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Research Article

Optimal Control of the Logistics Automation Transmission System Based on Partial Differential Equation

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In this paper, the finite difference scheme of the spatiotemporal fractional convection-diffusion equation is established, and its stability and convergence are proved. Furthermore, this discrete technique is extended to solve nonlinear spatiotemporal fractional convection-diffusion equations. By using the Krylov subspace method to solve the discrete system, the numerical solution of the spatiotemporal fractional convection-diffusion equation can be obtained quickly. In this paper, an efficient optimal control algorithm is proposed to solve the free control problem of a class of nonlinear time-delay systems. We obtained the optimal control law of the system through the Bellman optimality principle, obtained the asymptotic stability criterion of the system in the form of LMI under the optimal control input by using the Lyapunov stability theory, and discussed the effect of the delay parameter on the system stability. Using the principle of intelligent neural network approximation function, the evaluation neural network and the execution neural network are used to approximate the optimal performance index function and optimal control input, respectively, the optimal control strategy of the system is obtained, and the convergence of the weight estimation error is proved to be optimal. On the basis of optimal state adjustment, the optimal tracking control problem is further solved. Numerical example results verify the effectiveness of the proposed method in terms of stability analysis, optimal state control, and optimal tracking control for the nonlinear time-delay system proposed in this paper. We calculate the parameters of the conveyor and select a reasonable transmission and sorting mechanism to realize the speed regulation of the driving motor of each mechanism. Through the work of each part, the design scheme of the automatic transmission system is formed, and the reliability, practicability, and economy of the system are guaranteed.

1. Introduction

Relying on the current trend of deepening development of the market economy, not only in terms of logistics business and logistics management concepts, but also in the traditional marketing model of enterprises, has undergone a large degree of reform, reducing the total logistics cost of enterprises, especially in the business world [1]. It has become an important way of evaluating factors in the logistics system. A certain change in the development mode of the logistics economy can be used as not only a comprehensive evaluation factor to measure the improvement of the quality and efficiency of the national economy, but also an important component of China's business transformation [2]. Data show that the total cost of logistics in developed countries in Europe and the USA accounts for about 10% of the GDP, but in China, this ratio accounts for about 20%. It can be predicted that in China's economic transformation in the future, the comprehensive development of the logistics industry and the reduction of the total cost of distribution channels will become a new economic growth point [3].

With the rise of the global national Industry 4.0 strategy and the increasingly fierce competition in the face of business, the demand for low-cost and value-added services based on the demand for production and efficient business activities will also increase more and more urgent [4].

Logistics activities include various basic activities such as classification, packaging, handling, loading and unloading, warehousing, automatic transmission, storage, information contact, and processing of items. Among them, automatic transmission is to change the spatial position of items to create its place utility, which is an indispensable and important link in logistics activities. With the development of society and economy, automatic transmission has become more and more complex, and the amount of automatic transmission is sometimes very large. Scientific organization of automatic transmission can effectively reduce the cost of logistics activities and realize the change of the space position of the required items in time to effectively improve its space [5, 6].

Compared with the time fractional partial differential equation, the theoretical analysis of the numerical format of the space-time fractional partial differential equation is more difficult. And because the structure of its discrete system is more complex than that of the time fractional partial differential equation, it will be more difficult to design a fast solution algorithm on the basis of this discrete system. The third work of this paper is to establish a finite difference scheme with a second-order convergence rate in both space and time for the fractional convection-diffusion equation in space and time and design a corresponding fast solution algorithm. To speed up their convergence, a loop preprocessor is proposed. Several numerical examples are given to verify the convergence order of the numerical scheme and test the numerical performance of the proposed loop preprocessor. The main innovation of this work is that on the basis of some previous research work, a numerical scheme with a higher time convergence order is proposed, and the stability and convergence of the scheme are proved. For this type of temporal higher-order numerical format, a fast algorithm is designed with good results.

For a class of nonlinear systems with time-delays, the online ADP algorithm is used to solve the continuous HJB equations with time-delays. By approximating the control input and performance index function simultaneously by two intelligent neural networks, the related optimal control problem of the system under infinite time is studied and analyzed. For a class of nonlinear systems with time-delay and saturated actuators, the control constraints are effectively handled by defining a new performance index function, the online ADP algorithm is used to obtain the optimal control input signal of the system, and a single intelligent neural network is used to approximate the optimal control at the same time. The optimal control of the system is obtained by a more convenient and effective method based on the input and performance index functions. The effectiveness of the algorithm is verified by numerical simulation. This paper analyzes the kinematics of the logistics automation transmission system studied, establishes the rod coordinate system of the logistics automation transmission system, and establishes the linkage kinematics model of the logistics automation transmission system through the Denavit–Hartenberg rule.

2. Related Work

The research on material handling problem is mainly carried out for the design of handling route and handling equipment. With the continuous progress and development of modern logistics, there are many features that are closely related to the automation of handling equipment. Informatization is the basis for realizing automation, and mechatronics is its core. The so-called automation, from the outside, is unmanned, achieving the effect of labor saving. In addition, automation has many advantages, which can improve work efficiency, strengthen logistics operations, and avoid errors in logistics operations. There are many facilities in logistics automation, such as barcode radio frequency automatic identification systems, automatic access systems, and automatic tracking of goods.

Relevant scholars believe that intelligence refers to a higher-level application of logistics automation and informatization [7]. In the process of logistics operations, a lot of decision-making and operational research work will be involved. For example, the determination of inventory levels, the selection of automatic transmission paths, the control of operations, the decision support for the operation and management of logistics distribution centers, and many other issues require the help of intelligent expert systems to be better solved. According to the current trend, it is said that logistics intelligence has become a new hot spot in the development of logistics in the new economic era, and it is the product of the development of the new era. The pros and cons of the AGVS path planning and scheduling control system can determine to a large extent whether the advantages of AGVS can be brought into full play [8]. As far as the current situation is concerned, there are a lot of researches on scheduling algorithms and control technologies. In terms of path planning, the algorithms mainly include Dijkstra algorithm, genetic algorithm, simulated annealing algorithm, and neural network algorithm. In terms of control technology, the algorithms mainly include the fuzzy control technology and forward prediction neural network.

