# Resistance Spot Welding Quality Evaluation System based on Improved Neural Network Model

**Yan Wang[1], Fengjiao Jiang[1,*], Wenmin Zhao[1], Lin Li[1], Xiankun Li[2]**

[1]*Department of Intelligent Agricultural Engineering, Shanghai Vocational College of Agriculture and Forestry, Shanghai, 201699, China*

[2]*School of Mechanical and Power Engineering, Dalian Ocean University, Dalian, 116023, China*

**Corresponding author.*

**Abstract:**

Resistance spot welding is an important branch of welding technology, the quality of its solder joints directly determines the safety and stability of equipment or system. However, resistance spot welding is a complex process of electrical, thermal, magnetic, force, phase change and other multi-factor coupling, and the quality of solder joints is easily affected by many factors, resulting in low detection accuracy, high equipment cost and poor versatility. Therefore, a quality voltage evaluation system of resistance spot welding based on improved BP neural network algorithm is proposed in this paper to realize real-time monitoring of solder joint quality. The BP neural network algorithm is improved to provide training data and algorithm validation data. The characteristic parameters of electrode voltage are selected as the input end of the neural network. The sampling of characteristic parameters is completed through the detection platform. Finally, the sampling points were used as the training set to train the improved BP neural network algorithm, and the neural network model was obtained and tested. The accuracy of the predicted solder joint quality was as high as 94%, which verified the accuracy of the resistance spot welding quality evaluation method.

**Keywords:** improved neural network algorithm, electrode voltage, resistance spot welding, electrode current, welding quality

## INTRODUCTION

Since ElihuThomson invented the resistance spot welding machine in 1877, the resistance spot welding process has been widely used in aviation, automobile manufacturing and other industries. It has the characteristics of energy concentration, high production efficiency, and easy automation [1,2]. The joint quality of resistance spot welding is very easy to be affected by external factors. In the working process of resistance spot welding machine, the welding core is formed in a narrow space where the welding parts contact each other, which cannot be visible to the naked eye, and relevant information about the quality of the welding spot cannot be directly obtained [3,4]. The traditional post-welding sampling inspection method has poor real-time performance, high cost, a large amount of manpower and material resources, and high randomness, and can not find the solder joint defects in time and remedy them [5]. At present, the main means of the domestic and foreign industrial production lines are based on the experience of workers to judge the quality of the welds. Therefore, a reliable artificial intelligence -based neural network algorithm evaluation technology is required to realize the accurate and effective welding quality testing of various welds [6-8].

Primoz Podrzaj et al. built a spot welding quality detection system with electrode displacement as the main research object. By collecting electrode displacement signals in the welding process, they established a relationship model between electrode displacement signals and spatter, achieving the purpose of controlling welding quality [9]. In order to study the welding quality estimation method, Wen et al. established the estimation model based on the regression analysis and back propagation neural network, which improved the accuracy of the eigenvalue estimation of the dynamic signal during the resistance spot welding process [10]. Darshan Shah focused on the development and evaluation of neural network-based systems for trial resistance spot welding process control and weld quality assessment. Parametric study shows the effect of different parameters i.e., weld current, cycle time, and thickness on the weld strength. The relations between parameters are plotted on the graphs [11]. Moslem Valaee-Tale et al. established a theoretical model of resistance spot welding, predicted the occurrence of sputtering based on electrode pressure and displacement, and analyzed the diameter of molten core, electrode pressure, and mechanical properties of welding materials [12,13]. Sang Mok Park et al. proposed a non-destructive testing method using structural vibration to evaluate spot welding quality, and confirmed that welding quality has an impact on the dynamic performance and resonant modal vibration of the tested part, and the quality of the solder joint is judged by modal vibration [14,15]. Dawei Zhao The welding current and the voltage between the upper and lower electrodes were obtained using the Rogowski coil and a line voltage sensor. And then the variations of the dynamic resistance curve and the efects of the welding current and welding time on the dynamic resistance signals were investigated [16].

