

Operating Frequency Estimation of Slot Antenna by Using Adapted kNN Algorithm

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Abstract: In this study ultra-high frequency slot antenna's operating frequency is estimated by using adapted k-nearest neighbor (kNN) algorithm. kNN doesn't use the training data points to do any generalization and it can be usually used for many classification. However, kNN can be adapted to estimate slot antenna's operating frequency by assessing the best k-nearest value. To find the optimal k for operating frequency estimation, 96 slot antennas with seven antenna parameters are simulated with respect to the operating frequency by using a computational electromagnetic software. Antenna parameters includes the patch dimensions, height and relative permittivity of the substrate. The simulated 81 antennas are used to construct feature data pool and the residual 15 antennas are used to test kNN algorithm. The performance of the kNN is evaluated by comparing the output of operating frequency to the simulated one. Then the proposed model is corroborated with simulated antennas and validating with prototyped antenna data. The results shows that the kNN based model simply and fast computes the operating frequency of the slot antennas much close to real one without performing any simulations or measurement.

Keywords: Slot antenna, antenna analysis, operating frequency, kNN algorithm

1. Introduction

Slot antennas are the microwave antennas in which the radiation patterns are determined by the size and shape of a slot in a radiating surface. Slot loading technique are commonly used to form little patch antennas, suitable for modern wireless technologies. Therefore the miniaturization in size and tuning the operating frequency for slot antennas have become popular [1-9]. In literature there can be found different shaped slot antennas such as rectangular ring [1], L [2], C [3] and E [4] shapes. While this type of antennas are commonly loaded in symmetrical with respect to the edge of the patch, slot antennas are constituted by asymmetrical notching one side of the patch [5]. For this reason, slot antennas needs great effort for analysis, like cavity model [6] and transmission line model [7] because of its irregular shapes. In general, these techniques [6, 7] could not be employed to analysis the slot antennas alone. On the other hand, thanks to computer-based software combined with computational electromagnetic (CEM) [8], the slot antennas can be simulated and analyzed by using very expensive CEM-based simulation tools experience. In order to find the alternative techniques of simply analyzing the slot antennas, (particularly operating frequency determination) artificial intelligence systems have used recently [9-13]. These techniques usually need training and generalization procedure to make best estimation. On the other hand, k-nearest neighbor (kNN) doesn't need to use the training data points to do any generalization so it can be easily used for many categorizations or classification [14-16]. Although kNN is the simplest controlled learning algorithm, it hasn't been used to estimate operating frequency of the antennas so far. In this study kNN is adapted to estimate the operating frequency of the slot antenna. For this purpose, the performance of the kNN algorithm is defined to find best k value

that gives the minimum error between target and output. In kNN algorithm, the relations between the features of the input parameters can be defined by using different distance metric. In this study, Euclidean distance metric is used to estimate the operating frequency of the designed antenna with six physical parameters and a relative permittivity of the substrate. In order to generate the feature data and estimate the best k value, 96 slot antenna with different parameters are simulated in terms of operating frequency by using a CEM software. The simulated data of 81 antenna is used to generate feature data and the 15 are utilized to test the accuracy. After using kNN algorithm, for k=1 the 15 testing data is estimated with mean absolute error (MAE) of 0.019. Then the proposed estimator is validated using constructed slot antenna prototyped.

2. k-Nearest Neighbor Algorithm

kNN is the simplest controlled learning algorithm among the whole machine learning algorithms [14]. It doesn't use the training data points to do any generalization so it is also called a lazy algorithm. In order to apply kNN algorithm, feature vectors in a multidimensional feature space have to be created. Thus, the desired test object can be defined according to distance to the nearest neighbor feature. The frequently used distance metric for variables is Euclidean distance and number of the neighbor objects is defined by k coefficient. In the chosen k-nearest neighborhood, the query object is appointed to class of the most uncategorized data. For example, the test sample (red square) given in Fig.1 should be classified either to the yellow spheres or to the black stars. If k value is chosen as four (dashed line) query object is assigned to the yellow sphere because there are 3 yellow spheres and only 1 black star inside the inner dashed circle. If k is chosen as seven (solid line circle) it is assigned to the second class because there are four black star inside the inner circle. So, the query object can be defined with respect to k value. However, if we need to make estimation instead of classification, we have to re-define

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query object appointment as given in section 3.2 in detail.