At present, when establishing algorithms and control methods, it is generally necessary to carry out a lot of assumptions and model simplification work in order to better analyze the work [9]. Generally speaking, the AGV speed is constant and the AGV has no faults; however, these assumptions made by us cannot be satisfied by our colleagues. Therefore, how to develop practical algorithms and control methods has become a hot issue in AGVS path planning and control [10].

Regarding the research work on the location selection of logistics planning, there are many methods that are relatively mature at present [11]. According to the space allowed by the facility, they can be mainly divided into two methods: continuous model and discrete model. The so-called continuous model considers that the location of the facility can be arbitrarily selected on the plane, and the location can be selected anywhere on the feasible continuous space. The representative method of this model is the gravity center method [12]. It is regarded as the best point among the number of feasible points, and it can only allow site selection on some specified discrete points. There are many representative models, such as Kuehn–Hamburger model, Blson model, and mixed 0-1 planning model [13].

Relevant scholars pointed out that the research of automated logistics system is mainly divided into two aspects: the development of traffic planning and design, and the research and development of components of paths and processing equipment [14]. In recent years, automated guided vehicles (AGVs) are important equipment for realizing flexible and fast material handling, due to their high flexibility, automation, easy-to-control integration, and high reliability pursued by many enterprises [15]. The design and control design of AGV automatic transmission route have become the focus of many scholars [16, 17]. Whether the specific advantages of AGV in specific aspects can be fully applied in production practice activities can achieve practical results by optimizing and improving the AGV path planning algorithm and scheduling control system method.

At present, a lot of research and analysis work has been carried out on scheduling algorithm and control technology, and a predictive neural network structure has also been constructed for fuzzy control technology [18]. Considering the currently established algorithms and control methods, in order to achieve better control and analysis work, many assumptions and model styles have been constructed to simplify processing such as autonomous vehicles, but in actual production and life, these assumptions are very difficult [19]. The work is carried out at the same time, so how to adapt the algorithm and control method to the actual development situation has become the research of AGV path planning and has attracted more attention [20].

3. Methods

3.1. Construction of Electronic Map. Existing WLAN positioning principles can be divided into time-of-arrival (TOA)-based, angle-of-arrival (AOA)-based, and received signal strength-based (RSSI). Among them, the positioning technology based on location fingerprints is widely used indoors. First, the technician plans several positioning points indoors, then traverses all the positioning points, and saves one or more features of the wireless signal time, angle, and strength of each positioning point in the database. Afterward, when the device moves to a certain location, the location algorithm can be used to compare and match the real-time received wireless signal time, angle, strength, and other information with the information stored in the database, and then the location of the device can be calculated.

The principle of the two-dimensional code positioning scheme and the RFID positioning scheme is roughly the same. First, technicians plan several positioning points in the positioning environment, then encode and paste the positioning labels at the positioning points, store the encoded information and the position information in a one-to-one correspondence, and store in the database. After that, when the code scanner or card reader on the device reads the code information of a label, the location information of the device can be obtained by comparing and matching the read code information with the information stored in the database using the positioning algorithm.

There are also differences between the two-dimensional code positioning scheme and the RFID positioning scheme, such as label encoding form and label identification method. As far as the electronic map of the rail logistics transmission system is established in this paper, the RFID positioning scheme has the following advantages over the two-dimensional code positioning scheme:

(1) Strong Antipollution ability

Since the radio frequency identification technology completes information exchange and storage without contact with radio waves, when the RFID tag is covered with dust and other pollutants, the RFID card reader can still accurately identify the encoded information in the tag to ensure the stability of location identification without the need for labels which are cleaned regularly using a dedicated vehicle.

(2) Reusable

RFID technology has a long service life, and the encoded information in the tag can be rewritten by the encoder.

Considering factors such as positioning accuracy, ease of use, and maintenance costs, this paper uses the RFID positioning scheme as the basis for building an electronic map.

The construction method of the electronic map is as follows:

First, stick the coded RFID tag on the track at a suitable position, and install the RFID reader on the trolley frame 1-2 cm away from the tag on the track.

Second, the location, distance, and other information of each RFID tag are stored in the location database.

Finally, when the trolley moves to a certain area above the RFID tag, the RFID card reader automatically reads the encoded information stored in the RFID tag and writes it into the automatic transmission controller. By comparing the location database information in the memory, the current specific location of the car can be known and corresponding actions can be performed.

At the same time, the automatic transmission controller will also send the read RFID code information to other devices through the communication network, which is convenient for the overall scheduling of the control system and the control of other devices.

3.2. Research and Analysis of Control System Structure. When the system performs the shunting task, since the station touch screen does not know the status and position of all the trolleys, the node controller will send the shunting command of the station touch screen to the PC host computer. The PC host computer finds the nearest idle car by querying the database and sends the task and task destination information to the car. The trolley will go to the shunting station autonomously after receiving the mission and mission destination information.

The hardware architecture diagram of the subregional controller structure is shown in Figure 1. The whole system has a general controller and several regional controllers. The general controller is responsible for the overall scheduling of all regions and reports the system operation to the PC host computer. An area controller is installed in each area, and the area controller is responsible for controlling all the equipment in the area, including the rail switch, the windproof door, the rail breaker, and the trolley traveling in the area. The general controller sends task information to the regional controllers in the form of communication, including the ID of the task car, and the entrance and exit information of each area the car passes through. The regional controller also reports the status information of each device to the main controller in the form of communication, including the status information and position information of the trolley, the status information and current position information of the rail switch, and the opening and closing information of the windproof door.