At present, the research is usually only aimed at monitoring a certain physical quantity or some physical quantity in the welding process, and establishing the relationship between the physical quantity and the solder joint quality through simple fitting technology. However, resistance welding is an extremely complex physical process, so detecting only a single parameter will inevitably introduce errors. Based on the improved neural network algorithm, this article proposes one of the efficient and accurate resistance point welding quality evaluation system that considers many characteristic parameters and non -linear factors, which can improve the efficiency of welding in the aviation and automotive industry.

## IMPROVED NEURAL NETWORK MODEL

The BP neural network is based on a single neuron, as shown in Figure 1, which is a general neuron model with n input, net as the basis function and f as the activation function.

Error-back propagation network is a multi-layer and feedforward network model that learns by means of minimum mean square error. BP neural network consists of input layer, intermediate layer (one or more layers), output layer, each layer contains several neurons. The learning process of BP neural network consists of two parts: forward propagation and back propagation. The structure of BP neural network model is shown in Figure 2.

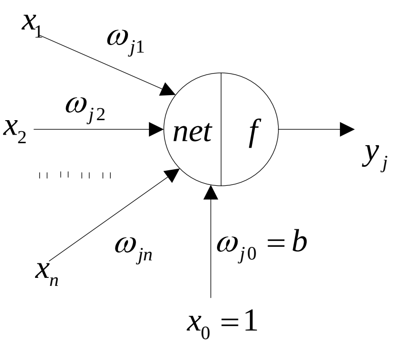


Figure 1. Universal neuron model

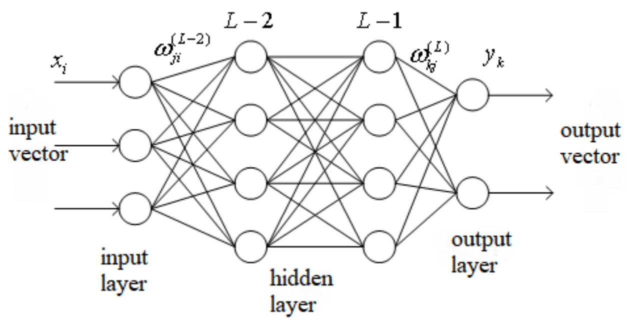


Figure 2. Model of BP neural network

The optimization of the connection weight $\omega_{ji}^{(L-1)}$ and threshold $b_j^{(L-1)}$ of the hidden layer from layer $L-2$ to layer $L-1$ is shown in Figure 3.

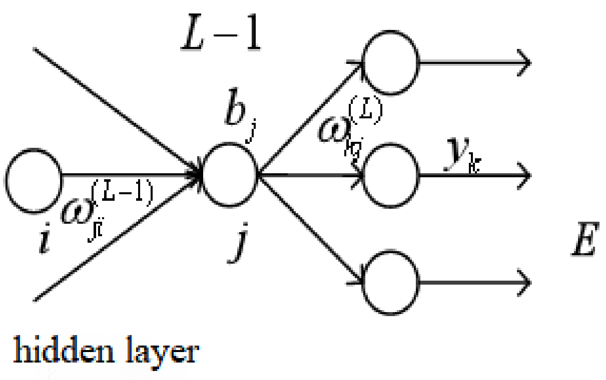


Figure 3. BP neural network error adjustment

For each iteration of BP algorithm, the connection weights and thresholds of neurons at each layer are optimized according to the following gradient descent method:

$$\begin{cases} \omega_{ij}^{(l)} = \omega_{ij}^{(l)} - \eta \dfrac{1}{P} \cdot \sum_{p=1}^{P} \dfrac{\partial E}{\partial \omega_{ij}^{(l)}} \\ b_i^{(l)} = b_i^{(l)} - \eta \dfrac{1}{P} \cdot \sum_{p=1}^{P} \dfrac{\partial E}{\partial b_i^{(l)}} \end{cases} \quad (1)$$

Where, the connected weight value $\omega_{ij}^{(l)}$ and threshold value $b_i^{(l)}$ on the right side of the equation are the values before this iteration optimization, and the left side of the equation are the values after this iteration optimization; $\eta$ is the learning rate.

