Hindawi
Advances in Multimedia
Volume 2022, Article ID 9226576, 8 pages
https://doi.org/10.1155/2022/9226576

Research Article

Automatic Control System Design for Industrial Robots Based on Simulated Annealing and PID Algorithms

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Received 26 March 2022; Revised 5 May 2022; Accepted 17 May 2022; Published 26 May 2022

Academic Editor: Qiangyi Li

The industry is at the heart of a country's development, and robot automation is the key to this. The automation of industrial robots is extremely beneficial to industrial development. Although China has been increasing its investment in industrial robot automation and control research, there are still many problems in the field of automation and control in the application of industrial robot technology, and there is still a certain gap between the developed countries. On the one hand, this is a serious obstacle to the development of industrial robotics in China, and on the other hand, it has a direct impact on the automation of industrial production, which has a very restrictive effect on industrial development. Therefore, it is necessary to focus on the value of computer technology, automation control technology, and sensor technology in the field of automation. The use of industrial robots can replace monotonous manual labour, reduce the intensity of operations, and increase productivity through high operational precision values. Scientific progress has driven the development process of industrial automation to a new level, allowing fully automated production equipment to become mainstream and gradually replace manual operations. In recent years, the development of industrial automation has led to the development of a series of related industries, of which automated manipulators are one. As a new automatic production line operation equipment, the development of manipulators can greatly improve the automation production level of enterprises and improve labour efficiency. This paper explores the development status of automated manipulators and explore the optimal motion path of manipulators in automatic control engineering by combining simulated annealing algorithm and PID algorithm, so as to greatly enhance the application of truss manipulators in production lines.

1. Introduction

In recent years, as the world economy as a whole has continued to grow, so too has science and technology. The economic strength of a country cannot be measured by economic strength alone, and the widespread use of new technologies such as industrial robots is an important reference point for measuring the level of automation in a country [1]. In order to ensure that industrial robots are widely used, the relevant authorities have issued detailed specifications for the development of industrial robots. With the promotion of various application technologies and policies, the era of industrial robots in China is accelerating and the future of industrial development can be made more intelligent. In the context of the important stage of China's industrial manufacturing development and the urgent need to transform most traditional industries, industrial robots can effectively promote the transformation of China's industrial development and the optimisation and upgrading of many industries. It can accelerate the efficiency of industrial production, control the cost of human resources and production costs, and expand the production efficiency of enterprises [2]. As an important part of the automation production line, industrial robots are being used more and more widely. The study of motion control systems for industrial robots to ensure the accuracy of robot movements is an inevitable trend in the current development of automation [3]. High-performance digital processors occupy an

important position in motion control systems by virtue of their good performance in terms of stability and speed [4, 5]. At the same time, the development of industrial Ethernet technology is becoming more and more mature, and its advantages such as high speed and efficiency and strong information transmission capacity are obvious in the industrial environment [6].

In recent years, the development of industrial robots in various countries has gradually shifted to research directions such as computers [7] and artificial intelligence [8]. Artificial intelligence technology and other areas of synergy development are imminent, so the combination and reform of artificial intelligence technology and industrial automation technology can effectively enhance the degree of national industrial informatization. At the same time, the rapid development of the degree of industrial informatization has to a certain extent driven the development of industrial automation [9]. The development trend of industrial automation is becoming more and more intense among the international community, which also shows that the development space and prospects of industrial automation are very broad [10]. Industrial robots concentrate on the intersection and synergistic development of multiple disciplines such as key computer technology, intelligent control technology, and automatic control theory [11]. Therefore, the application development of industrial robotics is an important symbol and means of measuring the development of national industrialisation. To a certain extent, the development of the machinery manufacturing industry in the direction of information technology and intelligence has promoted the development of industrial robots and automated manipulators. Meanwhile, with the ever-increasing efficiency and accuracy requirements of automated production, motion control technology is also facing huge challenges [12]. With the rapid development of microelectronics technology in recent years, the processing power of microprocessor products is becoming more and more powerful and can meet the requirements in motion control [13]. Motion control technology research in foreign countries started earlier and the development is more mature. At present there are many companies that have developed a series of motion controller products, widely used in industrial robots and many other fields. In the foreign markets, American products dominate, and these products have the advantages of fast computing speed, good compatibility, and a wide range of applications.