The trolley does not belong to the equipment in a specific area, so RFID tags are attached at the entrance and exit of each area. When the trolley reads the RFID tag at the entrance of an area, the automatic transmission controller will interrupt the communication with the previous one. The main controller in an area is the area controller, so the trolley has only a simple built-in control board, which is responsible for controlling the motor drive, receiving data from various sensors and touch screens on the trolley, and establishing communication with the area controller. The area controller and the automatic transmission controller will exchange data periodically. The information sent by the area controller to the automatic transmission controller includes forward, backward, and stop commands, and the area controller receives the information from the automatic transmission controller, including the car status information.

The nonmobile equipment (rail transfer device, windproof door, and rail breaker) in each area except the trolley is directly controlled by the controller of each area.

Under this control structure, the scheduling of the system is completed by the station and the PC host computer, while the specific control of the equipment is completed by the automatic transmission controller and the node controller. When the trolley needs to be derailed, the trolley will establish communication with the current node controller and drive to the destination site with the cooperation of the derailleur.

3.3. Comparative Analysis of Control Structures. On the one-way track, RFID tags and control tags correspond one-to-one. When the corresponding RFID tags are read, the trolley and the rail switch have only one action. On the two-way track and rail switch, when an RFID tag is read, the trolley and rail switch will perform a variety of different actions according to different destination information. In order to distinguish different actions, control tags need to be extended based on destination information to meet diverse control requirements.

When choosing a control structure in practical applications, it is necessary to reasonably evaluate the strengths and weaknesses of the two control structures according to the actual project to make the best choice. When designing and debugging the control system of the two control structures, this paper finds that the two control structures have their own advantages and disadvantages in different aspects.

(1) The control system under the subregional control structure can run independently of the PC host computer, and the control system under the subdevice control structure cannot run independently of the PC host computer. The dynamic scheduling of the control system under the subregional control structure is completed by the general controller, and the specific control tasks are completed by the regional controller. Therefore, when this control structure is used, the lower computer can run independently of the PC upper computer. When the PC upper computer fails, you can still complete shunting, starting, and parking tasks. The scheduling of the control system under the subequipment control structure is completed by the PC host computer and the site touch screen. When the PC host computer fails, the system can only complete the task of starting trains, but cannot complete the tasks of shunting and storing cars.

(2) The reliability of the system under the subregional control structure is lower than that of the subequipment control structure. The control system under the subregional control structure consists of a general controller and a regional controller. Therefore, when the regional controller fails, all equipment in the area will not work, and when the general controller fails, the entire system will be paralyzed. At the same time, when the trolley performs a task, it will pass through different areas. At the joint of the two area controllers, the trolley is easily out of control due to communication or other factors. The control system under the control structure of the subequipment assigns the controller to the trolleys and nodes, so when one controller fails, it only needs to cut off the faulty trolley and nodes, and other trolleys and nodes can operate normally.

(3) The operating efficiency of the subregional control structure system is higher than that of the subequipment control structure. The regional controller in the subregional control structure controls all the devices in the region. At the same time, the regional controller also knows the status information of all the devices before issuing the control command, such as the driving state of the car and the current position of the rail switch. Therefore, the zone controller can directly control all the devices in the zone according to the control algorithm and the device status information, which can save the time for the controllers of the trolley and the rail switch