## WELDING CURRENT DETECTION CIRCUIT DESIGN

### Current Sensor Design

A large number of experiments and practices by scholars at home and abroad have fully proved that in the case of the same welding cycle number, the size of the spot welding current represents the amount of energy input to the welding part of the resistance spot welding machine when working, the more energy, the more metal melted during welding, in the case of no spatter, the larger the melt core, the better the strength of the solder joint. According to the characteristics of welding current in the welding process, a current transformer, Rogowski Coil, is the best detection sensor. It has the following advantages: 1) Because the coil has no iron core, there is no saturation characteristic, so it has good linearity and measurement accuracy in the range of 0.1A to $10^6$A. 2) It has a fast response speed in the current frequency range from 0.1Hz to 1GHz. 3) Compared with other types of sensors, there is no danger of secondary open circuit, and the safety is higher. 4) Easy installation and maintenance, no need to string into the main circuit of the measured current during measurement, can achieve isolated measurement.

### Rokowski Coil Design

The Rocoves base coil is a hollow ring coil uniformly wound on a non-ferromagnetic material, which is composed of two parts: the coil itself and the non-magnetic skeleton, which is divided into flexible and non-flexible. The installation and use of the Rokovs base coil is very simple, and the wire can be directly wrapped in the measured conductor and as far as possible to ensure that the conductor is in the center of the coil. The basic principle of the Rokowski coil is shown in Figure 4:

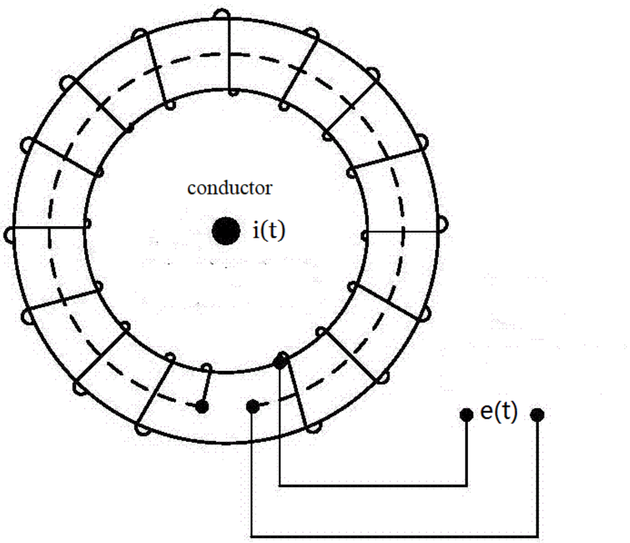


Figure 4. Rokowski coil schematic

The range of this current sensor is from a few milliamps to tens of thousands of amps, with a quick instantaneous response ability and its frequency of measured current, the size of the current, the size of the measured conductor has a strong adaptability, easy installation and debugging, strong anti-interference ability, widely used in large current measurement occasions.

**The Design of Integrated Circuits**

Since the output signal of the Rocoves baseline coil is the differential value of the current flowing through the conductor, the signal detection system needs an integral link to collect the specific value of the detected current. The integral circuit is a circuit that makes the output signal proportional to the time integral value of the input signal, which is mainly used in signal waveform transformation and integral compensation in closed-loop control. An integrated circuit designed and constructed using an integrated operational amplifier compared to a passive integrated circuit.

