Predictive Study of Uniformity of Variable Frequency Microwave Heating Based on PSO-SVM

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ABSTRACT

Due to the complexity of temporal and spatial characteristics during microwave heating, the unpredictability of the magnetic field makes it difficult to accurately predict the heating effect by traditional modeling methods. Aiming at the problems of uneven material temperature distribution and unpredictable heating results during microwave heating, a variable frequency strategy is proposed to improve the heating uniformity and estimate the heating effect using a support vector machine. Firstly, this paper proposes variable frequency heating to move the hot spot position according to the fixed frequency heating effect. Then the particle swarm optimization (PSO) algorithm support vector machine (SVM) model is introduced to predict the uniformity index of variable microwave heating. The numerical calculation results show that the proposed method has accurate prediction results for the heating results of the variable strategy.

Keywords: microwave heating, variable frequency, particle swarm optimisation, support vector machine, uniformity index prediction

1. INTRODUCTION

Microwave heating is widely used in industrial production and daily life due to its high efficiency and energy-saving features, but uneven heating can lead to the reproduction and survival of harmful organisms causing food safety issues [1]. There are many ways to improve the uniformity of microwave heating, there have been studies from the reaction cavity internal modification, JIANG et al. considered that moving elements affect the pattern of the electric field in the cavity and proposed a combination of rotation and boundary motion. A continuous algorithm based on a moving grid was used to simulate the heating process. This method can balance the heating uniformity and efficiency [2]. Modifying the internal structure of the cavity is often costly and limited in application. Optimizing the parameters of the microwave source can also achieve improved uniformity and is easier to implement. DU et al. compared simulated temperature distributions at a fixed frequency with different frequency shift rate rise and fall processes and demonstrated that the heating uniformity and efficiency are highly influenced by the head and tail frequencies as well as the frequency shift rate [3]. Frequency changes will affect the magnetic field distribution changes in the cavity and thus change the temperature distribution, the use of good use of the characteristics of each frequency will be able to maximize the potential of inverter microwave heating.

The particle swarm optimization algorithm is a heuristic technique for solving problems in which many events occur simultaneously. Over the years, the particle swarm algorithm has been improved to solve many other types of optimization problems. Chen et al. proposed a new set-based particle swarm optimization (S-PSO) algorithm for solving certain combinatorial optimization problems in discrete space [4]. Adnan et al. proposed a hybrid prediction method combining PSO with grey wolf optimization and an extreme learning machine for the runoff prediction in the MANGLA watershed in northern Pakistan [5]. It is feasible to improve PSO for use as a solution to the prediction problem. In this paper, we propose a method to predict the uniformity of variable frequency microwave heating using PSO improved SVM's model, which provides new ideas for subsequent research on variable frequency microwave heating.

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2. MICROWAVE HEATING

Here to study a basic microwave heating system, the heating specimen selected during the heating process without significant magnetisation phenomenon of potatoes, cavity parameters shown in figure 1:

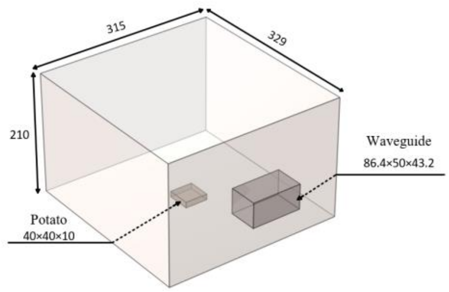

Figure 1. Microwave heating three-dimensional diagram (Unit: mm).

Microwave heating is a complex process, usually, the microwave propagation part is described by a system of Maxwell's equations, and the rate of warming of the heated material derived in the literature [6] can be finally expressed as:

$$\frac{\partial T}{\partial t} = \frac{\pi f \varepsilon_0 \varepsilon'' |E|^2}{\rho_m C_p} \tag{1}$$

Where: ρm denotes the density of the medium; Cp is the specific heat capacity; f denotes the frequency of the electromagnetic wave; T denotes the real-time temperature. From the equation, the microwave frequency has a great influence on the temperature rise. The selection of variable frequency heating can influence the temperature field distribution. The temperature uniformity index (UI) is expressed as follows [7]:

$$UI = \frac{\frac{1}{V_{vol}} \int_{V_{vol}} \sqrt{(T - T_{av})^2} dV_{vol}}{T_{av} - T_{initial}} \tag{2}$$

Where: Vvol is the material volume and Tav the average temperature. the smaller the UI value, the better the variable frequency uniformity.