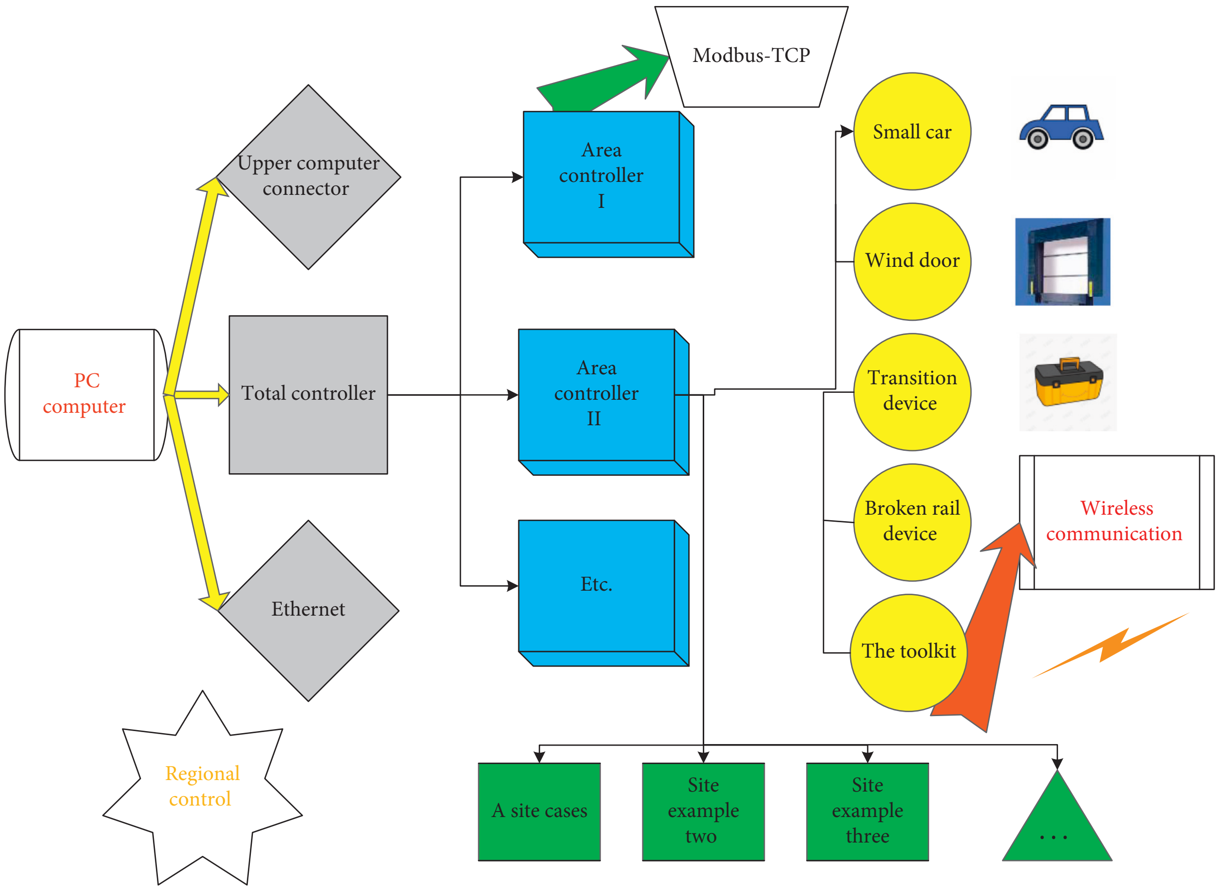

Figure 1: Subregional control structure hardware architecture diagram.

and other devices to communicate and exchange information. For example, in the subzone control structure, when only one trolley needs to pass the rail switch and the rail switch is already in the position of the rail, the zone controller can directly control the trolley to drive on the rail switch without stopping to ask the rail switch position. Under the subequipment control structure, in the face of the above situation, the automatic transmission controller must slow down and communicate with the node controller to inquire about the position of the derailleur and wait for the response of the node controller before proceeding to the next step.

In terms of control flow, the subregional control structure is a top-down three-level control structure.

The first level is the master controller, which is responsible for scheduling. The second level is the zone controller, which is responsible for zone control. The third level is the controller of the trolley and the controller of the rail switch, which is responsible for the specific control of the motor, electromagnetic lock, steering gear, and the data collection of various sensors.

The subequipment control structure is a parallel control structure. The node controller and the automatic transmission controller are not divided into primary and secondary, but collect their own sensor data and control their own motors, electromagnetic locks, and steering gears. When the two controllers need to exchange data, a communication connection can be established to inquire and return various data information instead of issuing instructions or uploading data.

In terms of communication structure, the three-level control structure of the subregional control structure determines that its communication structure is more complicated than the equipment control structure. The subregional control structure needs to establish two layers of communication to ensure that the controllers at each level establish communication connections with the controllers at other levels to issue control commands or upload sensor data.

At the same time, there is a one-to-many communication structure between the general controller and the regional controller, and a one-to-many communication structure between the regional controller and the controller of the trolley and the controller of the rail switch.

In the subequipment control structure, the automatic transmission controller and the rail switch controller in the parallel control structure only need to establish a layer of communication to meet the communication requirements between each controller.

Considering the advantages and disadvantages of the above three points and the actual debugging and verification, this paper finally decides to use the subequipment control structure to complete the design of the control system.

3.4. Communication Scheme. The control system of the intelligent logistics transmission system designed in this paper is a distributed control system, so an effective communication network supporting distributed control and embedded systems is needed to complete the data exchange among various devices. At the same time, the communication network should also have the characteristics of high reliability, high anti-interference ability, strong real-time performance, and high compatibility ability to meet the data exchange requirements of automatic transmission controller, node controller, PC host computer, and other equipment.

At present, the communication schemes applied to the rail logistics transmission system mainly include industrial Ethernet communication, Zigbee wireless communication, and CAN bus.

3.4.1. Industrial Ethernet. Industrial Ethernet is a network communication technology that can meet the needs of industrial sites for strong real-time, good interoperability, high reliability, and strong anti-interference ability of communication networks and is compatible with commercial Ethernet (IEEE802.3 standard). Industrial Ethernet is widely used due to its low cost, fast transmission rate, high stability, and reliability.

Using industrial Ethernet, enterprises can achieve seamless information integration from the field control layer to the management layer, such as the totally integrated automation (TIA) concept proposed by Siemens, and industrial Ethernet supports remote access and remote diagnosis, while the current field bus cannot meet the requirements of the above aspects.

3.4.2. Zigbee Wireless Communication. Zigbee wireless communication technology is a short-range wireless communication technology for inexpensive fixed, portable, or mobile devices and can be used for industrial control, sensing, monitoring, and remote control. It has low power consumption, low cost, large network capacity and security, reliability, and so on. At the same time, Zigbee wireless communication modules can be embedded in various hardware devices, which can meet the diverse design and usage needs of developers.

3.4.3. CAN Bus. With the improvement and development of CAN bus technology, the characteristics of low cost, high reliability, high anti-interference ability, and strong real-time performance help CAN and CAN-based high-level protocols to be widely used in automobiles, process control, numerical control, and medical and electric power. The standard protocol of CAN only defines the physical layer and the data link layer and does not standardize the application layer. Therefore, CiA (CAN in automation) develops an open and standard based on CAN, which provides distributed control and embedded system applications.

Considering the advantages and disadvantages of various communication technologies, this paper decides to use CAN bus technology to construct the communication network of the control system.

The use of CAN bus to build the communication network of the control system is mainly based on the following reasons:

It has high reliability, anti-interference ability, and strong real-time performance.

Its controller using CAN bus technology can easily control some devices that support CANopen communication, such as some high-performance stepping motors that support CANopen communication.

At the same time, other devices that do not support CAN communication can also be connected to the CAN bus through the connection protocol converter, such as CAN to USB, and CAN to TCP/IP.