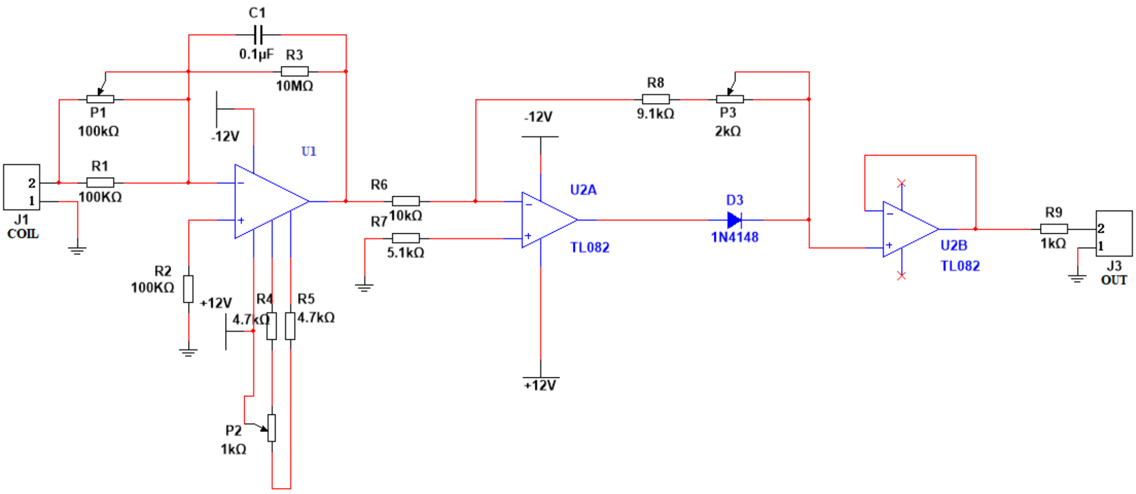


Figure 5. Signal conditioning circuit design

In the signal conditioning circuit shown in Figure 5, the left half is an integrating circuit, and the right half is an amplifying circuit. The main function of resistor R1 is to limit the current and prevent the input current to the operational amplifier from being too large. The main function of the potentiometer P1 in parallel with R1 is to adjust the resistance of the inverse input of the operational amplifier, so as to achieve the purpose of adjusting the amplification factor of the input voltage and the output voltage. Although P1 in the integrated circuit can achieve the function of adjusting the magnification of the signal, the signal load capacity is still weak, so an amplifier circuit is needed to amplify the signal and improve the load capacity of the signal. Amplifying the circuit part, using the operational amplifier TL082, which is a voltage follower, will not affect the size of the signal in the circuit, can improve the load capacity of the circuit and operation accuracy.

**Data Acquisition Program Design**

MATLAB can not directly operate the data collected by the USB data acquisition card. In order to realize the transmission of sensor signal -> Data acquisition card ->MATLAB, this paper uses C language to write an application program to call the driver function to realize the real-time reading of the underlying hardware I/O. Mex file is used as the program interface of MATLAB and C language, and the program is compiled into a function that can be directly called in MATLAB, which realizes the reading and writing operation of USB interface data of PC by MATLAB software, and further data processing by MATLAB to realize the collection and storage of relevant data of resistance spot welding [17-20]. The program flow is shown in Figure 6:

