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

Vol. 3, No. 1, pp. 17-21, 2023
Research Article
Received: 30/04/2023 Accepted: 03/06/2023

Data Driven Modelling of Microstrip Patch Antenna

Mehmet BEREKET, Mehmet A. BELEN*, Aysu BELEN

Abstract

The design and analysis of microstrip patch antennas are crucial for microwave applications, such as communication systems, radar, and imaging devices. However, the complex interactions between the antenna's geometrical parameters, material properties, and performance characteristics make the design process computationally expensive and time-consuming. This paper presents a comprehensive study on data-driven surrogate modeling techniques for efficient design and optimization of microstrip patch antennas. We discuss various surrogate modeling techniques, such as support vector regression machine, Gaussian process models, artificial neural networks, and deep learning-based approaches, and evaluate their performance in predicting the antenna's performance metrics. Additionally, we demonstrate the application of surrogate modeling in the optimization of microstrip patch antennas and address the challenges and future research directions in this field.

Keywords: Antenna; artificial intelligence; optimization; surrogate models.

1. Introduction

The utilization of Radio Frequency (RF) communication has become an essential component of contemporary society, with its implementation extending across diverse fields, including telecommunications, sensing, and wireless power transmission. The Industrial, Scientific, and Medical (ISM) band is a significant segment in the RF spectrum that presents a distinctive prospect for a broad spectrum of applications owing to its unlicensed nature. The International Telecommunication Union (ITU) has allocated the ISM bands, which are usually centered around 2.4 GHz, 5.8 GHz, and 24 GHz, to cater to a diverse range of applications without requiring explicit licensing or regulatory approval. The adaptability of these frequency bands has facilitated the swift advancement and dissemination of wireless technologies and apparatuses, thereby engendering new and inventive implementations.

Microstrip patch antennas have gained widespread popularity in microwave applications due to their low-profile, lightweight nature, and ease of fabrication [1-4]. The design of microstrip patch antennas involves the optimization of various geometrical parameters, such as patch dimensions, substrate thickness, and feed position, to achieve the desired performance characteristics, such as radiation pattern, bandwidth, and gain [5]. However, the complex relationships between these parameters and the antenna's performance characteristics make the design process computationally expensive and time-consuming, particularly when employing traditional electromagnetic simulation tools [6].

In recent years, there have been notable advancements in the design of microwave antennas, which can be attributed to the increasing need for communication, sensing, and radar systems with superior performance. The growing complexity and evolving requirements of these systems have resulted in a heightened demand for modelling techniques that are both efficient and accurate. These techniques are necessary to enable swift design iterations and performance optimization. The accuracy of traditional full-wave electromagnetic (EM) simulations is well-established, however, their computational demands are substantial and time-consuming, which can present obstacles for tasks that require timely decision-making and optimization. The utilization of data-driven surrogate modelling has surfaced as a potent and adaptable approach that connects the disparity between computationally costly simulations and prompt, dependable predictions. Surrogate models, also referred to as metamodels, utilize data derived from a restricted set of simulations or experiments to furnish an estimation of the fundamental systems. This approach offers valuable insights into the behavior of the systems while considerably mitigating the computational load. Data-driven surrogate modeling offers an attractive solution to overcome these challenges by

*Corresponding author

MEHMET BEREKET; İskenderun Technical University, Faculty of Engineering and Natural Sciences, Electrical Electronic Engineering, Hatay, Türkiye, mehmet.bereket@iste.edu.tr; 0000-0002-9332-9643

MEHMET ALİ BELEN; İskenderun Technical University, Faculty of Engineering and Natural Sciences, Electrical Electronic Engineering, Hatay, Türkiye, mali.belen@iste.edu.tr; 0000-0001-5588-9407

AYSU BELEN; İskenderun Technical University, Iskenderun Vocational School of Higher Education, Department of Hybrid and Electric Vehicles Technology, Hatay, Türkiye, e-mail: aysu.belen@iste.edu.tr; 0000-0001-5038-424X

providing rapid and accurate predictions of the antenna's performance characteristics based on a limited set of input-output data [7]. Surrogate models, also known as metamodels are approximations of the underlying complex system, which can be trained using available data to provide predictions at a significantly reduced computational cost [8]. In this paper, we present a comprehensive study on data-driven surrogate modeling techniques for efficient design and optimization of microstrip patch antennas for microwave applications [9].

