A Comprehensive Review on Machine Learning Based Optimization Algorithms for Antenna Design

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Abstract: Machine learning has become a great attention to find optimize solutions in different areas and is anticipated to play a vital role in our upcoming technologies. This paper presents a comprehensive review on basic optimization algorithms for micro-strip patch antenna design using machine learning. Classification of machine learning based algorithms: deterministic, stochastic and surrogate model assistant is discussed. Further machine learning models training for optimizing output and for prediction of antenna parameters is presented in this paper. This paper is useful to the readers who work on a particular antenna using the Machine Learning Techniques.

1. Introduction
Since last few years, the concept of Machine Learning (ML) has been a go to tool for science and engineering with its omni directional applications in automating difficult and long tasks with exclusive detailing. It is in its infancy but a phenomenon in technology industry with the machine leaning users changing the foundations of hundreds of industries and also research works especially in the field of antenna. In this age of Big Data, ML has become a great head turner in this field. Also, ML is showing a well-drawn promise in the optimization of antenna by estimating the behaviour of antenna and also speeding up the optimization with accuracy and efficiency. Antenna being of different shapes, they do not have finite and closed form solutions. So, with approximation of solutions, the physical insight can be gained on design of antenna. Integral equations through Method of moments (MoM) [2] are used for solving the solutions of linear antenna. With the computers advanced form, the possibility to solving Maxwell’s equations by integration and differentials. Unknowns are appended for solving more complicated antenna design through differential equations as they can be solved involving larger unknowns. The disadvantages were relative size of memory and CPU usages with structure and parameters of antenna. Development of method called iterative method helped in reducing of the memory and CPU requirements.

The common method used in designing antenna is numerical analysis. Numerical analysis methods widely used in exercising and testability of antenna are finite difference time domain for antenna radiation [3], finite element method electromagnetic [4], and Method of Moments applied to antenna [5]. Radiation field of antennas can be observed using optical approximation method. Simulations in antenna require the solving partial differential equations with boundary conditions. These can be done through computers and EM simulators. To reduce these irregularities and increase optimized results, ML is chosen to be a perfect method. ML remains a part of artificial intelligence (AI) emphasizing on extracting information out of data which makes it being used every time for statistical data science field.

This paper provides a detailed survey of few antennae designs which was obtained from the various ML methods. Various designs of antenna are listed basing on the type and their category making it fruitful for beginners to understand the concept and application of ML Techniques.
2. Optimization Algorithms: Training ML Models
Optimization algorithms are treated as an important part of ML as they are used to obtain optimum weight along with parameters of model. Training algorithms give out optimum values at minimum cost function. The performance of ML is resulted after training. Implementation of optimizers is based on the designer, data available and the type of data. All these are based on the use of optimization algorithms. The ever widely used optimizers in antenna are:

2.1 Gradient Descent
Gradient Descent algorithm, synonym GD, updates the values once after the execution of whole of the data set. It makes the optimizer slow. Also, optimizer is vulnerable as it goes into stuck mode in local minima. When the data samples count goes to millions, this optimizer fails in its performance due to slowness. To optimize this Levenberg-Marquardt (LM) algorithm is used. It is efficient for medium or small sized datasets [6].

2.2 Bayesian Regularized Artificial Neural Network (BRANN)
Bayesian regularization (BR) is implemented for training Artificial Neural Networks for an intention of skipping the cross-validation process [7]. BRANNs are used for not to extra train or sub fit the data sets.

2.3 Algorithms Based on Evolution
Evolutionary algorithms are one such kind of algorithms taken from evolution pattern of living creatures. It contains genetic algorithm, particle swarm optimization (PSO) which is widely used in optimization [8]. It can be implemented in antenna design as well.

3. Optimizing the Output: ML Models
A huge number of works have been done in ML for antenna design and optimization. Maximum of the works have showed that ANN was implemented to find the connections between parameters of antenna and their characteristics. But with increase in complex antenna structure, parameters also increase, connection set up becomes difficult and the values also become hard to obtain. The generic method for optimizing is: simulate antenna, take output, then implement ML technique to speed up process and bring to closeness of the desired values. In general, the following steps are followed:

1) Inputs with their respective outputs obtained from simulation are stored.
2) The created database is slit for training, validating and test sets.
3) A Machine Learning algorithm is used to get training from this data. The option lies on number of data, complexity of the problem-solving method.
4) Prediction of the values extracted from training.
5) Even process requires an execution for creation of data block to train. The model is designed. Proper predictions can be done faster, efficient and with great precision.

4. Prediction of Antenna Parameters: ML models

4.1 Circular Patch Micro Strip Antenna
Typical kind of micro-strip antennas is circular patch antenna. The generation of the resonance frequency using Machine Learning Programming and radial basis function (RBF) networks obtained from ANN which takes its feed input as the height as well as radius of the patch, along with permittivity. The efficiency of algorithms in training of Machine Learning programming is being followed and noted down namely extended delta-bar-delta (EDBD), directed random search (DRS). Genetic Algorithm, delta-bar-delta (DBD), quick propagation (QP). For design and computation of feed of a circular antenna, neural networks were implemented.

4.1.1 The first network
An NN with two hidden layers was implemented for prediction of radius, directivity and effective radius of patch antenna. Input parameters are thickness of antenna, resonant frequency, dielectric constant and LM optimization algorithm was used. The training samples were 45 and it was found
out that Mean Square Error came to be as $9.70 \times 10^{-4}$, $9.80 \times 10^{-4}$, and $7.76 \times 10^{-4}$ for respective inputs.