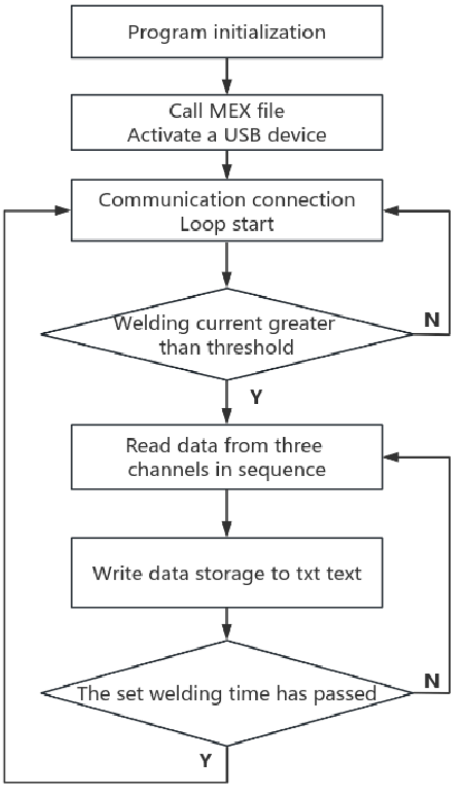


Figure 6. The flow chart of program

## WELDING EXPERIMENT AND CHARACTERISTIC PARAMETER ACQUISITION

### Construction of Welding Experiment Platform

The resistance spot welding machine used in this paper is a suspension spot welding machine produced by Tianjin Qisuo High-tech Co., LTD., as shown in Figure 7. This type of spot welding is a small hanging spot welding machine, due to the smaller power is mainly used in thin plate structure of low carbon steel, coated steel plate and other parts spot welding processing. The working process of the spot welding machine is controlled by the logic control unit in a closed loop, and the welding current is kept constant during the welding process through feedback. There are three control modes: constant current mode, constant voltage mode and constant phase mode. The main engine is equipped with protective measures to protect the personal safety of the operator.


Figure 7. The control cabinet and welding tongs of the welding machine

Electrode is an important part of resistance spot welding machine, different welding materials, welding process parameters need to use different types of electrodes, different materials. The electrode used in the experiment is shaped like a cone table, the electrode material is chrome-zirconium copper alloy, and the diameter of the cone table electrode is 6.5mm.

In this paper, the welding experiment is mainly for 0.8mm thick, grade 10# low carbon steel plate spot welding test. 10# steel average carbon content is 10 ‰, the material plasticity, toughness is very good, easy hot and cold processing forming, normalizing or cold processing after cutting performance is good, excellent weldability, no tempering brittleness, hardenability and hardenability are poor, used for manufacturing requirements of the force is not large, high toughness parts, the material mechanical properties parameters are shown in Table 1.

Table 1. Mechanical properties of 10# steel

| strength of extension($\sigma_b$/MPa) | yield strength($\sigma_s$/MPa) | Yield of regulation(δ5/%) | reduction of area(ψ/%) |
|---|---|---|---|
| ≥335 | ≥205 | 55 | 31 |

**Feature Parameter Detection Platform Access and Parameter Acquisition**

The processed specimens of spot welding experiment are cut according to the standard size of specimens specified in the tensile test method of welded joints in national standards such as GB2651-89, GB2649-89, GB228, etc. The size of the specimen is 100×20×0.8mm [21-23]. The welding process specification used in the spot welding experiment is selected according to the thickness and material characteristics of the welding material. After consulting the welding process specification, the recommended welding time of 10# steel plate with a thickness of 0.8mm is 20 cycles, the electrode pressure is 2000N (the pressure of compressed air in the cylinder of the welding clamp is about 0.33Mpa), and the welding current is adjusted within a reasonable range. The changes of electrode pressure and electrode voltage under different conditions were recorded, as shown in Figure 8. The value range of welding current in this study (3000A,8000A) and the welding process parameters used are shown in Table 2. A total of ten groups of welding process parameters, five specimens were welded in each experimental group, all of which were subjected to tensile experiments. The data collection process took welding current signal as the trigger signal, and the data acquisition system collected current signal in real time. When the value of the welding current is detected to be greater than the set threshold, the data collection begins [24-27].

Table 2. The welding parameters of tests

| No | Welding time (cycle) | welding current (A) | cylinder pressure (MPa) | Number of specimens | Solder joint condition |
|---|---|---|---|---|---|
| Test1 | 20 | 3000 | 0.33 | 5 | incomplete fusion |
| Test2 | 20 | 3500 | 0.33 | 5 | incomplete fusion |
| Test3 | 20 | 4000 | 0.33 | 5 | No spray |
| Test4 | 20 | 4500 | 0.33 | 5 | No spray |
| Test5 | 20 | 5000 | 0.33 | 5 | No spray |
| Test6 | 20 | 5500 | 0.33 | 5 | No spray |
| Test7 | 20 | 6000 | 0.33 | 5 | No spray |
| Test8 | 20 | 6500 | 0.33 | 5 | Light spatter |
| Test9 | 20 | 7000 | 0.33 | 5 | Heavy spatter |
| Test10 | 7 | 8000 | 0.33 | 5 | Heavy spatter |

