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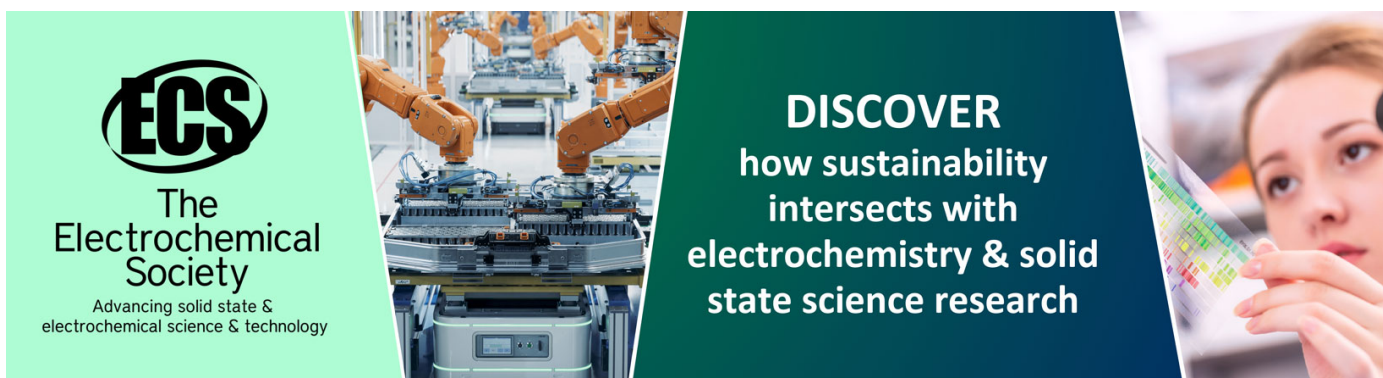
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Research on HF Radio Propagation on the Sea by Machine Learning Optimized Model

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Abstract. In order to research HF radio propagation, the energy attenuation of HF radio propagation in the transmission process has been studied, especially under the condition of sea surface with wind waves. A multi-objective optimization model is obtained by the method of machine learning. First, A multi-objective optimization model(M-BOM) were set up, which is based on machine learning to calculate the signal energy loss. The optimal transmission target is achieved by determining the control variable frequency and launching angle. Meanwhile, the database of equivalent virtual height is established by using the global map data. Next, the method machine learning is used to synthesize continuous functional relationships from data that is called from the database each time. Through these functional relationships, the minimum energy loss solution can be obtained with any environmental parameter. Additionally, we get the generate energy loss and launch angle of specific values and maximum jump hops through MATLAB programming.

1. Introduction

High frequency (HF) radio propagation is one kind of radio propagation, which defined to be 3 – 30MHz. Radio propagation mainly relies on reflection upon the ionosphere to carry out long-distance transmission. At travel process, radio propagation will loss energy, when its strength falls below usable signal-to-noise ratio (SNR), the signal will not travel any more.

In order to meet requirements coming from national defense, fishery and natural resources' high quality communication environment demands, we need to build high-quality, real-time and stable radio communication network. In the design of radio communication system, it is very important to predict the energy loss of radio propagation. So we determined to solve this question from the angle of mathematic theories [1].

2. Electric field intensity and energy loss of the receiving point

The energy loss in each reflection of radio propagation is extremely complex. Not only we combine with practical requirements, but simplify and program the calculation model of the classical wave propagation receiving point field strength. We get the electric field intensity of the receiving point equation:



$$E_t = 137.2 + 20lgf + 10lgP + G_t - L_b \quad (1)$$

E_t stands for the signal strength of receiving point in wave propagation ($dB(\mu V/m)$)

f stands for work efficiency (MHz), P stands for success rate of launch (kW), G_t stands for antenna radiation direction gain (dB).

There are four parts which consist the consumption of radio propagation:

$$L_b = L_{bf} + L_i + L_g + Y_p \quad (2)$$

L_{bf} means basic propagation loss in free space, L_i means the loss in absorption of ionospheric, L_g means loss in ground reflection, Y_p means loss in additional system. The following figure shows the loss of four parts: L_{bf} is the energy loss in free space, L_i is the energy loss in absorption of ionospheric, L_g is the energy loss earth's surface reflection, Y_p is the energy loss in additional system[2-5].