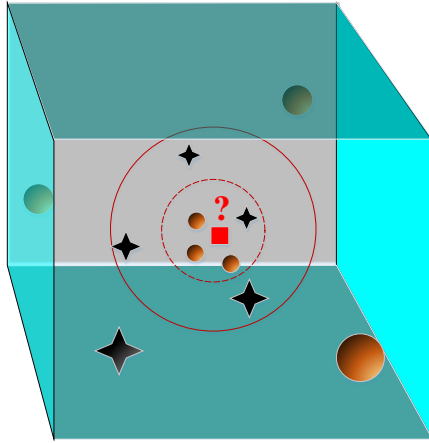


Fig. 1. Demonstration of KNN detection

3. Design of slot antenna and query object appointment

The constructed slot antenna's geometry is illustrated in Fig.2. The length and width of antenna is identified as L and W respectively. It consists of ground layer, substrate with h thickness and ϵ_r relative permittivity. The probe feed is positioned at (x_0, y_0) . The dimensions of the rectangular slot is defined with l and w and shifted as d from the upper side as seen in Fig.2. To determine the operating frequency of the designed slot antenna, 7 parameters are simulated and used as input feature data of the kNN model. The kNN feature data pool is constructed with 81 antenna data and then for each test (query) object the nearest neighborhood relations calculated for different k values. The objective of the kNN algorithm is to find best k coefficient which gives the minimum MAE between the target and output.

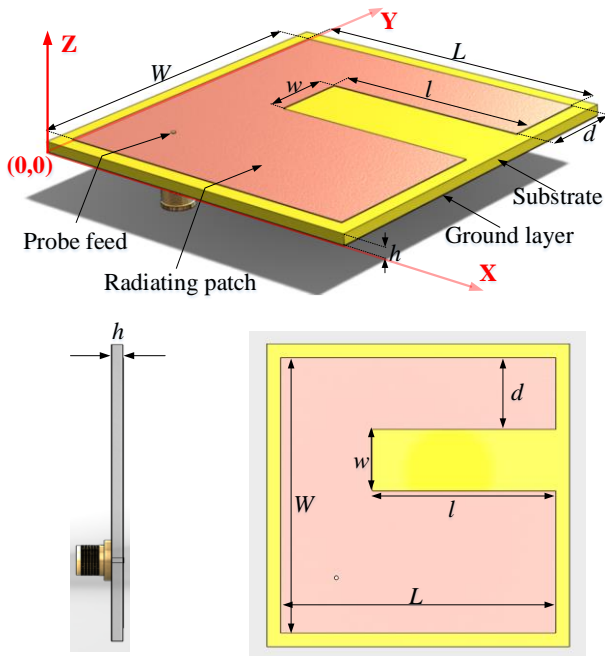


Fig. 2. Three dimensional representation of the designed slot antenna

3.1. Simulations

In order to be used for ultra-high frequency (UHF) band applications, the antennas' parameters are determined so that they operate between 1.15 GHz and 3.35 GHz. 96 different antennas are simulated by means of CEM software HyperLynx® 3D EM [17]

running method of moment and all parameters are given in Table 1. To make a uniformly distributed data pool, the outer sizes of the slot antennas are selected in three groups. Each groups has 32 antenna and outer dimensions of groups are 30, 20; 40, 30 and 50, 40 including different parameters of l, w, d, h and relative permittivity ϵ_r . The antennas source coordinates are defined as $x_0 = 5mm, y_0 = 5mm$ and 1 volt wave source is used to feed them. Simulations are realized between 1 to 5 GHz for a total of 81 discrete points.

Table 1: Simulated slot antenna parameters

	Patch dimensions (mm)				h mm	ϵ_r
	L	W	l	w		
30	20	10;20	5;10	3;6	1.6;	2.33;
40	30	15;30	7.5;15	5;10	2.5	4.4
50	40	20;40	10;20	7;14		

3.2. Adapted kNN Algorithm

At the end of the 96 simulation, the simulated data of 81 antenna is used to generate feature data pool and the 15 are utilized to test the accuracy. To create feature vector the 81 antennas are located with respect to multidimensional distance to origin as given equation 1.

$$d_{0a} = \sqrt{L_a^2 + W_a^2 + l_a^2 + w_a^2 + d_a^2 + h_a^2 + \epsilon_{r_a}^2} \quad (1)$$

where d_{0a} is the Euclidian distance vector of each test antenna with respect to origin $(0, 0)$. In Eq.1, $a = 1$ to 81 indicates the each antenna and each $d_{0a} \equiv d_{fa}$ correspond to operating frequency d_{fa} , which is obtained by simulations. In order to find test antennas operating frequency, the distances from each test antennas to each d_{0a} is obtained by using Eq. 2.