Industrial robots are intelligent, programmable, and intelligent devices that can be programmed and taught in advance so that it can operate automatically [14]. Fundamentally, robot control is closely related to dynamics and mechanism mechanics, and different coordinates are used to accurately describe the robot's hand and foot state [15]. In addition to this, the robot is able to follow the will of the human by means of a computer-coordinated independent servo system and can be given the appropriate work content [16]. As a result, industrial robots, like human beings, can have certain visual functions and can make independent judgements and decisions about the working environment and work objects and work logic. Thus, they can replace humans in all complex, hazardous, and repetitive manual work [17]. In the process of the gradual improvement of China's manufacturing and industrial level, the strength of the manufacturing industry has increased; one of the most exemplary representatives is the automotive industry. The automotive industry is gradually moving towards flexible production and intelligent manufacturing [18]. In the field of industrial robots, the application of automated arms occupies a large proportion and has become the representative of industrial robots. For example, some intelligent algorithms or models can be used in the field of construction [19, 20] and manufacturing [21]. A robot resembles a human arm and is able to perform certain movements in accordance with the human arm; it is able to follow a given input program. The use of robotic arms marks the point where research into single direction automation has become a thing of the past. Human beings have used robotic technology to combine intelligent control technology with computer control systems and other related cutting-edge disciplines to further advance the height of intelligent manufacturing.

Industrial robots are multi-degree-of-freedom devices, which normally require three to five degrees of freedom [22]. The different degrees of freedom can be combined to form different multivariable control systems, which allow the industrial robot to describe its hand and foot state in different coordinates and to transform and select the coordinates. In order to ensure that industrial robots operate in accordance with human wishes, they are controlled by computers and controlled intelligently. Nonlinear mathematical models are used to describe the basic operating conditions and movements of industrial robots [23]. The different simulation parameters are transformed according to the robot's movement path, and there is a coupling between the different variables. Under normal circumstances, current industrial robots are able to regulate their movements in a variety of ways and paths to standardise their execution [24]. In addition, high-level industrial robots require a well-developed computerised information base, which can be controlled on the basis of artificial intelligence [25]. In terms of functionality, robots are machines that perform various operations automatically. The industrial robots currently used in industry are capable of performing different operations based on control and power and are equipped with multiple degrees of freedom and mechanical manipulators. They can be guided by human command and can also be made to work freely in advance. As technologies have evolved, industrial robots have also gone through different stages of development. From programmable robots to robots with sensing capabilities and positioning recognition, industrial robots are now increasingly capable of walking and adapting to various environments. Based on the teachings, the memory system of the industrial robot keeps a logical record of the teaching process. During the teaching process, the industrial robot is able to execute the contents of the memory. In the machine control of industrial robots, various status and position information changes, which have a direct impact on the working state. Therefore, it is important to integrate the different dynamic information in the industrial robot application and pass it on to the main system so that it can keep track of the system's stable operation.

At this stage, manufacturers are also being developed and popularised in engine production lines. Improving the level of automation and production efficiency requires a strong theoretical basis to support it. At the same time, the degree of industrial automation in China is not high, and most enterprises still rely on manual means to complete. The disadvantages of manual means lie in the low efficiency and high labour costs. The emergence of robots in production line automation is therefore the solution to these problems, replacing manual operations to complete the process of high-risk operations and repeated operations. In the actual production process, robotic control technology can help manufacturers to reduce labour time and intensity to a great extent, thus achieving the production goal of automated workpiece transport. Therefore, robotic automation control technology is of reference significance for improving the automation level and labour efficiency of enterprises. Manipulators have many advantages, such as the application of robotic loading and unloading technology in machine tool loading and unloading, which can help companies to speed up movement in industrial production and improve movement flexibility [26]. And the advantages of fully automatic robotic loading and unloading equipment also lie in its functional applicability and precise positioning. In the actual working process, the robot is able to work continuously and repetitively, completing continuous work operations. Therefore, in the automated production process, the application of robots can effectively improve the efficiency and manufacturing level, thus effectively reducing the cost of enterprises and enhancing the competitiveness of enterprises in the market. What is more, because the robot can work continuously, there are no work-related accidents in manual operation, and the gripping force can be designed according to the requirements, so it is more necessary to use the robot in harsh working environment.