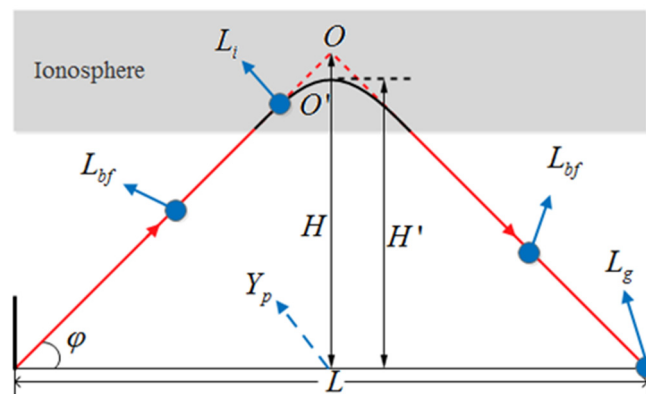


Figure 1. The consumption of radio propagation

We found that the launch angle is the core factor affecting the minimum energy loss, by which maximum numbers of hops can be calculated.

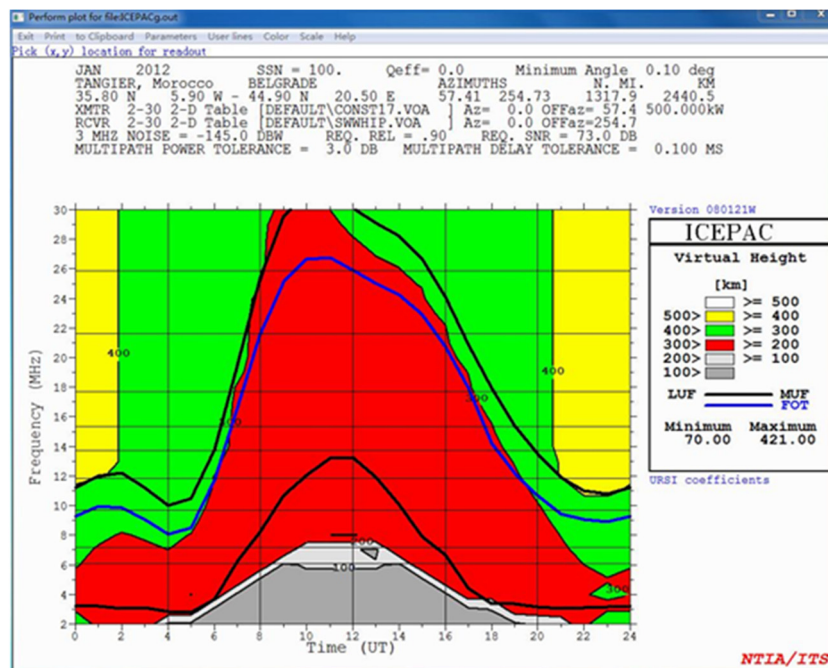


Figure 2. Lomograph

Too many variables may lead to complicated calculating. Hence, we want to get the equation which only has φ as variate, so we have to confirm the relationship between other variates. With the help of HFant, a software can analysis and predict HF propagation, we fit the figure of Lonogram, (Vertical measurement ionization diagram), and the relationship between frequency f and height of ionosphere H' . Lastly, we quantification the equation. The Figure 2 shows the result of Lonogram.

Meanwhile, Sea waves are another count for much factor affecting maritime communications. Sea level waves are usually described by numerical series of sea state [6].

Table 1. The sea condition level of Douglas

Sea condition level	Douglas	
	Root-mean-square of waveform height	Description of sea surface roughness
0	0	Calm
1	< 0.3	Smooth
2	0.3~0.9	Slight
3	0.9~1.5	Mitigatory
4	1.5~2.4	Rough
5	2.4~3.7	Very rough
6	3.7~6.1	High
7	6.1~12.2	Very high
8	over 12.2	Steep
9	...	...

3. Optimization fitting based on machine learning

We have established a database which is related to latitude and longitude by the HFant software with launching angle φ as the argument, measuring frequency f as dependent variables. The database can realize the virtual high H' fitting function of the world by changing different launch angle φ .