When the data acquisition system receives the trigger signal of the welding current, it begins to collect the pressure signal between the upper and lower electrodes until the welding time is up. The original electrode pressure signal collected by the signal acquisition system is shown in Figure 9. The horizontal coordinate is the welding time and the 20 cycle waves are 140ms, and the vertical coordinate is the electrode pressure value obtained after conversion of the signal collected by the gas pressure sensor. It can be seen from the figure that the electrode pressure curve fluctuates between 2005N and 2015N, indicating serious interference noise. After filtering, as shown in Figure 10, the signal curve becomes like a straight line.

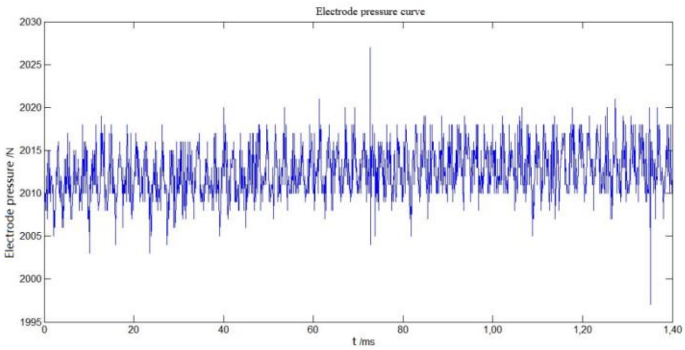


Figure 8. The original signal of electrode pressure

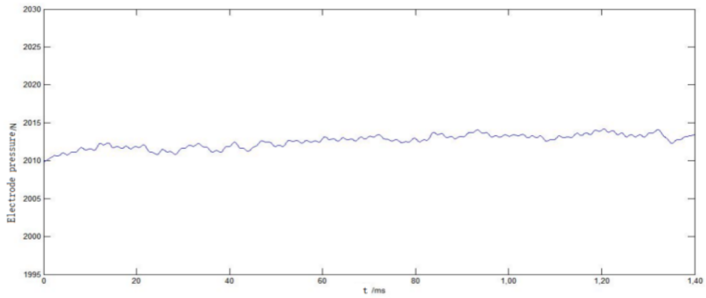


Figure 9. Filtered pressure curve

In order to verify the relationship between welding current and electrode pressure, the electrode pressure signals of all specimens were filtered, and the relationship between electrode pressure and welding current was drawn, as shown in Figure 10. In order to see the relationship between the two more clearly and accurately, the electrode pressure signals of 5 specimens with the same welding parameters were averaged, and the curve force of welding current and electrode pressure was drawn, as shown in Figure 11.