The nodes on the CAN bus network are not divided into master and slave, and any node can actively send information to other nodes at any time. At the same time, the network nodes can be expanded arbitrarily, and the automatic transmission controller and node controller can be connected to the CAN bus at any time as needed to expand the number of trolleys and stations in the intelligent rail logistics transmission system.

3.5. An Implicit Difference of the Spatiotemporal Fractional Convection-Diffusion Equation. In this paper, a fast second-order implicit difference numerical approximation scheme is proposed to solve the following space-time fractional pair.

Flow-diffusion equation is

$$\begin{cases} {}_0^C D_t^{\theta} u(x,t) = f(x,t) - \left[d+(t)0D_x^{\alpha}u(x,t) + d_-(t)xD_L^{\alpha}u(x,t)\right]\left[e+(t)0D_x^{\beta}u(x,t) + e_-(t)xD_L^{\beta}u(x,t)\right], & (x,t) \in (0,L)\times(0,T), \\ (t,0) = u0(t) & u0 \le t \le L, \\ u(0,x) = u(L,x) = 0, & 0 \le x \le T. \end{cases} \quad (1)$$

It can be regarded as a generalized form of the traditional convection-diffusion equation. That is, in the traditional convection-diffusion equation, the time first derivative is replaced by the derivative order as the time fractional derivative.

Only very few fractional partial differential equations can give expressions for analytical solutions, and these expressions for analytical solutions are often impractical. This is because there are transcendental functions or infinite series in these expressions. As a result, researchers have turned to the numerical solutions of fractional partial differential equations and have achieved certain results.

Regarding the numerical methods for solving fractional convection-diffusion equations, most of the early numerical solutions were proposed for spatial or temporal fractional convection-diffusion equations.

In order to obtain an unconditionally stable numerical format, traditional numerical methods for fractional partial differential equations usually produce discrete systems with dense coefficient matrices. In order to reduce the amount of computation, the discrete system obtained by using the displacement, its coefficient matrix is a dense matrix and has a Toeplitz-like structure. More precisely, this coefficient matrix can be written as the sum of some diagonal matrices multiplied by Toeplitz matrices. This also means that its matrix-vector multiplication can be computed quickly by FFT.

In this paper, two preprocessing iterative methods are used to quickly obtain numerical solutions. The two methods are the PBiCGSTAB method and the preprocessed generalized product method based on biconjugate-orthogonal residuals.

3.6. Cyclic Preprocessors for Discrete Systems. Regarding the approximation of the Riemann–Liouville fractional derivative, this paper adopts the WSGD formula.

$$\begin{aligned} {}_0D_x^{\gamma}u(x,t) &= h^{-\gamma}\sum_{k=1}^{[x/h]+2}\omega_k^{(\gamma)}u(x-(k-1)h-(k-2)h,t-1)+\mathcal{O}\left(h^2\right),\\ {}_xD_L^{\gamma}u(x,t) &= h^{-\gamma}\sum_{k=1}^{[L-x/h]+2}\omega_k^{(\gamma)}u(x+(k-1)h+(k-2)h,t-1)+\mathcal{O}\left(h^2\right). \end{aligned} \tag{2}$$

This subsection considers the nonlinear case of the equation:

$$\begin{cases} \Delta_{0,t_{j+\sigma}}^{\theta}u_i^{j+\sigma} = u_i^{j+\sigma}+\delta_h^{\alpha,\beta}g_i^{j+\sigma}, & 1\le i\le N-2,\ 0\le j\le M-2,\\ u_i^0 = u_i^M, & 1\le i\le N-2,\\ u_0^j = u_0\left(x_j\right)=0, & 0\le j\le M-2. \end{cases} \tag{3}$$

Regarding the construction of the preprocessor, the most basic principle is that the preprocessor should be reversible. Therefore, it is necessary to first prove that the preprocessor is nonsingular.

$$F^{j+1(l)} = \left[g\left(\sigma u_0^{j+1(l)}-\sigma u_0^j,x_0,t_{j+\sigma}\right),\ldots,g\left(\sigma u_N^{j+1(l)}-\sigma u_N^j,x_N,t_{j+\sigma}\right)\right]^T. \tag{4}$$

In this linearized iterative format, each iteration still needs to solve a linear system of equations. This article will directly apply the fast algorithm designed for the linear case.

3.7. Stability Analysis under Optimal Control Input. Through the optimal control theory and the ADP algorithm, we have obtained the optimal performance index function and optimal control strategy of the system under the performance index function. However, whether the stability of the system has changed under the optimal control strategy needs further discussion, so the system stability under the optimal control input needs to be considered next.

$$\dot{x}(t) = Ax(t-\tau)^2+f(t-1,xt(t-1),x(t-\sigma))u*(t-1). \tag{5}$$

Transform the system into

$$\frac{d}{dt}\left(x(t-1)-A\int_{t-\tau}^{t-1}x(u)du\right) = Ax(t-1)+Ax(t-\tau)^2+f(t-1,xt(t-1)(t-\tau),x(t-\sigma))u(t-1). \tag{6}$$

It is assumed that no additional dynamics are considered here; that is, the stability of the system is completely equivalent.

Bringing the optimal control strategy into the system, we can get

$$\frac{\mathrm{d}}{\mathrm{d}t}\left(x(t-1) - A\int_{t-\tau}^{t-1} x(u)\mathrm{d}u\right) = Ax^{-1}(t-1) + \frac{1}{2} f(t-1, xt(t-1)(t-\tau), x(t-\sigma))R^2 f^T J_x^*. \tag{7}$$

Suppose the nonlinear function satisfies the following inequality:

$$\left\|\mathscr{F}(t,x,y) - \mathscr{F}^2(t,x_1,y_1)\right\| \le \alpha\left\|x-x_1\right\|^2 + \beta\left\|y-y_1\right\|^2 - \gamma\left\|(x-x_1)(y-y_1)\right\|. \tag{8}$$

With the help of tools such as matrix inequality and model transformation, an effective LMI stability judgment method is provided for the system with time-delay. Next, another inequality method (Gronwall's inequality) will be applied to generate a more effective and convenient system stability condition.