In recent years, along with the development of artificial intelligence technology, manipulator automation control technology has also been gradually combined with artificial intelligence technology and information flow systems and has been elevated to a new level in the field of intelligent control. The information flow system consists of a number of modules such as a logistics control computer, which is generally used as the master control system to achieve intelligent output and control during the processing and transport of workpieces [27]. In summary, manipulators involve mechanical automation, intelligent control technology, electronics theory, and many other disciplines. Today's computer control technology is also relatively mature, with digitally integrated system networks that are substantially more accurate and stable. At the same time, the rapid development of the macromarket and the demand for computer control technology are also promoting the improvement of automatic control technology for robots. In order to achieve a manipulator that is well adapted to the times, the application of rapidly developing information technology, the addition of simulated annealing neural network algorithms, and the combination of PID control strategies will enable the design of manipulators to meet market needs.

2. Industrial Robot Control System

2.1. Component of Industrial Robot Control System. The industrial robot control system consists of a number of components, including a demonstration box, computer, axis controller, sensors, connection ports, and auxiliary equipment. The control computer of the robot control system is mainly composed of microprocessors and microcomputers, and the control computer mainly plays a comprehensive command role. The demonstration box is equipped with a CPU and a self-contained storage unit. The basic function of the application is to set a number of parameters and to demonstrate them on the basis of a human-computer interaction. The main sensor applications are tactile, visual, and force sensors, which are used to detect different information and to control the industrial robot. Axis controllers are of high value and are used to control the speed of the robot as well as the different operating sequences. The various auxiliary devices are mainly used in conjunction with the industrial robots and are important auxiliary devices as shown in Figure 1.

2.2. Programme Selection of Industrial Robot Control System. With the increasing automation of modern industry, robot production lines are becoming increasingly large and complex, involving more and more robots and therefore placing higher demands on robot control systems. A common robot automation scheme nowadays is shown in Figure 2. In this scheme, the PC cannot perform algorithmic processing, but rather acts as a human-machine interface, with the motion controller performing the complex arithmetic processing. The PC's real-time impact can be minimised when developing the software for the host computer. Therefore, the real-time requirements of the PC are very low and although the workload of the motion controller is increased, the requirements can be met by using a high-performance processor such as DSP. At the same time, the combination of industrial Ethernet technology can solve the problem of numerous cables and serious interference caused by traditional motion control cards connected to PCs via PCI.

Furthermore, Figure 3 shows the structure principle of the industrial robot automation design. The PC is an ordinary PC running Windows, which is the main interface for human-machine interaction. The motion control card with EtherCAT network interface is connected to the PC via a network cable and performs interpolation operations and control algorithms according to the commands given by the PC.

2.3. Analysis of Control Methods for Industrial Robot Control System. Actuators are used in industrial robots to control only some of the points. This type of control allows the robot to be used without the need for multiple specifications to reach the corresponding target points. Unilateral control of the robot's position at adjacent points and basic speed is sufficient, requiring precise and stable movement. The main application of torque control is the application of industrial robots in the gripping and assembly of various objects,

