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Human Positioning System based on Pyroelectric Infrared Sensor and GA-BP Neural Network

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Abstract: *In order to use the PIR sensor to position the human body more effectively, this article proposes a human target positioning system based on multiple sensors layouts and GA-BP neural network. On the hardware, an PIR peripheral circuit is designed to detect, amplify, and filter infrared signals. On the software, this article uses genetic algorithm to optimize BP neural network, and designs a trilateration algorithm to convert the distances from the three sensors to human into coordinates. The experimental results show that the GA-BP neural network converges faster, the mean square error of the X-axis and Y-axis are reduced by 90.3% and 81.9%, and the positioning error is reduced by 0.24m.*

Keywords: *PIR, Human target positioning, amplifying and filtering circuit, GA-BP neural network, trilateration*

1. Introduction

With the improvement of people's safety awareness, there is an increasing demand for human target positioning to achieve large-scale monitoring in various application fields. Human target positioning is mainly divided into two categories, video detection and PIR detection.Although video detection has high detection accuracy, it is costly, occupies a large amount of storage, easily leaks privacy, and is greatly affected by environmental changes. In contrast, PIR has the advantages of low energy consumption, low price, easy installation, strong anti-interference ability, and not easily affected by background and light[1]. Therefore, PIR has broad market demands and application scenarios in reconnaissance and security[2].

However, there are two existing problems with using PIR for human target positioning: (1) Hardware: Most detectors are based on a single sensor, but the detection angle is limited and the complete information cannot be obtained; (2) Software: The previous algorithm can only judge whether there is someone or no one in a certain area, and it is difficult to obtain the relationship between the voltage signal detected by the PIR sensor and the specific position of the human target[3].

To solve the above situation, this article chooses to use BP neural network algorithm to achieve the human target positioning. It is a multilayer feedforward neural network according to the error back propagation. Although it has a simple network structure and strong nonlinear mapping capabilities, it also has many shortcomings: it is easy to fall into the local optimum,its convergence speed is slow, and the network structure is also not easy to determine[4]. In order to overcome these shortcomings, some optimization algorithms can be added into the design of the BP neural networks, such as genetic algorithm and particle swarm optimization algorithm[5].

Genetic algorithm uses genetic operation and natural selection of survival of the fittest to determine the search direction, which can optimize the topological structure of the BP neural network and its weights and thresholds. Genetic algorithm has good adaptability and robustness.It can effectively solve the problem of BP network being easily trapped in local optima and slow convergence speed, and can select the quantity of hidden layer neurons reasonably[6].

Therefore, this article optimizes the BP neural network based on genetic algorithm, takes weights and thresholds as genes, optimizes its initial weights and thresholds, and obtains the nonlinear relationship between the infrared signal and the distance of the human target.

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2. PIR Detection System

The PIR sensor is a pyroelectric infrared sensor based on the pyroelectric effect. Its working principle is to detect the change in the intensity of infrared light irradiated on the sensor, trigger the change in the heat of the pyroelectric crystal, and convert it into an electrical signal[7]. The PIR detector is composed of a PIR sensor, a Fresnel lens, and a peripheral circuit.

2.1. PIR Detector

2.1.1. PIR Sensor

The PIR sensor consists of a filter, two pyroelectric detectors of opposite polarity connected in series, and a field effect transistor [8].Its structure is shown in Figure 1.

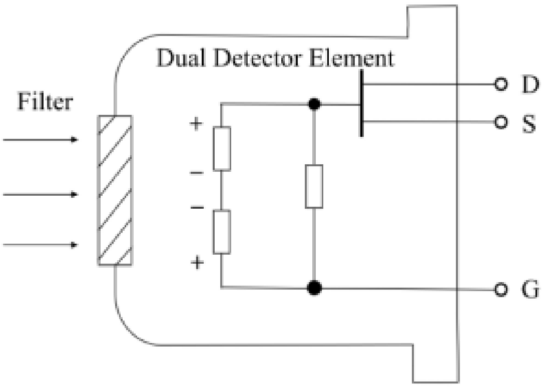

Figure 1: Structure diagram of PIR.