2. Antenna Design and Its Surrogate Modelling

Herein, the present study investigates a Microstrip patch antenna design (depicted in Figure 1) featuring a square-shaped radiator and a tapered transmission line. Table 1 provides the lower and upper bounds of the variable space for the given problem. The Latin-Hyper cube Sampling (LHS) technique has been selected as the sampling approach for producing training and testing samples, utilizing the input domain specified in Table 1. A set of 800 data samples was utilized to assess the efficacy of the data-driven models, with 800 samples allocated for training and 200 for hold-out purposes. Each data sample generated in this study includes the scattering parameter response within the frequency range of 1-4 GHz, with a step size of 0.1 GHz. This study employs prevalent artificial intelligence algorithms for data-driven surrogate modelling, and their outcomes are exhibited in Table 2. The results presented in this study were obtained through a k-fold validation approach, where k was set to 5. Additionally, a hold-out dataset consisting of 200 samples was used, and the Relative Mean Error (RME) metric (as defined in Equation 1) was employed. The M2LP model has been determined to be optimal for this problem based on its lowest error value in both k-fold validation and hold out data sets.

$$RME = \frac{1}{N}\sum_{i=1}^{N}\frac{|Target_i - Predicted_i|}{|Target_i|} \tag{1}$$

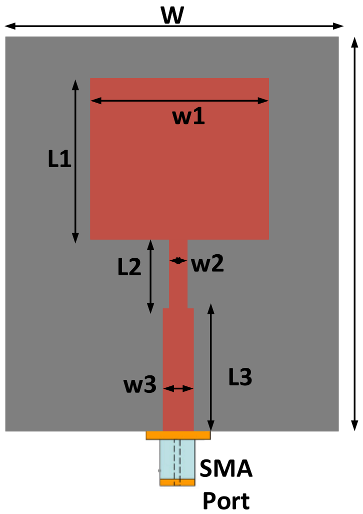


Figure 1. *Schematic of the studied antenna.*

Table 1. *Design variables and their variation limits*

Parameter	Lower	Upper	Parameter	Lower	Upper
L1	20	30	W1	30	40
L2	5	15	W2	0.5	1.5
L3	5	15	W3	2	4

Table 2. *Performance results of algorithms.*

Model	Hyper-Parameters	K-fold/Holdout
SVRM [10]	Epsilon=0.2, Kernel of Radial basis	9.9% / 10.7 %
Gaussian Process Regression [11]	Kernel 'ardmatern52', predication Block coordinate descent block size of 1500	6.4% / 7.6%
MLP [12]	Two hidden layers with 25-30 hidden neurons with trained with Levenberg-Marquardt back propagation	7.3% / 8.2%
M2LP [13]	depth of 3 with initial neurons size of 128	4.2% % 5.1 %

3. Study Case

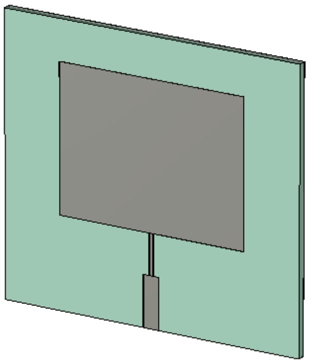
Optimization plays a crucial role in various scientific and engineering applications. The search for efficient optimization techniques has led to the development of several nature-inspired algorithms, including Genetic Algorithms, Ant Colony Optimization, and Particle Swarm Optimization (PSO). It was proposed by Kennedy and Eberhart in 1995, and since then PSO has attracted considerable attention due to its simple nature and working principle [14]. In PSO each individual, called a particle, represents a potential solution in the search space. The particles move iteratively through the search space, updating their positions and velocities according to their own experiences and those of their neighbors. The best position found by any particle in the swarm is named as “global-best”, while the best position found by a particle individually is called “personal-best”. The present study has opted for PSO as a proficient meta-heuristic optimization method to optimize antenna geometries [15-17]. The cost function, as represented by Eq. (2), has been employed to steer the search process.