$$d_{ta} = \sqrt{\begin{matrix} (L_a - L_t)^2 + (W_a - W_t)^2 + \\ (l_a - l_t)^2 + (w_a - w_t)^2 + \\ (d_a - d_t)^2 + (h_a - h_t)^2 + (\epsilon_{r_a} - \epsilon_{r_t})^2 \end{matrix}} \quad (2)$$

In Eq. 2, t indicates the query antenna and d_{ta} is the $1 \times a$ sized distance vector. To find nearest neighborhood, d_{ta} vector is reordered from minimum (nearest) to maximum (farthest) and corresponding operating frequencies are defined as d_{tfm} . By using d_{tfm} , different neighborhood values can be calculated with respect to m value. In this study m is scanned between 1 to $k = 10$ and the query objects (q_{otk}) are appointed regarding to k , as given in Eq. 3.

$$q_{otk} = \frac{\sum_{m=1}^k d_{tfm}}{k} \quad (3)$$

where q_{otk} is the appointed operating frequency vector regarding to k value. After determining the q_{otk} for each k , the absolute error (AE) is calculated as given below;

$$AE_{tk} = q_{otk} - of_t \quad (4)$$

where of_t is the operating frequency of t 'th test antenna derived by simulation. The MAE is calculated by taking average value of the whole query objects as given

$$MAE_k = \frac{\sum_{t=1}^N AE_{tk}}{N} \quad (5)$$

where N is the number of the test objects. For different k values MAE are compared among to each other and the minimum MAE is found with respect to k . Hence, the operating frequency determination algorithm is concluded, with the help of estimated k value.

4. Testing the kNN algorithm

The accuracy of the algorithm is tested through 15 slot antennas data that is not utilized in feature matrix. Parameters of 15 simulated antennas with respective operating frequency values are given in Table 2. These test antennas are then used for query object in kNN algorithm. The k value is changed from 1 to 10 and Eq. 3 is calculated for each k value and test antenna. The estimated operating frequencies of the query antennas for different k values along with MAE results are given in Table 3. The best estimation result is obtained for k=1 with MAE of 0.019.

Table 2: Simulated Test antennas parameters

t	Patch dimensions							ϵ_r	Operating Frequency of_t (GHz)
	L	W	l	w	d	h			
1	30	20	10	5	3	2.5	4.4	2.426	
2	30	20	10	10	6	2.5	2.33	3.140	
3	30	20	20	5	3	1.6	4.4	1.611	
4	30	20	20	5	6	1.6	2.33	2.015	
5	30	20	20	10	6	1.6	4.4	1.512	
6	40	30	15	7.5	5	1.6	4.4	1.860	
7	40	30	15	15	5	2.5	2.33	2.107	
8	40	30	30	7.5	5	1.6	2.33	1.357	
9	40	30	30	7.5	10	2.5	2.33	1.311	
10	40	30	30	15	5	2.5	4.4	1.695	
11	50	40	20	10	7	1.6	4.4	1.466	
12	50	40	20	10	14	2.5	4.4	1.174	
13	50	40	20	20	14	1.6	2.33	1.585	
14	50	40	40	10	7	2.5	4.4	1.421	
15	50	40	40	20	7	2.5	2.33	1.814	

Table 3: The estimated operating frequencies of the simulated antennas for different k values

of_t	Estimated frequencies (GHz) with respect to different k									
	1	2	3	4	5	6	7	8	9	10
2.430	2.410	2.830	2.970	2.830	2.740	2.810	2.740	2.700	2.740	2.780
3.140	3.150	2.770	2.640	2.760	2.830	2.760	2.700	2.760	2.720	2.680
1.610	1.630	1.870	1.960	1.850	1.790	1.840	1.790	1.760	1.790	1.820
2.020	2.050	1.790	1.710	1.810	1.880	1.840	1.860	1.880	1.840	1.860
1.510	1.540	1.770	1.860	1.780	1.730	1.780	1.820	1.780	1.760	1.790
1.860	1.870	2.220	2.330	2.130	2.030	2.040	2.040	1.990	1.940	1.960
2.110	2.100	1.840	1.750	1.840	1.900	1.850	1.810	1.900	1.980	1.960
1.360	1.380	1.570	1.640	1.550	1.590	1.620	1.580	1.540	1.560	1.530
1.310	1.280	1.530	1.610	1.550	1.600	1.620	1.580	1.550	1.560	1.580
1.700	1.670	1.490	1.430	1.500	1.540	1.500	1.470	1.510	1.540	1.520
1.470	1.490	1.560	1.590	1.480	1.500	1.510	1.460	1.430	1.440	1.450
1.170	1.160	1.360	1.420	1.440	1.480	1.510	1.460	1.430	1.450	1.420
1.590	1.600	1.390	1.320	1.380	1.420	1.380	1.350	1.380	1.400	1.370
1.420	1.410	1.670	1.740	1.660	1.610	1.660	1.700	1.650	1.620	1.630
1.810	1.790	1.570	1.490	1.580	1.640	1.590	1.560	1.600	1.630	1.610
MAE	0.019	0.250	0.330	0.240	0.210	0.250	0.240	0.210	0.200	0.210