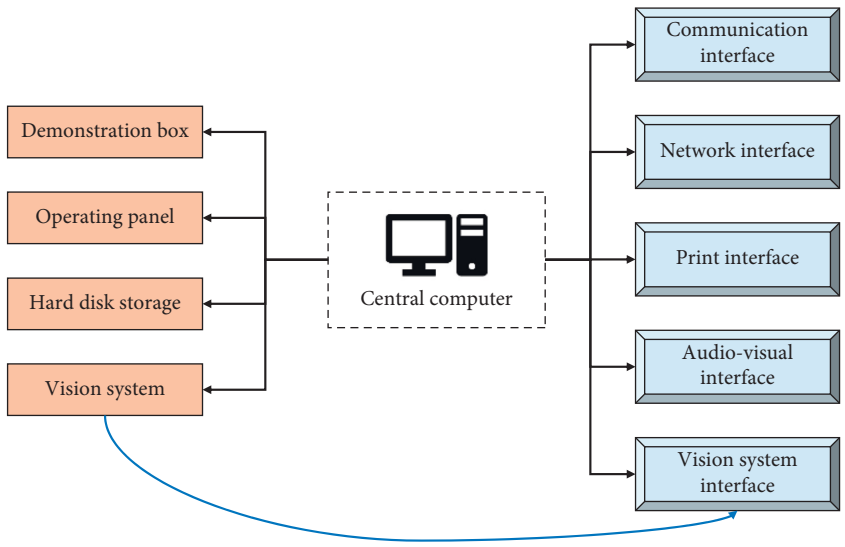

Figure 1: Component of robot control system.

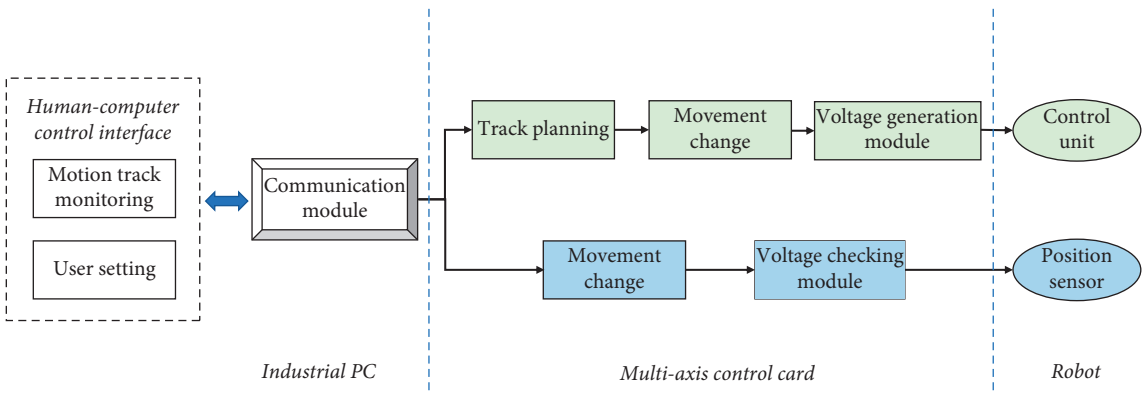

Figure 2: Robot automation control solution.

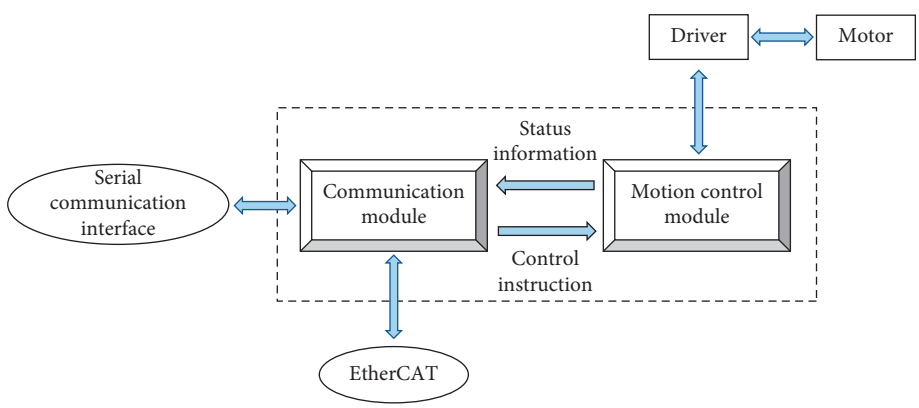

Figure 3: Motion controller structure.