2.1.2. Fresnel Lens

The front end of the PIR is equipped with a Fresnel lens that has two functions: (1) focus the infrared rays, increase the detection distance; (2) partition the detection area to form a constantly changing visible area and a blind area.When human pass through the detection area, there will be alternating changes in temperature, resulting in a change in the amount of charge on the sensor element[8].

2.1.3. Peripheral Circuit

Because the voltage signal output by the PIR is very weak, the peak value is about 3 to 5 mV, and it is also doped with other noise interference. Therefore, this article designs a peripheral circuit to filter and amplify the voltage signal that is weak and containing noise.It includes two parts: band-pass filter and two-stage amplifier, as shown in Figure 2.

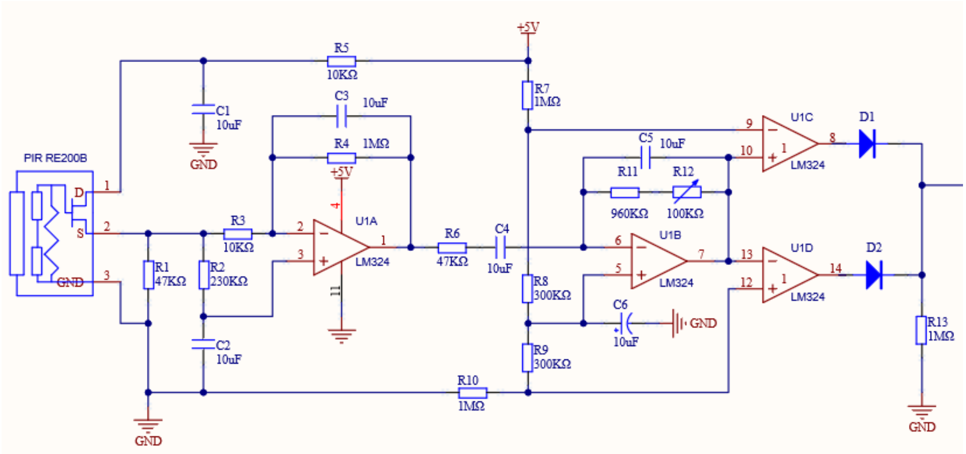

Figure 2: Peripheral circuit.

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2.2. Output Signal Characteristics

2.2.1. Amplitude

The amplitude of the PIR output voltage signal mainly depends on the distance between the human target and the PIR sensor, and the temperature difference between the human body and the background of the detection area. If the distance is smaller and the temperature difference is higher, the amplitude is bigger.

2.2.2. Frequency

The frequency of PIR output electrical signal is as in (1).

$$f = \frac{V_b \times f_b}{2\pi \times S \times L} \tag{1}$$

In the formula, V_b is the moving speed of the human body (m/s), f_b is the focal length of the optical lens system (mm), S is the area of the sensor's sensitive element (mm^2), and L is the distance between the human target and the PIR sensor (m).

3. GA-BP Neural Network

3.1. BP Neural Network

A typical BP neural network is mainly composed of three parts: input layer, hidden layer and output layer. Its structure is shown in Figure 3.

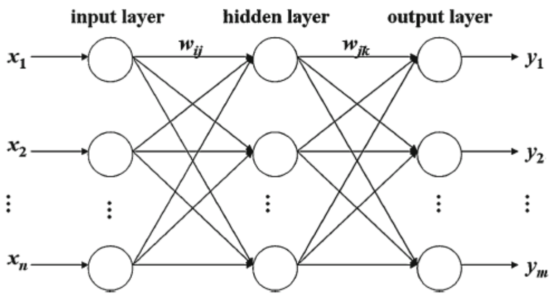

Figure 3: Structure diagram of BP neural network.

The calculation process of BP neural network is mainly divided into three stages [9]:

1) Calculation error:Information is transmitted from the input layer to the output layer, and compare the actual output with the expected output to get the error.