We can get the final number of energy loss by equation (2). We use the data which generate by HFant to fitting function, get the following Figure 3:

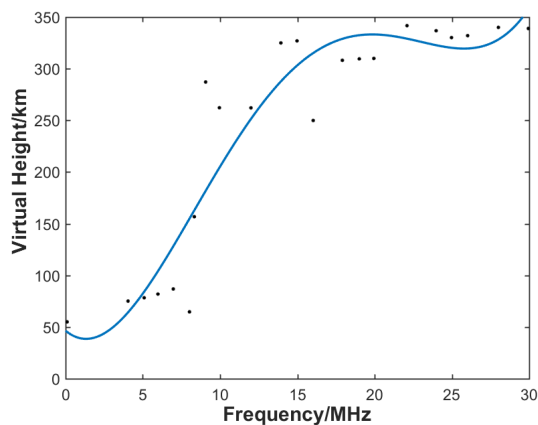


Figure 3. Four times fitting function

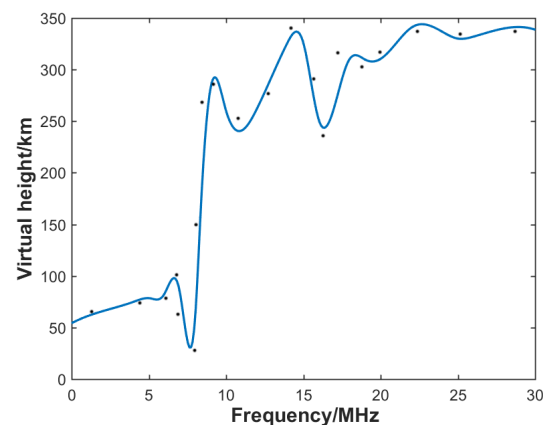


Figure 4. Machine Learning-based fitting function

After fitting, we get the function here: $y = 0.0046x^4 - 0.29x^3 + 5.2x^2 - 12x + 46$

From above picture we can find that the fitting result has a lot of error, so we use the Slope Descent Algorithm in Machine Learning to optimize the result. First, according to the result of initial fitting by MATLAB, we assume the fitting function is $H'(\theta) = \theta_0 + \theta_1x + \theta_2x^2 + \theta_3x^3 + \theta_4x^4$, where the frequency f is the number of training sets, the virtual high H' is the number of features. We can get the global optimal solution, by using gradient descent method to update each θ .

We can see from Figure 3 that the fitting result is good. Thus, a dynamic model of frequency f and virtual high H' is established. We can use above fitting function to calculate the total energy loss to get the maximum number of hops.

4. Take the Strait of Gibraltar as an example

In order to verify the effectiveness of the model, we select the Strait of Gibraltar (35.8N, 5.9W) as the signal start point. We invoke the vertical measurement ionization data from VOACAP analysis software. We can get the accurate energy loss spectra by inputting different frequencies and firing angles using the above model.

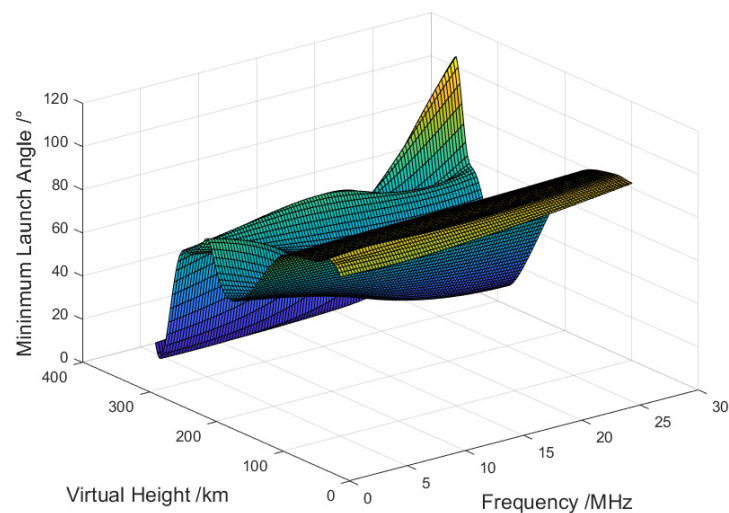
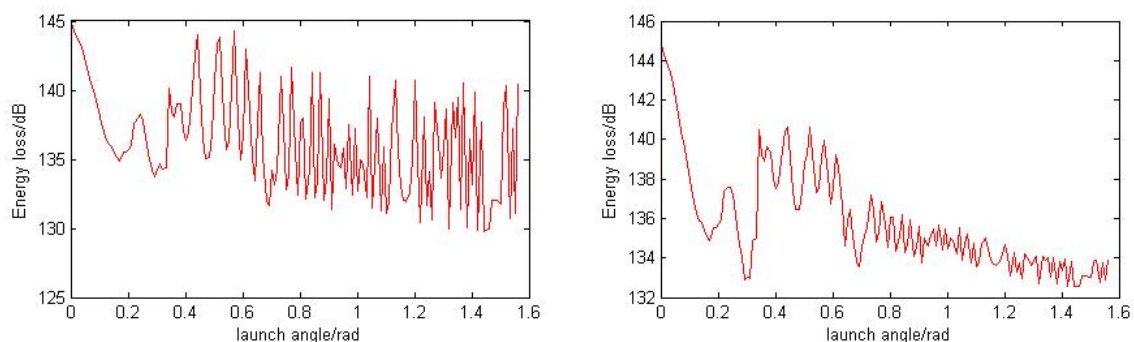