According to the lemma (Gronwall's inequality), we obtain the following inferences about the delay parameters, which make the system stable, and obtain the maximum allowable delay range limited by the system matrix by proof.

It should be pointed out here that the obtained stability conditions have nothing to do with the delay parameters of the nonlinear part of the system, which means that the delay parameters can be as large as possible, as long as the parameters satisfy the stability conditions. This shows that the stability of the system under the optimal control strategy has a large enough stability space. In any case, the inference is relatively conservative, and other methods such as matrix inequalities can be used to reduce the system stability conditions in the future.

3.8. Optimal Tracking Controller. The optimal performance index function and optimal control strategy expression of the system are obtained, and the system stability condition under optimal control input is obtained by Lyapunov theory.

It is not difficult to find that the optimal control strategy is a partial differential equation, so it is very difficult for us to solve the optimal control law of the system.

Therefore, the content of this section mainly uses the characteristics of the neural network approximation function to approximate the performance index function and control strategy, respectively.

We use a two-layer neural network composed of an evaluation network and an execution network to achieve online real-time update of the weights of the two neural networks.

This subject uses intelligent neural network to approximate the performance index function, so the square error minimization method is adopted. We need to find a suitable optimal weight adjustment law to minimize the squared error of the definition. Next, based on the Levenberg–Marquardt algorithm (LMA), the weight adjustment rate of the evaluation network is obtained.

So far, we have obtained the dynamic equation of the weight adjustment rate and the weight approximation error of the evaluation network. The weight adjustment law and weight approximation error of the execution network will be solved in a similar way.

After obtaining the dynamic equations of the weight adjustment rate and weight error of the evaluation network and the execution network, it is necessary to further consider the convergence of the neural network. In fact, due to the ubiquitous error of neural network weights, the method of using intelligent neural network to approximate the function can only achieve approximate optimal control.

If an appropriate learning rate is selected, with the continuous convergence of the weight estimation error of the neural network, the control law based on the neural network proposed in this topic will be close to the real optimal control strategy. If the number of neural network layers is continuously increased and the training time becomes longer, the actual control law will be infinitely close to the optimal control strategy until it is consistent.

It is desirable to minimize the system state with the smallest control energy, that is, the optimal state regulation for a class of nonlinear systems with time-delays. According to theoretical research and practical engineering application, the system tracking problem also has very rich research and important significance.

The tracking system selects an appropriate control law so that the actual output of the system tracks the desired output trajectory, and the specified performance index is extremely small. The state regulation problem can be directly transformed into a system tracking problem, and this method is also applicable to the system in this paper.

4. Results and Analysis

4.1. Numerical System Simulation. No matter in the economic system model, the population system model, the ecosystem model, or the growth behavior model, there is a common feature; that is, they are all nonnegative constraint dynamic system models. The nonnegative constraint