2) Adjust the weights and thresholds: The error is propagated back to the input layer layer by layer, adjust the weights and thresholds of each unit, and establish the training model.

3) Test:The test data is input into the trained model to verify the accuracy of the BP neural network model.

3.2. Genetic Algorithm

The genetic algorithm finds the global optimal solution of the network through operations such as selection, crossover, and mutation[10].

3.2.1. Encoding

Encoding is the conversion of individual chromosomal information into information that can be recognized by a computer. Common encoding methods are binary encoding and real number encoding. This article adopts real number coding, and the coding length is as in (2).

$$L=n*m+m*l+m+l \tag{2}$$

In the formula, n, m, and l are the quantity of neurons in the input layer, hidden layer, and output layer.

3.2.2. Population Initialization

The population size is generally set at 20-100, and the population size in this article is set at 40. The maximum genetic algebra is related to the end of the operation of the genetic algorithm. The maximum genetic algebra in this paper is set to 50.

3.2.3. Fitness Function

The fitness function reflects the convergence speed of the genetic algorithm and whether it can find the optimal value.It depends on the prediction error, which is the difference between the predicted output and the actual output. The formula is as in (3):

$$E=\sum_{i=1}^{N}(T_i - Y_i)^2 \tag{3}$$

In the formula, T_i and Y_i respectively represent the predicted output and the actual output of the training sample, and N represents the number of training samples.

3.2.4. Selection operator

Selection is to select excellent individuals from the group so that they have the opportunity to pass on good genes. Common selection operations include roulette method, tournament method and so on. This article adopts the roulette method, and its basic principle is to choose according to the individual's fitness. The formula is as in (4).

$$P_{si} = \frac{f_i}{\sum_{j=1}^{N} f_j} \tag{4}$$

In the formula, P_{si} is the probability of the individual being left, f_i is the individual fitness, and N is the number of populations.

3.2.5. Crossover Operator

Two paired chromosomes exchange part of their genes in a certain way to form two new individuals. This process is called crossover. The crossover probability is generally between[0.1, 0.9], and it is set to 0.7 in this article.

3.2.6. Mutation Operator

Mutation is the replacement of certain genes with other genes to form a new individual.The probability of mutation is generally between[0.001,0.1], and it is set to 0.1 in this article[11].

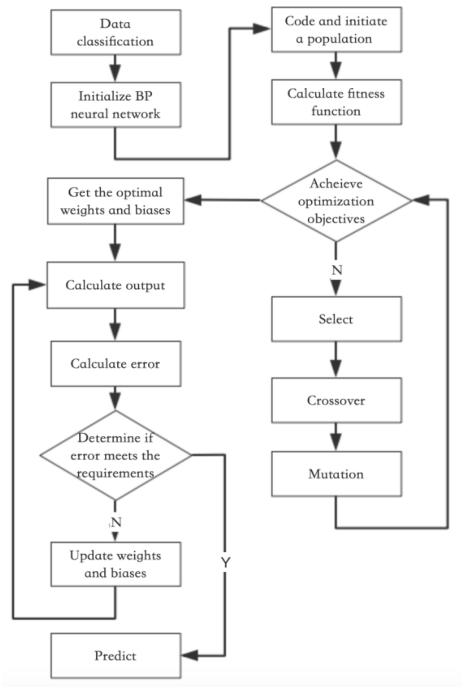

Figure 4: Algorithm flow of GA-BP.

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4. Experimental Program

4.1. Experimental Area

A 10m*10m indoor square area is selected as the positioning area, and three fixed nodes A(0,0), B(5,10), and C(10,0) are set. In order to convert the distance between the three PIR and the human into specific coordinates, this design uses the trilateration which refers to an algorithm based on the distance between the node to be located and the 3 fixed nodes[12]. 3 PIR are placed on the fixed node to detect the infrared signal of the node o (xo, yo) to be located, and the distances d1, d2, d3 from the fixed node A, B, C to the node o to be located are obtained through the GA-BP neural network. Finally, the predicted coordinates o(xd,yd) are calculated according to the three distances.