4.1.2 The second network

A radial basis function neural model with single hidden layer was implemented for prediction of input impedance [9]. The trained samples were pair of 200 input-output, produced a Mean Square Error of $2.69 \times 10^{-4}$ upon testing. Resonance frequency upon circular patch radius, height, and permittivity are used for generation of neural model and test. A Feed Forward Back Propagation NN was used to estimation of resonance frequency, antenna efficiency, gain, Bandwidth, and return loss (RL). Results obtained were achieved with an MSE of $9.96 \times 10^{-7}$.

4.2 Fractal Patch

Fractal patch antennas micro strip antennas with their design formulated by Artificial Neural Networks. The resonance frequency, RL, and the gain were computed using an Artificial Neural Networks with BP algorithm. IE3D software was the platform for generating the dataset for various iterations of antenna shape. The values thus obtained train a model for finding the position of the point of feed for generating optimal value impedance matching. In other paper work, the optimal value was obtained for square shaped antenna using Artificial Neural Networks [10]. For the reduction in antenna size, the iteration obtained from neural networks was executed in High frequency software to obtain efficient properties. Design of quasi-fractal patch antennas using Artificial Neural Networks was discussed [10]. Parameters of antenna operate on a specific frequency were recorded. The data then sent for training the model which predicts the perfect matching of parameter to the associated frequency of operation.

4.3 Elliptical Patch

Artificial Neural Networks were implemented for designing elliptical antenna. Artificial Neural Networks using radial basis function were used in design of elliptical micro-strip patch antenna [11]. Input parameters are permittivity, eccentricity, resonance frequency for even mode, for computing the resonance frequency for certain mode and semi major axis. Comparative results showed a low error percentage of 0.006% and 0.043%. In a different method of design, the computation of the gain and Return Loss of the antenna, a Feed Forward Back Propagation neural network was trained with major axes as input parameters. A data block or set was collected from simulation process. The comparative results again showed a very good low error of 0.2014 dB for the RL as well as for the Gain the value was 0.0202 dB.

4.4 Substrate Integrated Waveguide

Artificial Neural Networks were utilised for prediction of a SIW patch antenna with. Input being taking as inputs the desired Return Loss as well as resonance frequency. Feed-forward Machine Learning Programming and back propagation method were implemented to train the data block obtained from HFSS compilations. Designing of broadband millimetre wave Substrate integrated waveguide cavity-backed slot antenna using ML was discussed [12, 13]. Machine Learning assisted optimization method (MLOM) was implemented as reference comparison to a well-designed Machine Learning assisted method with additional feature (MLOMAF). It makes use of the population-based meta-heuristic optimization method. Sample database is set up, then train by the use of Latin-Hypercube-Sampling (LHS) and output was utilized to create a model. It was seen that the algorithm is ceased after 12 iterations which decreased the delay and the parameters and design of antenna was easier.
5. Machine Learning-Assisted Antenna Optimization

Few of the research were focused integrating the Machine Learning models inside the algorithm used for optimization for optimal results and better performance. This process will be faster as the simulation work is lessened. Interpolation combined with Genetic Algorithm is utilized to design an Ultra Wide Band ring monopole antenna [14] where parameter was approximated. The parameters are optimized and compared with prototypes from the obtained results. Various datasets were created to train an ANN model and it was concluded that the parameters increases with the increase in the data set. Artificial Neural Networks were utilized to design the patch antenna where the integration of Particle Swarm optimization method was introduced to achieve desired characteristics [15]. When the geometric characteristics of the antenna was found out, a mapping black box is designed. It is done in Artificial Neural Networks. The required bandwidth and frequencies are mapped with parameters of antenna. The comparison of evaluated results had an error of the order of $10^{-5}$. The Kriging algorithm and Differential evolution were used in the designing E-shaped antenna [16] with optimal structure. Antenna parameters the optimization process was done, like positions of feed and slot, length and width of Slot Antenna.

6. Discussion and Conclusion

ML techniques have proved their importance in design and analyses of various antennas. But few challenges await which states the lack of predefined block set of data for antenna. Had it been available, it could have been used directly for training ANN and obtain the desired output. But data is being generated using simulation prior to the process for creating a set of results which are stored in database of specific input and output variables. This becomes tiresome and time killing job as basic moto of Machine learning is to obtain faster design parameters and characteristics maintain accurate results. Heavy simulations also eat up the computational load too.

Next thing to be paid attention is the selection of the most efficient model characteristics leading to the efficient results. It is evident that Artificial Neural Network is the ultimate go to tool in Machine Learning with many systems and software packages with faster and accurate results as compared with generic methods. If the complexity of any antenna increases, the more important Neural is considered. It is important to figure out what type of model is to be designed for a specific type of antenna considering its characteristics and parameters.

The machine learning approach is the best considered approach for antenna design and parameters optimization faster and accurate but the process of training is tiresome. To make it simpler, one has to develop an antenna on ML itself instead of simulation method. Such an approach would increase the flexibility in design and can be utilised for large number of antenna arrays. Such would be faster, accurate and will be most efficient tool which a user has to only input the parameters required and automated results would be obtained.

This paper presents an in-depth study of Machine learning (ML) in designing and analysing antennas. Machine learning will ease the computational loads and speed up the process of designing unlike the conventional simulators. Different concepts of machine learning has been employed and this papers depicts that the overview is also provided helping the readers interested in this field to use as reference and tools effectively for their respective works furthermore.

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