Table 4. The measured and estimated operating frequencies of the prototyped slot antenna

Antenna Parameters							
Patch dimensions (mm)							
L	W	l	w	d	h	ϵ_r	
30	20	10	5	3	3	4	
Operating Frequency				Absolute error			
f simulation	f measurement	f estimated	AE simulation	AE measurement			
2.426	2.430	2.409	0.017	0.021			

5. Validating the estimator

To test and validate the proposed model's performance, the slot antenna is printed on a 25x35 mm² FR4 PCB substrate as seen in Fig. 3. The dielectric permittivity, tangent loss and thickness of the PCB are 4.4, 0.02 and 2.5 mm, respectively. The prototyped antenna of which parameters given in Table 4 is measured by the help of Keysight N5224A PNA network analyzer. The measured S₁₁ parameter is shown in Fig.4 in comparison with the simulated one.

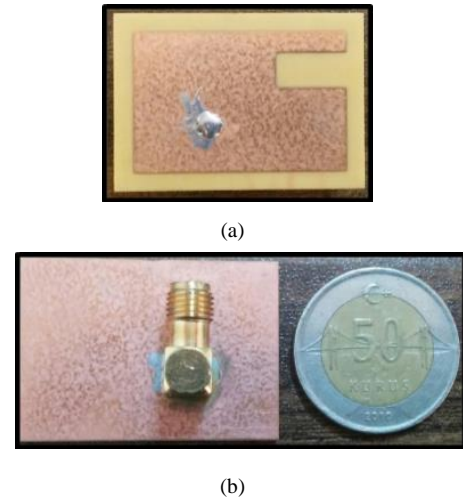


Fig. 3. The scene of prototyped slot antenna (a) front view, (b) back view with reference coin

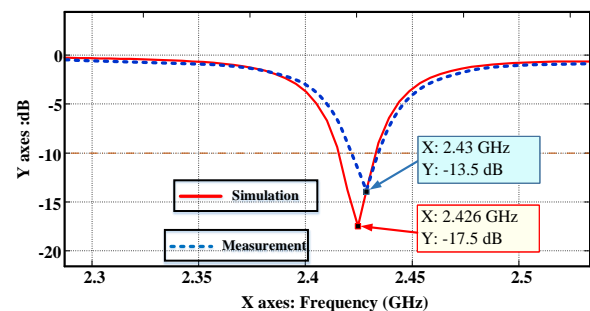


Fig. 4. S₁₁ measurement of both constructed and simulated slot antenna

It can clearly be comprehended from Fig.4 and Table 4 that, the estimated and measured operating frequencies are much close to simulated results. Thus, kNN based model can be effectively handled to compute the operating frequency of the slot antennas without solving complex mathematical functions and transformations. Additionally, the proposed kNN algorithm can be enhanced to handle similar tasks of nonlinear electromagnetic problems.

6. Conclusion

In this paper, kNN based estimator is implemented to finding the operating frequencies of the slot antennas. In order to make accurate estimation, the number of k neighborhood is varied for a total of 10 different distance metric. The feature matrix is constituted with 81 slot antennas having various physical and electrical parameters is simulated with the help of HyperLynx® 3D EM in terms of the operating frequency. In kNN model, 15 antennas are used as a query object for testing the best K estimation. The performance of the kNN is evaluated by comparing the appointed operating frequency to the simulated one. Then the proposed estimator is corroborated with simulated antennas and validated with prototyped antenna data. The results shows that the best estimation is occurred for k=1. Once the best k value is properly found, the operating frequency of patch antennas can be accurately computed.

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