$$\text{Cost} = \sum_{f_{\min_1}}^{f_{\max_1}} \frac{C_1}{\left| S_{11_i}(f) \right|} \tag{2}$$

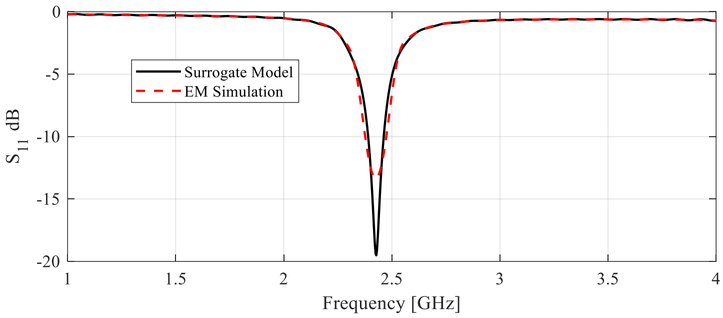
The value of weighing C1 is set to unity, and the frequency range is specified as 2.3 to 2.5, centered at 2.4 GHz, for applications in the ISM band. Table III displays the geometric design variables that were optimally selected through the implementation of PSO. Figure 2 displays the simulated performance of the antenna that has been optimally designed. To validate the efficacy of the proposed data-driven surrogate model, a comparison is made between the simulated performance of the optimal antenna obtained through M2LP and the results obtained through a full-wave simulation model. As depicted in Figure 2, the simulated S11 characteristics are in close agreement with the expected results presented in Table II.

Table 3. *Optimal determined design parameters of the Antenna in [mm]*

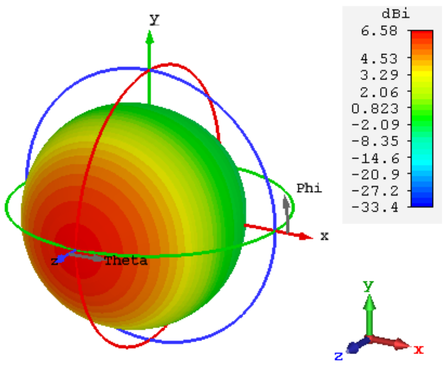
L1	28.8	**W1**	37.3
L2	8	**W2**	0.8
L3	10	**W3**	3.2
L	59.5	**W**	54.8



(a)



(b)



(c)

Figure 2. *(a) full wave simulation model of optimally designed antenna, (b) simulated S_{11} results of M2LP and full wave simulation model, (c) simulated radiation pattern of the antenna @ 2.4 GHz.*

4. Conclusion

This study presents a methodology for optimizing the design of a Microstrip Antenna using a computationally efficient approach that relies on data-driven surrogate modelling techniques. The surrogate representation of the antenna problem was created using data samples obtained from 3D electromagnetic simulators. The optimal solution for this problem was determined to be M2LP based on a performance comparison of a series of regression algorithms. Subsequently, in order to validate the proposed methodology, three distinct case studies were selected and treated as optimization problems to be solved using the aforementioned approach. The outcomes derived from this approach were then juxtaposed with those obtained from 3D EM full wave simulator results. The results demonstrate that the proposed surrogate modelling approach effectively identifies the desired geometrical design variables to elicit the desired design response. Furthermore, the results obtained exhibit a high degree of agreement with the outcomes of 3D EM simulations.

Declaration of Interest

The authors declare that there is no conflict of interest.

Author Contributions

Conceptualization, Mehmet BEREKET, Mehmet A. BELEN and Aysu BELEN; methodology, Mehmet BEREKET; data generation, Mehmet A. BELEN; investigation, Aysu BELEN; benchmarking models, Aysu BELEN; writing—original draft preparation, Aysu BELEN, Mehmet A. BELEN; writing—review and editing, Mehmet BEREKET and Mehmet A. BELEN; visualization, Mehmet A. BELEN; supervision, Mehmet A. BELEN; project administration, Mehmet A. BELEN. All authors reviewed the manuscript.