which requires the control of position points and the application of the most appropriate torque for the different tasks. The industrial robots need to be able to use the sensors in a comprehensive manner and to understand the basic environmental changes. Based on the knowledge stored in the robot, specific decisions are made in an intelligent way, which enables the robot to improve its self-learning and environmental adaptation capabilities. The actuators are used to determine the dynamic trajectory of the industrial robot, as well as the speed and position accuracy. It is important to ensure that the industrial robot maintains orderly motion for a fixed period of time, that the motion accuracy is improved, that it remains stable during different tasks, that the speed is always controlled, and that the

trajectory is smoother. The software system in this paper is divided into a master software for the upper computer and a slave software for the lower computer. The master consists of a PC with a network card and is developed on a Windows operating system. The slave software design includes the programming of the DSP and FPGA in CCS and Quartus software, respectively. The slave software design includes the programming of the DSP and FPGA and is developed under CCS and Quartus software, respectively. The software architecture of the control system is shown in Figure 4.

Centralised control is the use of computers to control multiple operations in the operation of industrial robots. Centralised control is an early development and requires a high level of computer performance and multifunctionality. In the past, the development of traditional computer technology was limited and many applications were not yet perfected, resulting in high costs in the production of various types of equipment. By using centralised control, it is more economical and more effective. However, the speed of centralised control needs to be increased and the basic internal structure needs to be optimised, so this type of structural control system is gradually being abandoned in the context of the rapid development of technologies. The current activities of industrial robots are mainly controlled through a distributed structure. The management system is divided into two components, focusing on the role of the primary master computer application and the efficient management of multiple systems. The interpolation of trajectories is budgeted for and multiple coordinates are converted. In the next level of the module, there are more CPUs and the different joints are controlled by the corresponding processors, so that the control tasks can be carried out efficiently. This enhances the control efficiency, improves the control process, and guarantees a reasonable connection between the microprocessor and the higher-level computer, mainly based on the bus application method.

3. Model Building Based on Simulated Annealing and PID Algorithms

3.1. Simulated Annealing Algorithm. The annealing algorithm is derived from the study of the statistical mechanics of materials. Particles at high temperatures contain large amounts of energy and are subject to random motion and recombination. As the temperature decreases, the particles reach a point where they are in thermal equilibrium. As the system cools completely, the crystals are in a completely low-energy state. The simulated annealing algorithm also belongs to one of the stochastic search algorithms and is an extension on the local algorithm. It is characterised by the combination of acceptance probability and search time to find the global optimal solution, thus effectively avoiding the dilemma of falling into a local optimum to a certain extent.

The mathematical principle of the simulated annealing algorithm is shown in Figure 5. The initial state A, B is assumed to be the locally optimal solution obtained as the number of iterations increases. The energy of the update to B is less than A, proving that it is close to the optimal solution, but as the number of iterations increases it is found that the energy of the next step rises when state B is reached. As gradient descent is not allowed to continue, it is necessary to find the relationship between the probability range and the current state and energy to allow the algorithm to continue to iterate forward. The simulated annealing algorithm can solve the problem of the optimisation algorithm being stuck in local optimisation.

The simulated annealing algorithm process approximates the physical annealing process, where the initial annealing temperature is based on long industrial production and working experience. The high temperature at the start of the setting phase is similar to the temperature increase process of a physical annealing process, reaching thermal equilibrium, similar to the isothermal process of physical annealing. The cooling function is similar to the cooling process of physical annealing. This means that a global search is carried out by sampling probabilities at a specified temperature state, so that the global optimum solution is found by means of a probability problem. To be specific, the detailed steps of implementing the simulated annealing algorithm process can be seen in Figure 6.