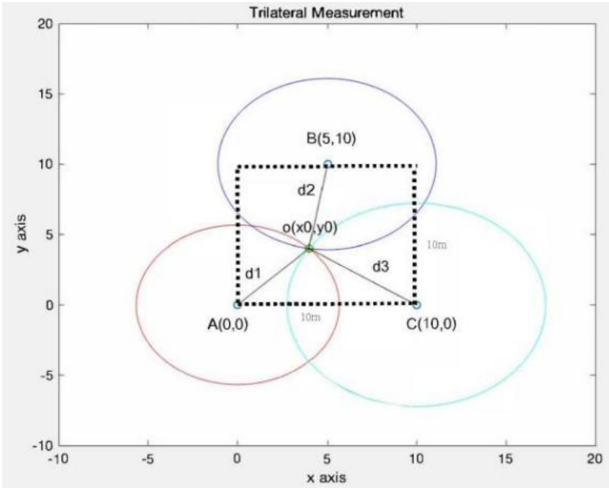

Figure 5: Trilateration.

4.2. Experimental Steps

4.2.1. Record the Actual Coordinates

When the experimenter tests 200 points to be located in a 10m*10m positioning area, each point is collected 5 times, and then record the actual coordinates.

4.2.2. PIR Collection

The infrared signals detected by the three PIRs are amplified and filtered by the peripheral circuit, and then converted into digital voltage signals through an ADC.

4.2.3. UART Transmission

The digital voltage signal is transmitted by the UART of the FPGA and recorded in real time through the serial port debugging tool on the PC side.

4.2.4. Training GA-BP Neural Network Model

3 PIR output signals of the predetermined position are used as the input of the training set, and the distances of the human from the three PIRs are used as the output of the training set to fit the corresponding relationship between the infrared signal and the distance of the target human.

4.2.5. Predicted Coordinates by Trilateration

Using trilateration method, the predicted coordinates (xdi, ydi) are calculated from the distance between the human target and the three PIR sensor,and calculate the error between actual coordinates and predicted coordinates.

5. Experimental Results

5.1. Training Error Curve

It can be seen from the training error curves of Figure 6 and Figure 7 that the BP neural network

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tends to be stable at the 25th iteration, and after optimization, the number of stable iterations is reduced to 15.

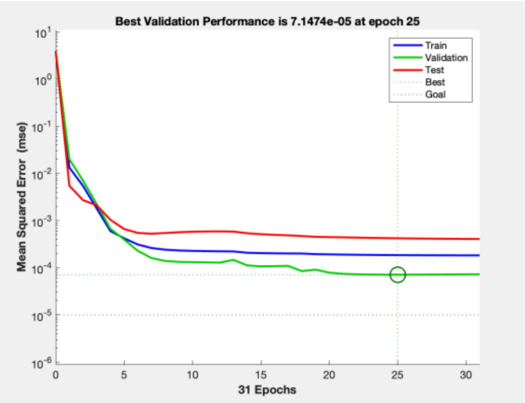

Figure 6: Training error curve of BP.

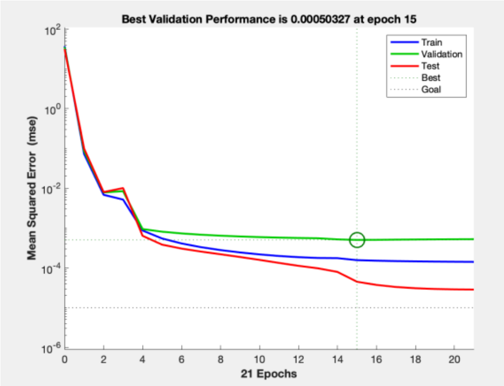

Figure 7: Training error curve of GA-BP.

5.2. Positioning Error

This design randomly selects 20 locations for positioning. The real coordinates, the predicted coordinates of the BP neural network, and the predicted coordinates of the GA-BP neural network are shown in Figure 8. It can be intuitively seen that the predicted coordinates after optimization are closer to the actual coordinates than the predicted coordinates before optimization.