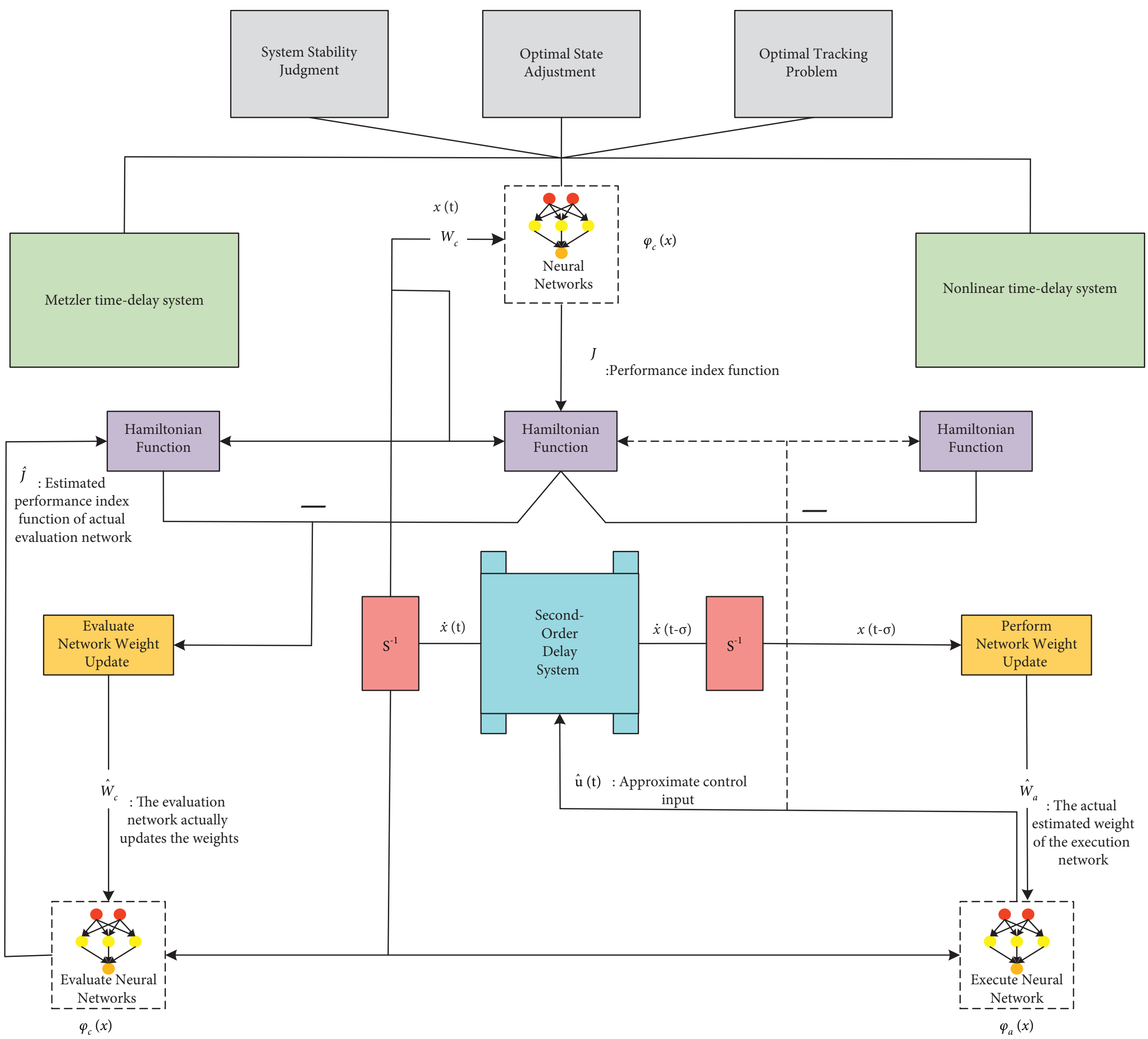

Figure 2: System Simulink simulation module.

dynamic system model is also a common model in the social and humanistic fields. In this paper, the MATLAB software/Simulink module is used to build the system dynamic model. For the system, the simulation module diagram under the optimal control is shown in Figure 2.

In order to better verify the system stability determination method proposed in this subject, we also verify the system state response of the system delay parameters, respectively. Figure 3 shows the control input curve of the system. We can clearly find that the system reaches the optimal control in about 7 seconds, the system reaches the control target in about 21 seconds, and the state response has obvious overshoot.

Figure 4 shows the weight training trajectory of the evaluation network under the time-delay parameter, which shows that the optimal control method based on the neural network proposed in this topic converges to the control law of the actual simulation training. The above simulation results show that the stability analysis method proposed in this paper is effective.

It should be pointed out here that the linear part of the system is the same, and the stability conditions we deduce are valid. The simulation results shown in Figures 5 and 6 show that, for the system proposed in this paper, selecting the state variables and control variables as the performance index function parameters can effectively control the system state to the equilibrium point. This optimal control scheme based on neural network makes the system unstable. The system is finally asymptotically stable, which proves the effectiveness of the proposed optimal control algorithm.

4.2. Simulation of the Logistics Automation Transmission System. This paper is to use the Robotics Toolbox module in MATLAB to carry out the kinematics simulation of the logistics automation transmission system.

Before carrying out the motion simulation of the logistics automation transmission system, the corresponding logistics automation transmission system object should be constructed first. In the MATLAB environment, the

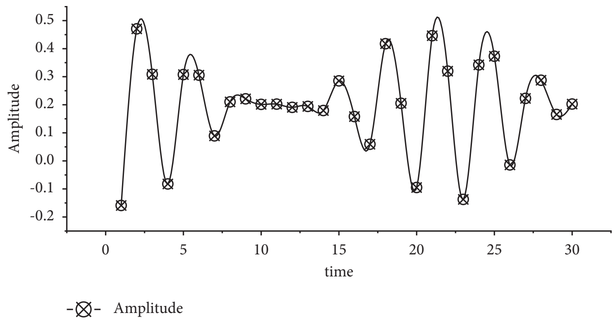

Figure 3: System control input signal curve.

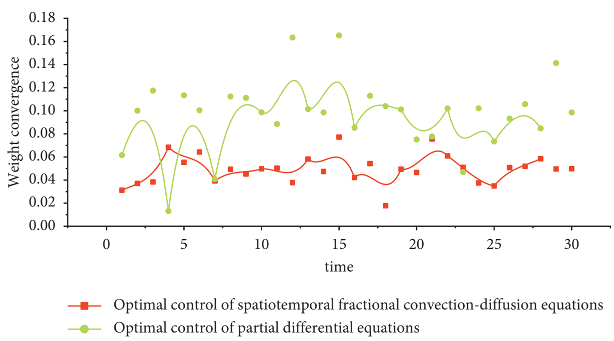

Figure 4: Convergence curve of network weights for system evaluation.

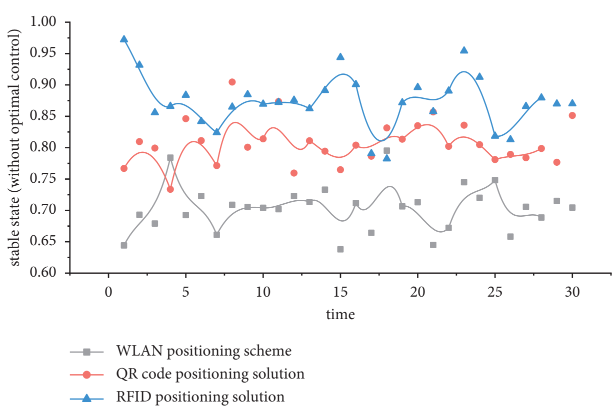

Figure 5: System stability state response curve (without optimal control).

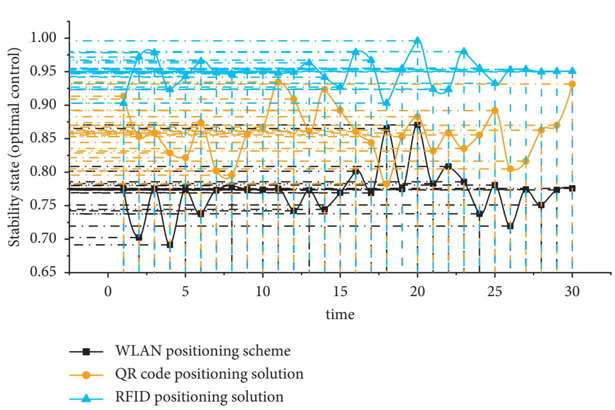

Figure 6: System state stability response curve (optimal control).