3.2. BP Neural Network. The core of a BP neural network is to explore the input and output relationships in the input, hidden, and output layers by reducing the error by means of gradient descent. The backpropagation algorithm continuously optimises the weights and biases to obtain the mapping relationships from input to output, so the BP neural network has a powerful learning storage capacity. The advantage of the BP neural network algorithm is that it relies only on its own training and learning and does not need to determine the relationship between input and output in advance in order to obtain the closest possible output. The principle of the BP neural network algorithm is a multilayer feedforward network trained by mean square backpropagation. The BP neural network has two processes: the forward pass algorithm and the backpropagation. With the forward pass algorithm, the input to output relationship is constructed based on the corresponding weights and biases. The predicted output value is then obtained and the backpropagation algorithm is designed to find the bias of the weights and biases by chaining the derivatives through the mean square difference between the predicted output value and the actual value. Finally, the bias derivatives are multiplied by the learning rate and parameter updates are performed to complete the gradient descent process so as to optimise the parameters.

The structure of a three-layer neural network is shown in Figure 7. The structure contains 18 weights and 6 biases and requires the processing of 24 sets of parameters. The predicted values are first calculated by a forward propagation algorithm based on the predetermined weights and biases. A loss function is then created from the predicted and actual values to obtain the mean squared deviation, and the bias is then calculated for each of the 24 sets of parameters by the backpropagation algorithm. Finally, the parameters are updated to achieve a gradient descent operation, so that the predicted values of the corresponding x inputs are calculated to be closer and closer to the actual values, thus achieving the purpose of prediction.

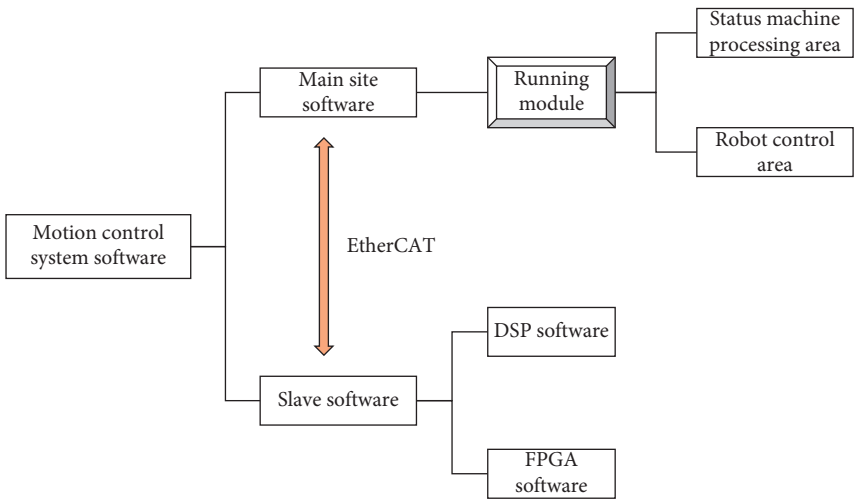

Figure 4: Software control system.

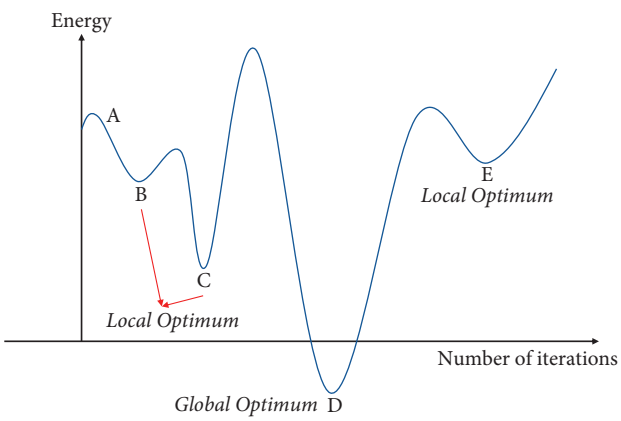

Figure 5: Principle of the simulated annealing algorithm.