Figure 9 shows the absolute error of the X-axis and Y-axis of the predicted coordinates before and after optimization. When not optimized, the mean square error of the X-axis is 0.1118m, and the mean square error of the Y-axis is 0.0414m. After optimization by genetic algorithm, the mean square error of the X-axis is 0.0108m, and the mean square error of the Y-axis is 0.0075m. The mean square error of X-axis and Y-axis are reduced by about 90.3% and 81.9%.

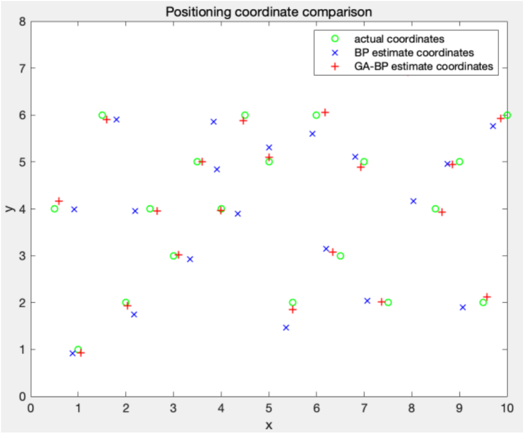

Figure 8: Coordinates comparison.

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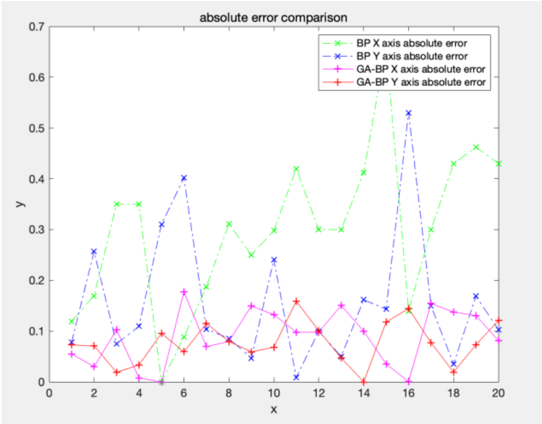

Figure 9: Absolute errors of predicted coordinates.

It can be seen from Table 1 that without optimization, the average positioning error is 0.374m. After optimization, the average positioning error is 0.13 and reduced by 0.24m and 65.2%.

Table 1: This caption has one line so it is centered.

Actual	BP		GA-BP	
(x,y)	(x,y)	error(m)	(x,y)	error(m)
(1, 1)	(0.88,0.92)	0.143	(1.05, 0.93)	0.091
(2, 2)	(2.17,1.74)	0.308	(2.03, 1.93)	0.077
(3, 4)	(3.35,2.92)	0.358	(3.10,3.02)	0.104
(4, 4)	(4.35, 3.89)	0.366	(3.99, 3.96)	0.034
(5, 5)	(5, 5.31)	0.310	(5, 5.1)	0.095
(6, 6)	(5.91, 5,60)	0.411	(6.17, 6.06)	0.198
(7, 5)	(6.81, 5.10)	0.214	(6.93, 4.88)	0.134
(8, 7)	(8.31, 7.08)	0.323	(7.92, 6.92)	0.112
(9, 5)	(8.76, 4.95)	0.254	(8.85, 4.94)	0.161
(10, 6)	(9.70, 5.76)	0.383	(9.86, 5.93)	0.149

6. Conclusions

This article first studies the working principle and output signal characteristics of PIR, and designs a peripheral circuit with amplifying and filtering functions. In order to overcome the shortcomings of BP neural network, this article proposes to use genetic algorithm to optimize and obtain the nonlinear relationship between infrared signal and distance.This article designs a trilateration positioning method, which converts the distance between the three sensors and the target human body into specific coordinates. Finally, an experimental platform is built to verify the feasibility of the improved algorithm, and the results of the GA-BP neural network are compared and analyzed. The experimental results show that the GA-BP neural network has faster convergence speed and higher positioning accuracy.

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