3. PREDICTION MODEL FOR UNIFORMITY OF VARIABLE FREQUENCY HEATING BASED ON PSO-SVM

The fixed hot spot position generated during heating at a fixed frequency (2.4-2.5GHz) will result in a larger temperature difference between cold and hot spots and a continuous deterioration of material temperature uniformity. There are two main advantages to using variable frequency heating. One is its ability to provide uniform heating on large volumes with high energy coupling efficiency, and the other is its selective heating on different parts of the object, which has different dielectric properties on the main body [8]. This study sets the heating duration to 20 seconds and a step size of 2 seconds. For each step size, an appropriate frequency (step size of 0.01 GHz within the range of 2.4-2.5 GHz) is selected. The selective heating feature of variable frequency heating is utilized to move the hot spot position to the cold spot, thereby balancing the material temperature difference. The final variable frequency curve is shown in figure 2:

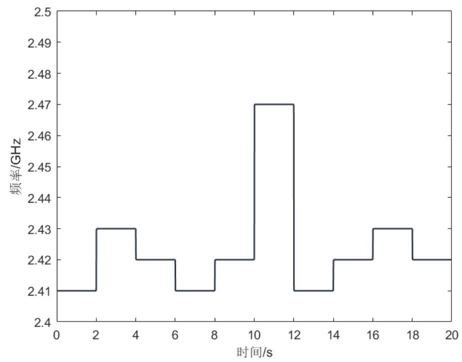

Figure 2. Variable frequency curve.

The heating results obtained by the variable frequency strategy in figure 2 are shown in figure 3. From figure 3, it can be seen that the UI data is better than fixed frequency heating (2.40-2.50 GHz), the uniformity is improved by 9.23% - 42.5% compared to fixed frequency heating, and the heating efficiency is improved by 4.46-40.88 ℃, proving that the variable frequency strategy helps to improve heating uniformity.

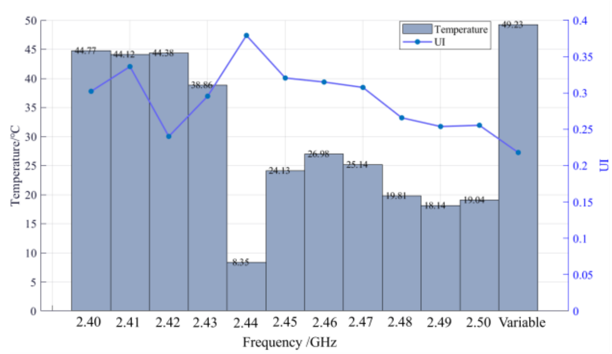

Figure 3. Comparison of heating results.

For the data samples of variable frequency microwave heating, the SVM regression method aims to establish an optimal hyperplane, classify the positive and negative samples, and maximize the edge distance between the two. The penalty factor c and kernel function parameter g play a decisive role in the performance of SVM classifiers. The particle swarm optimization algorithm is used to optimize the selection of SVM parameters c and g. Construct a variable frequency microwave heating uniformity prediction model based on the PSO-SVM algorithm, and obtain the flowchart shown in figure 4:

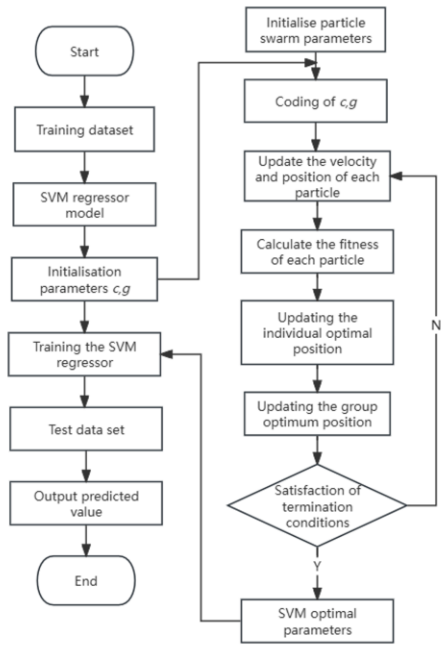

Figure 4. Flow chart for predicting the uniformity of variable frequency microwave heating based on PSO-SVM.

