameter; and ϵ_t = random number obtained from Gaussian distribution(Yang, 2010). These coefficients are effective in the efficient operation of the Firefly Algorithm.

In order to achieve the best performance in the Firefly Algorithm, the number of generations was chosen as 100, the number of fireflies as 50, the randomization parameter as α = 0.25, attractiveness = 0.2 and the light absorption coefficient γ = 1 in this algorithm.

2.1. Firefly Algorithm for Training MLP

Firefly Algorithm is implemented to train an MLP network with two hidden layers. The design parameters on the HFSS of the Seljuk star shaped microstrip antenna, such as the input part a of the ANN, were selected and the result parameters obtained from the simulated antenna were used as the output part. Two significant aspects are taken into emphasis when the approach is intended: the population of n fireflies in the FA and the selection of the fitness function. We need weights and biases matrix length in order to determine the population of n fireflies in the FA. Number of weights and biases is given by

$$n = (i+1) \times h + (h+1) \times h + \dots + o \times (h+1) \tag{4}$$

Where n is number of weights, i=13 is number of input neurons, o=5 is number of output neurons, h=10,7 is number of neurons of hidden layer. After the matrix length is determined, the FA generates random values within search space. The initial distribution does not affect the efficiency of the algorithm notably. Once the desired number of repetitions is reached, the attractiveness of all fireflies to a location in the search field increases. As a result, the global minimum point is found. For Firefly Algorithm, the cost function to be minimized as fitness function, Mean Square Error (MSE), was determined. MSE is shown in Eq. (3).

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(y-\hat{y})^2 \quad (5)$$

where y is the actual value, $\hat{y}$ is the predicted value and n is number of samples in the training dataset.

Because of its high local optimum avoidance and convergence speed rapidly, the Firefly algorithm has been an considerable motivation for training the Artificial Neural Network. The training problem of MLPs was first formulated using Mean square error, which is a minimization problem that occurs as a result of the determined weights. The objective function was to minimize MSE and match the network outputs with simulation results. The FA was operated to find the best fitness values for weights and biases to reduce the MSE and overcome backpropagation algorithm drawbacks.

3. Results

As mentioned before, the Mean Square Error have been used to determine the criteria of the study. As a first step, Firefly algorithm was run using 100 iterations to reduce this error value, and it reduced the error value at the desired level by avoiding local minimums. Figure 5 shows descending cost of Firely Algorithm against the progress of generations of fireflies.

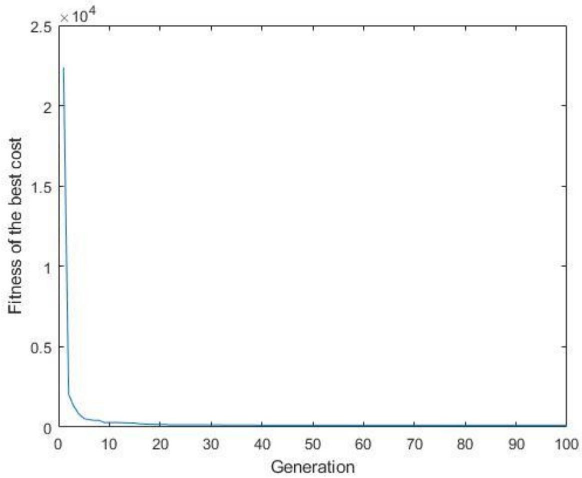

Figure 5 Convergence for MSE optimization problem of Firefly Algorithm

Over-fitting occurs when an artificial neural network memorizes the historic training set without learning to generalize to new test data. If the training R-value is much closer to one instead of the validation and test R-value, the model does not work correctly contrary to misconception. The result of regression is good comparatively in this model, since all the training, the testing as well as validation R-value is near to 1.

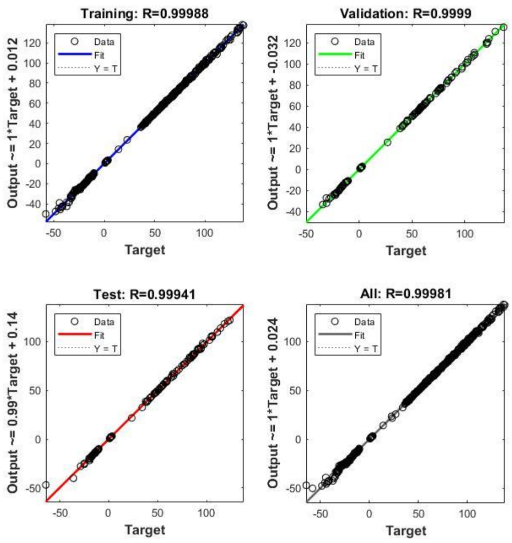

Figure 6 Regression Plot

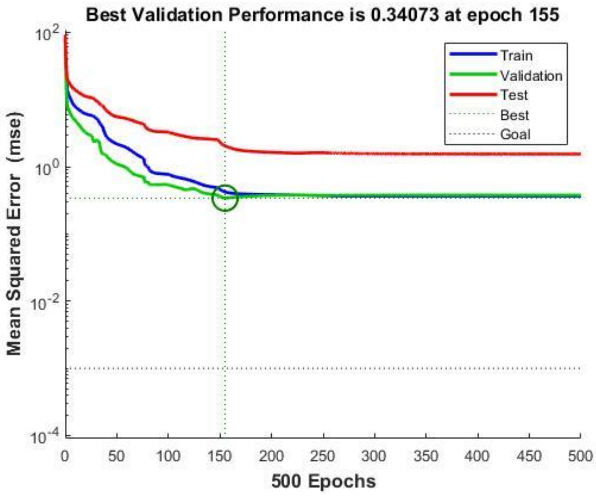

Figure 7 The Performance Plot

The above results are from the Artificial Neural Network using Firefly Algorithm with two hidden layers. This result is acceptable since the decrease in MSE of training graph. The best validation performance of ANN model is 0.34073 at epoch 155.

4. Conclusion

Seljuk Star microstrip antenna on a substrate of DE104, double faced with 1.55mm dielectric and 35um conductor thickness has been designed with variation in the parameters ε_r,h, $X_{f,}$, Y_f, r. Firely Algorithm is utilized to solve Mean Square Error optimization problem and generate weights and biases for ANN. This optimization algorithm is effortless to figure out and implement. By avoiding local minimums, it has fulfilled the desired task hybridized with back propagation algorithm in reaching the result by helping to train the artificial neural network.

As a future study, by combining ANN with other optimization algorithms, a comprehensive comparison of ANN structure using Firefly algorithm applied in this study could be investigate.

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