Figure 5. The accurate energy loss spectra

After the SNR is introduced, we obtain the relationship between the hops number and the emission frequency and the launch angle. Under the condition of the problem, the maximum number of hops is calculated as follows: occurs at a certain frequency, certain angle.

We first use the above model to calculate the radio's energy loss in propagation at the clam ocean. The function diagram of launch angel and the energy loss can be found in Figure 5. Then, we need to distinguish the difference between clam ocean and waves ocean, we introduce the concept of root-mean-square of waveform height. You can find the value of RMS of WH in Table 1

So, we can change the level of sea condition to describe the wave's level, and we can forming the different sea condition level's function diagram. We chose level 0, 3, 6 and 9 as typical, shows in Figure 6.



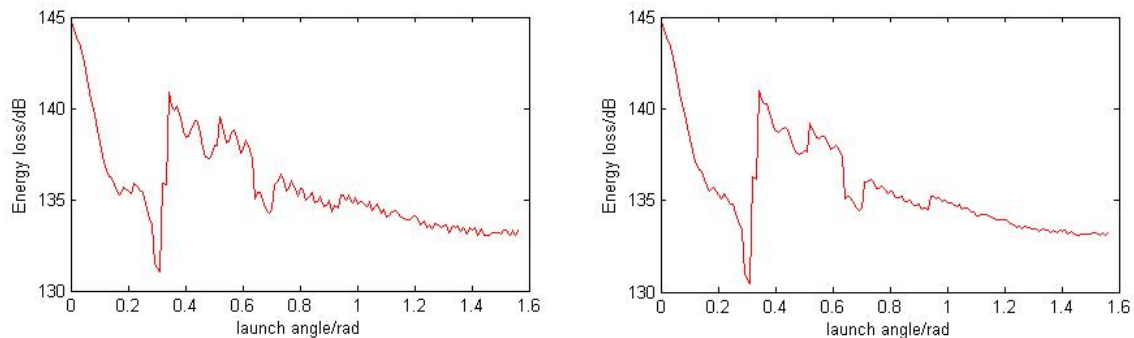


Figure 6. Sea condition level at 0, 3, 6, 9 respectively

5. Conclusion

Based on the existing research results of HF Radio Propagation, this paper studies the energy loss process of HF Radio Propagation and the relationship between launch angle and other variables by means of machine learning optimized model. Finally, the maximum hop number of the primary signal in the range of energy loss is calculated. Finally, the following important results were obtained:

① When use the same frequency to launch HF radio, the volatility of loss's changing decrease if launch angle increase gradually.

② Under different sea wave state, we found that the minimum energy loss corresponds the launch angle is getting smaller with the increasing of waves' height.

③ In the case of 100-watt HF constant-carrier signal and reflections take place off calm oceans, we found that the HF radio which is launched at Gibraltar (35.8N, 5.9W) its maximum number of hops is 4 times. If we change the conditions of the transmitted signal, we may get different conclusions.

HF radiography has important applications in information transmission, accurate positioning, and improving the efficiency of signal use. At the same time, it has the advantages of long detection distance, wide coverage and strong survivability. Therefore, HF radio related research is very necessary. We hope our researches are helpful for research of radio propagation, especially for some energy loss and the integration with machine learning, optimization [3].

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