4. EXPERIMENTAL RESULTS

If using empirical methods to test frequencies one by one within each step size is time-consuming and inefficient, utilizing the powerful learning ability of machine learning can quickly and accurately obtain the uniformity UI of microwave heating results for different frequency shift sequences. The average time taken by the finite element method is 652 seconds, while the method proposed in this article takes 38 seconds. This study uses MATLAB programming language to implement a prediction model for the uniformity of variable frequency microwave heating. Firstly, the sample data of variable frequency microwave heating is imported into the support vector machine (SVM) model for machine learning. Then, the support vector machine (PSO-SVM) optimized by particle swarm optimization is used to import the sample data into the model for machine learning. Multi-source information fusion is carried out on the temperature uniformity index parameters of variable frequency microwave heating, to accurately predict the frequency shift microwave heating change law of the entire process of heat conduction in the reaction chamber. Divide 1120 sets of data into an 85% training set and a 15% testing set. In PSO, the learning factors c1 and c2 respectively change the maximum step size for particles to move towards individual and population optima, set to 1.5 and 1.7, set the population size to 10, and set the maximum number of evolutions to 100. The range of variation of c and g in SVM is [0.1, 100].

Using RMSE and MAE as indicators to evaluate the trend of changes between the predicted values of the model and the actual measured values, the expression is:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}$$
$$MAE = \frac{1}{n}\sum_{i=1}^{n}|\hat{y}_i - y_i| \quad (3)$$

Where: n is the total amount of measurement data, $\hat{y}_i$ and y_i are the actual and estimated values of microwave heating uniformity UI at time t, respectively.

As a comparison the original SVM model was used to predict the UI as well, see figure 5.

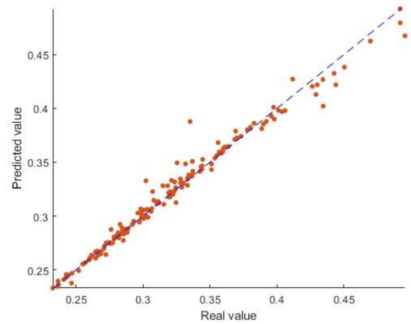

Figure 5. Test set prediction results based on SVM.

In PSO-SVM, the particle swarm algorithm can find the optimal parameter combination after approximately 54 iterations, and the fitness curve is shown in figure 6.

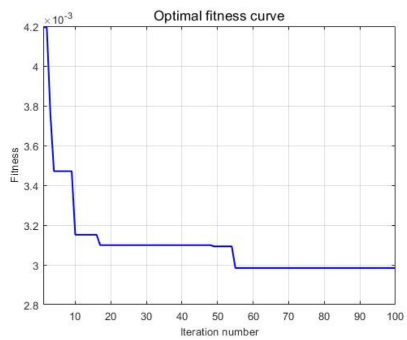

Figure 6. Fitness curve.

The comparison between the predicted and actual values of the test set of the PSO-SVM based variable frequency microwave heating uniformity prediction model is shown in figure 7.

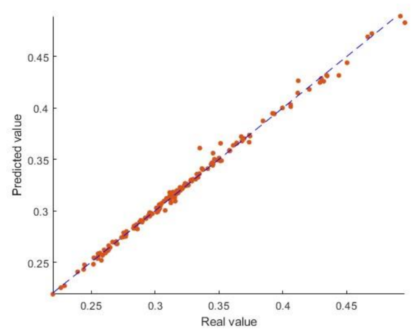

Figure 7. Test set prediction results based on PSO-SVM.

As can be seen in figure 7, the PSO-SVM prediction model has a very good prediction effect on the uniformity of inverter microwave heating, and the majority of the data are accurately predicted, except for some data with a slight error. Its RMSE reaches 0.0044, which is 51.65% higher than the 0.0091 of the SVM-based model, and similarly, the MAE increases by 50% from 0.0027 to 0.0054. The optimization effect of PSO-SVM is very obvious, and the two models can predict the UI more accurately in most cases, with PSO-SVM obtaining a better fitting effect.

5. CONCLUSION

Choosing the appropriate frequency sequence can effectively improve the uniformity of microwave heating. It is time-consuming and laborious to test each frequency in the finite element method, and using the PSO-SVM model can quickly obtain the uniformity index value.

(1) The variable frequency heating of microwave has improved the uniformity by 9.23% -42.5% compared to fixed frequency heating, and the heating efficiency has increased by 4.46-40.88 ℃, proving that the variable frequency strategy helps to improve the heating uniformity.

(2) The variable frequency microwave heating uniformity prediction model based on PSO-SVM can quickly and accurately obtain UI values, and PSO-SVM has a better fitting effect than the SVM model.

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