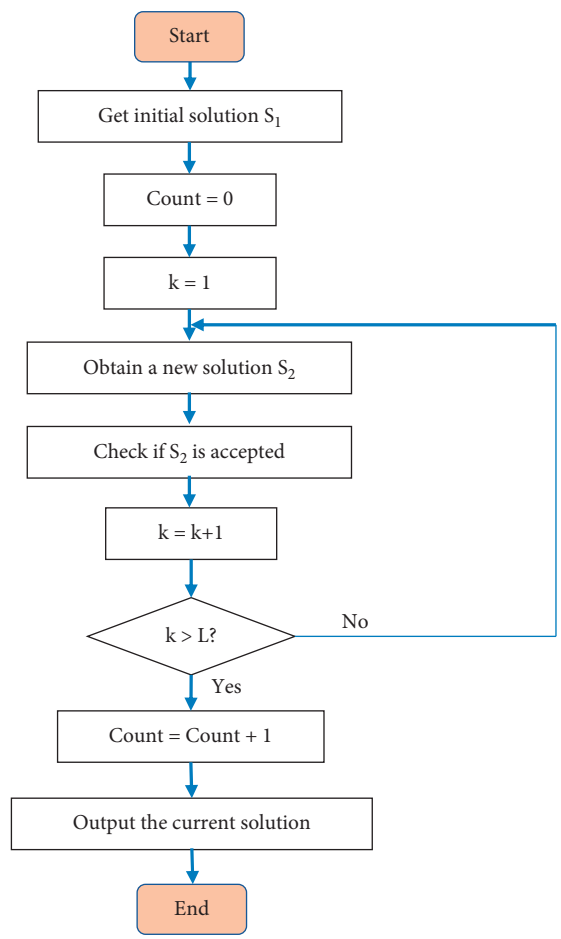

Figure 6: Steps of the simulated annealing algorithm.

3.3. PID Algorithm. The combination of the simulated annealing algorithm with the neural network algorithm also requires the neural network to be combined with PID control. When the manipulator is controlled, the real-time data of the manipulator's posture is used as input data to the neural network, and the optimal trajectory is output after the implicit layer. The output trajectory data cannot be accurately controlled in real time due to errors, so PID control algorithms are introduced to correct the trajectory data with PID to eliminate or reduce errors. During system operation, if the drive signal is interrupted, the system will process the interruption signal; otherwise the search will continue. If a key press is detected, the system will detect jitter, if jitter occurs, the scanning operation will continue, and if the result of the detection is not jitter, the system will enter the function key processing operation to make the robot meet the precise requirements. A neural network based PID controller system can also be thought of as a conventional PID controller and a neural network. Conventional PID controllers obtain their control parameters by online adaptive tuning. The neural network, on the other hand, learns from the neural network and then adjusts the weights, with the adjustment process producing three parameters that can be adaptively adjusted. The system structure is shown in Figure 8.

In this study, the BP neural network is set up as a single hidden layer structure. The complexity of the system can directly affect the number of neurons in the input layer, and the number of neurons in the hidden layer directly affects the

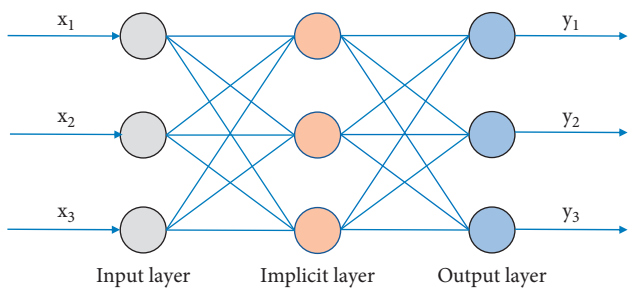

Figure 7: Structure of a three-layer neural network.