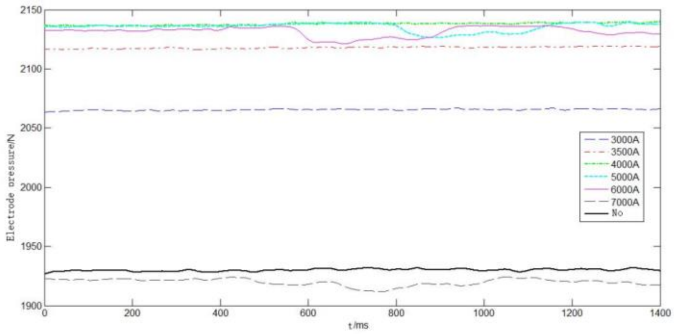


Figure 10. Electrode pressure curve corresponding to different welding currents

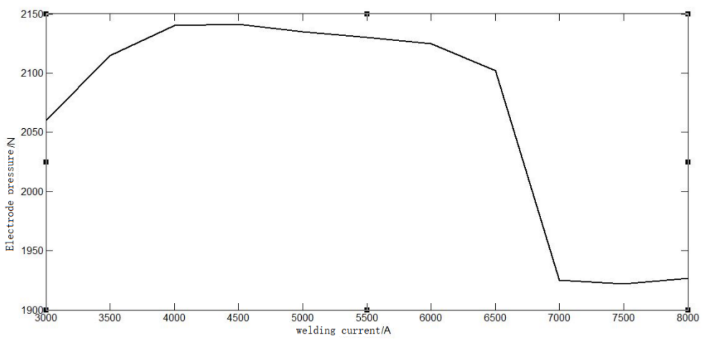


Figure 11. Current-mean pressure curve

**IMPROVED VALIDATION OF BP ARTIFICIAL NEURAL NETWORK MODEL**

The established artificial neural network model is trained and simulated for 10 times respectively, and the training set and test set of each experiment are randomly generated, among which the training set has 50 groups of data samples. The results of one training are shown in Figure 12, 13 and 14. Figure 12 shows the process of root-mean-square error decreasing gradually as the number of iterations increases. When the number of iterations reaches 467, the root-mean-square error is less than 0.001, and the set target value is reached, and the iteration process stops. The top half of Figure 13 shows the process of gradient descent with the increase of the number of iterations, while the bottom half shows cross-validation. 0 indicates that the training process does not fail, and the training process ends after 6 consecutive verification failures. In this case, the performance of the trained model is not good. Figure 14 shows regression for training, cross-validation, and testing.