References

[1] Singh, I., & Tripathi, V. S. (2011). Micro strip patch antenna and its applications: a survey. Int. J. Comp. Tech. Appl, 2(5), 1595-1599.

[2] Wang, Xinhai, Liqiong Wu, Hua Chen, Wei Wang, and Zhaoping Liu. "Frequency-Reconfigurable Microstrip Patch Antenna Based on Graphene Film." Electronics 12, no. 10 (2023): 2307.

[3] Tomura, Takeshi, Sakuyoshi Saito, and Yuichi Kimura. "A consideration on a dual-polarized single-layer wideband ring microstrip antenna fed by two L-probes." IEICE Technical Report; IEICE Tech. Rep. 122, no. 34 (2022): 24-29.

[4] Froumsia, Dokrom, Shao-Wen Yao, Essiben Dikoundou Jean-François, Houwe Alphonse, and Mustafa Inc. "A review of the miniaturization of microstrip patch antenna based on fractal shapes." (2022).

[5] Khan, M. U., Sharawi, M. S., & Mittra, R. (2015). Microstrip patch antenna miniaturisation techniques: a review. IET Microwaves, Antennas & Propagation, 9(9), 913-922.

[6] Mahouti, P. (2019). Design optimization of a pattern reconfigurable microstrip antenna using differential evolution and 3D EM simulation-based neural network model. International Journal of RF and Microwave Computer-Aided Engineering, 29(8), e21796.

[7] Koziel, S., Bekasiewicz, A., & Leifsson, L. (2015). Rapid EM-driven antenna dimension scaling through inverse modeling. IEEE Antennas and Wireless Propagation Letters, 15, 714-717.

[8] Cui, C., Hu, M., Weir, J. D., & Wu, T. (2016). A recommendation system for meta-modeling: A meta-learning based approach. Expert Systems with Applications, 46, 33-44.

[9] Easum, J. A., Nagar, J., & Werner, D. H. (2017, July). Multi-objective surrogate-assisted optimization applied to patch antenna design. In 2017 IEEE international symposium on antennas and propagation & USNC/URSI national radio science meeting (pp. 339-340). IEEE.

[10] Dai, X. W., Da Li, M. I., Wu, H. T., & Zhang, Y. H. (2022). Design of Compact Patch Antenna Based on Support Vector Regression. Radioengineering, 31(3).

[11] Chen, W., Wu, Q., Yu, C., Wang, H., & Hong, W. (2022). Multibranch machine learning-assisted optimization and its application to antenna design. IEEE Transactions on Antennas and Propagation, 70(7), 4985-4996.

[12] Zhang, S., Huang, D., Niu, B., & Bai, M. (2022). High-efficient optimisation method of antenna array radiation pattern synthesis based on multi-layer perceptron network. IET Microwaves, Antennas & Propagation, 16(12), 763-770.

[13] Calik, N., Belen, M. A., & Mahouti, P. (2020). Deep learning base modified MLP model for precise scattering parameter prediction of capacitive feed antenna. International journal of numerical modelling: electronic networks, devices and fields, 33(2), e2682.

[14] Eberhart, R., & Kennedy, J. (1995, November). Particle swarm optimization. In Proceedings of the IEEE international conference on neural networks (Vol. 4, pp. 1942-1948).

[15] Lizzi, L., Viani, F., Azaro, R., & Massa, A. (2007). Optimization of a spline-shaped UWB antenna by PSO. IEEE Antennas and Wireless Propagation Letters, 6, 182-185.

[16] Li, Y. L., Shao, W., You, L., & Wang, B. Z. (2013). An improved PSO algorithm and its application to UWB antenna design. IEEE Antennas and wireless propagation letters, 12, 1236-1239.

[17] Najjar, M. S. Y., & Khodier, N. D. M. (2008). Design of non–uniform circular antenna arrays using particle swarm optimization. Journal of electrical engineering, 59(4), 216-220.