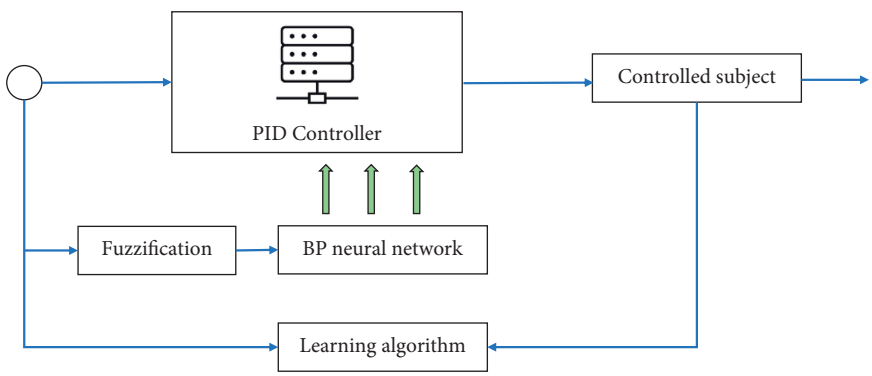

Figure 8: PID controller based on neural networks.

learning ability of the network. Therefore, the number of neurons in the input layer is set to n and the corresponding number of neurons in the hidden layer is set to p in the calculation process. The output layer is set as a nonnegative function of r, and the number of neurons in the output layer is 3. Since the input and output in the input layer are equal, then the following equation can be obtained:

$$a_j^{(1)} = x(j). \tag{1}$$

Then input and output in the implicit layer are

$$\begin{aligned} \mathrm{net}_i^{(2)}(r) &= \sum_{j=0}^{n} w_{ij}^{(2)} \times a_j^{(1)}, \\ a_i^{(2)}(r) &= y\left[\mathrm{net}_i^{(2)}(r)\right]. \end{aligned} \tag{2}$$

The core of a BP neural network is the correction of the neural network according to gradient descent. This means that the error is reduced by a transformation of the indicator function $e(r)$. To speed up learning, adding a measure of motion to the equation:

$$\Delta w_{ij}^{3}(r) = -\alpha \times \frac{\partial E(r)}{\partial w_{ij}^{3}(r)} + \beta \times \Delta w_{ij}^{3}(r-1). \tag{3}$$

Manipulators often encounter obstacles and other disturbances during their application, so they need to be able to avoid them effectively and to operate with precision. In order to solve the constraint problem, the interpolation algorithm of the multisegment trajectory is usually used for processing. The smooth arcs collected are generally transitioned into two intersecting straight lines, and the intersection of the two lines is then discarded for the line segment in the smooth position and after the actual collected points, and then after the calculation of the difference algorithm, will also get a new smooth curve; at this time the points on the line segment will be able to indicate the speed command and the location of the link and control the servo motor movement.

4. Conclusion

Although robotic technology is not yet widespread in our lives, the importance of robotics can be seen in the fact that it has been recognised as an advantage in industrial production and that it can be used in a wide range of applications, both in industrial production and in everyday life. Robotics is one of the most widely used and actively researched technologies in modern times, and the use of robotics is one of the hallmarks of a country's level of industrialisation. The use of industrial robotics in automated production is widespread and offers many benefits to industrial production. This paper investigates the simulation control algorithm during the operation of the manipulator. The simulated annealing algorithm and neural network learning are used to optimise the trajectory of the truss manipulator to obtain the shortest running trajectory data. Then the PID control algorithm is introduced to correct the trajectory data to eliminate or reduce errors. Finally, the neural network and PLC control system are combined to optimise the servo motor movement of the manipulator to achieve the shortest movement time and the highest efficiency. However, due to limited capacity,

a number of extensions have yet to be completed, so future research could also be undertaken in the following areas. In this study, neural networks combined with PID control are used to improve the control strategy, and parallel iterative optimisation strategies with BP neural networks and genetic algorithms can be explored in future research.

Data Availability

The labeled data set used to support the findings of this study is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

This work was supported by the Natural Science Foundation of Chongqing, China (no. cstc2021jcyj-msxmX1113).

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