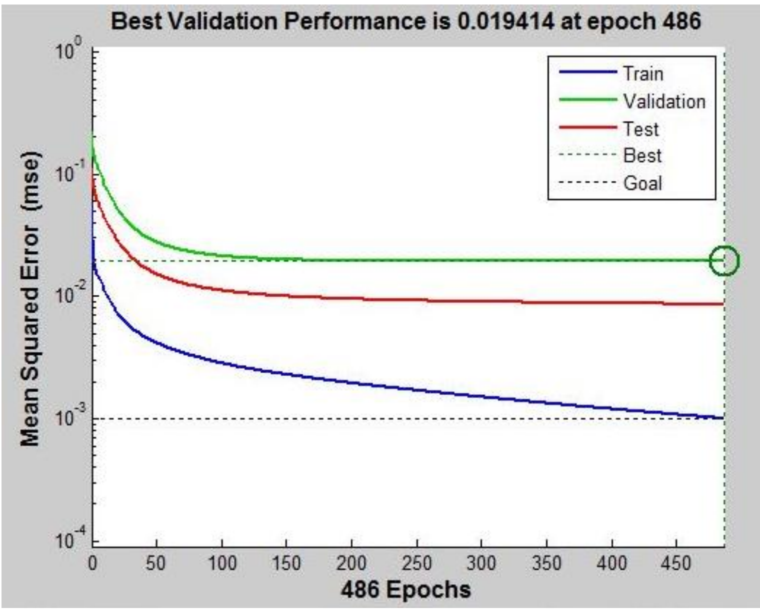


Figure 12. Root mean square error

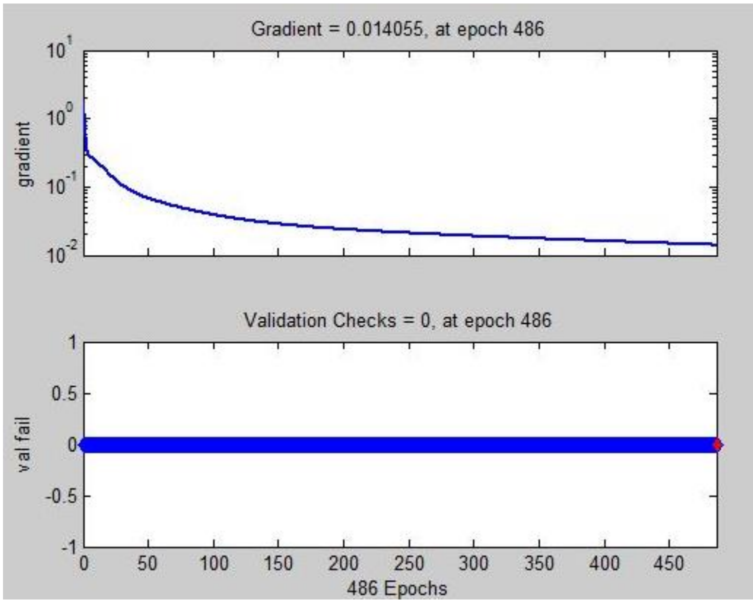


Figure 13. Gradient and cross validation

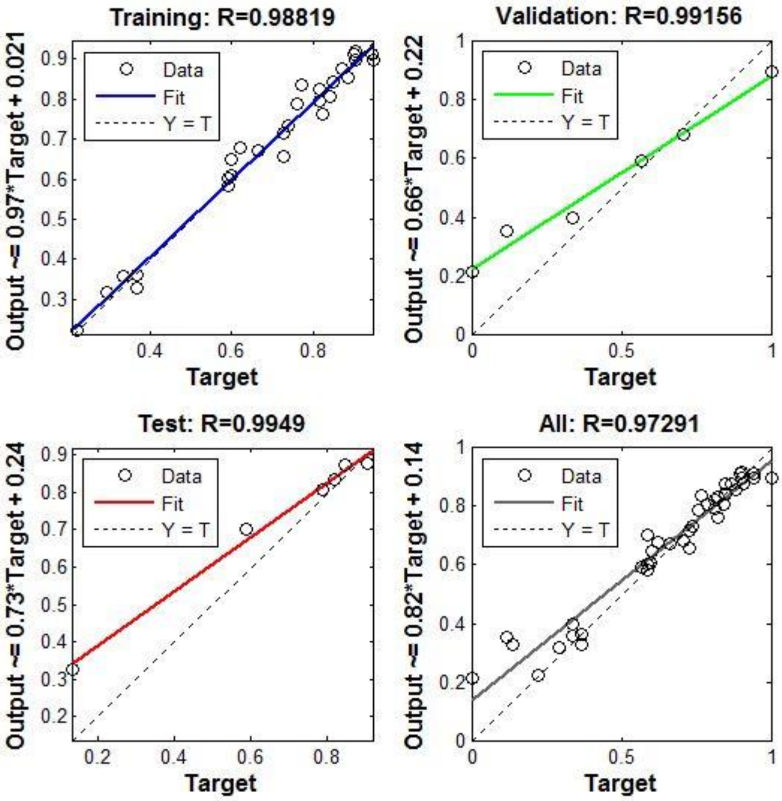


Figure 14. Linear regression

According to the analysis of the simulation experiment results, more than 94% of the results are no problem, and the relative error is less than 6%, which can meet the detection requirements of the tensile strength of the solder joint. The average relative error of 100 experiment results is 3.34%. In the experiment, there were 7 abnormal prediction results, and the maximum relative error of the prediction results reached 14.1%, which was caused by insufficient number of learning samples. When the learning sample data of the improved BP artificial neural network is large enough and meets the conditions of diversity, the performance of the network model will be further improved. Therefore, in subsequent experiments, the sample data of the experimental training needs to be increased to ensure that the experiment is smaller.

## CONCLUSION

The obtained data were preprocessed through data compression and normalization. The welding current signal, electrode pressure signal and electrode voltage signal of the sampling points of the training group were taken as the input of the improved BP neural network algorithm, and the welding joint tensile strength parameter of the sampling points of the training group was taken as the output of the improved BP neural network algorithm. The threshold value of each node and the weight between nodes were calculated by genetic algorithm. Finally, the improved BP neural network model is obtained. By substituting the input data of the test group and comparing the result with the real output data of the test group, the average relative error of the predicted result is 3.34%, which shows that the resistance spot welding quality evaluation system proposed in this paper has a certain accuracy. Of course, during the subsequent experiment, if the number of samples is increased, better accuracy will be obtained.

## ACKNOWLEDGMENT

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