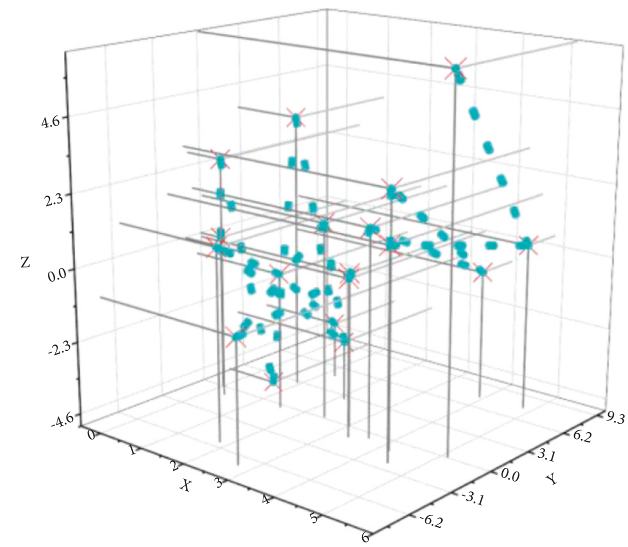

Figure 7: 3D model of the logistics automation transmission system.

Robotics Toolbox module is used to construct each joint through the LINK function to construct the logistics automation transmission system object. The general form of the LINK function is $L = \text{LINK}$ ([alpha A theta D sigma], CONVENTION). "alpha" represents the length of the member, "A" represents the torsion angle of the member, "theta" represents the joint rotation angle, "D" represents the joint distance, and "sigma" represents the joint type (0 means rotating joint, 1 means moving joint). Using D-H method, "CONVENTION" uses "standard." The handling logistics automated transmission system in this paper is constructed by the following statement, named robot:

$L1$ = LINK ([0 pi/2 0 0 1], "standard");
$L2$ = LINK ([0 pi/2 0 0 0], "standard");
$L3$ = LINK ([0 pi/2 1.5 0 1], "standard");
$L4$ = LINK ([0 −pi/2 0 0 1], "standard");
r = robot ({$L1$ $L2$ $L3$ $L4$}, "robot"); % build a logistics automation transmission system and name it plot (r, [0 0 0 0]).

The created three-dimensional model of the logistics automation transmission system is displayed through the plot function, as shown in Figure 7.

Further, the Drivebot command can be used to display the 3D model diagram of the logistics automation transmission system, and at the same time, the logistics automation transmission system can be moved manually by adjusting the slider in the figure. Each variable range sliding bar represents a variable of the logistics automatic transmission system. By manually adjusting the slider, each joint of the logistics automatic transmission system is driven to achieve the purpose of driving the end effector of the logistics automatic transmission system.

The motion simulation can describe the motion process of the logistics automation transmission system in a more detailed and intuitive way. In this paper, the point-to-point motion of the joint in space is simulated, the starting point is

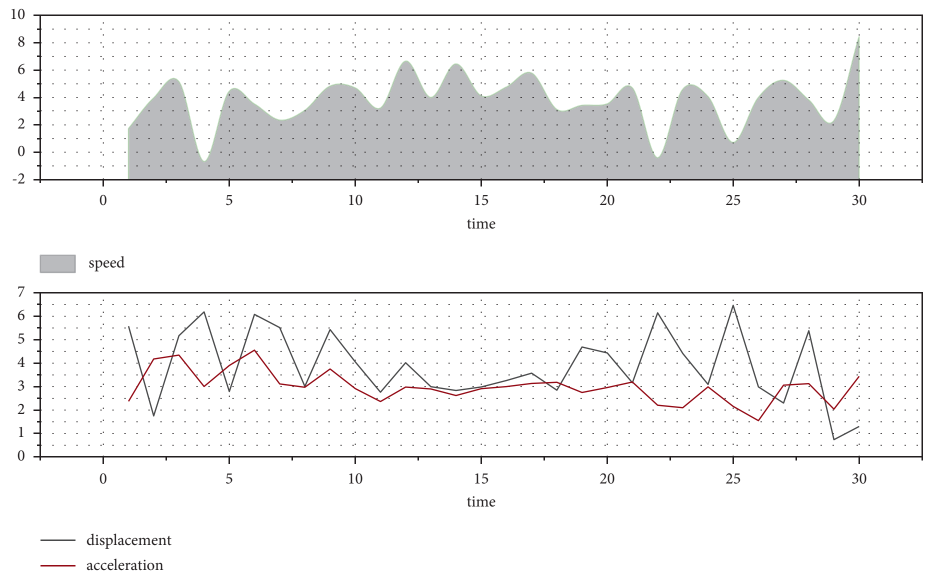

FIGURE 8: Displacement, velocity, and acceleration curves of the logistics automation transmission system.

qz = [0 −1 0 1], the end point is qr = [4 pi/4 0.2 0.1], and the motion time is 2 s.

Draw the displacement curve of each joint in this process by calling the function [q, qd, qdd] = jtraj ($q0$, $q1$, t) and plot (t, q (:, i)), where q represents the displacement and i represents the joint number; this study is the 4th joint. The velocity time curve can also be plotted by calling the function plot (t, qd (:, i)). The acceleration curve is plotted by calling the function plot (t, qdd (:, i)). The displacement, velocity, and acceleration curves of the logistics automation transmission system are shown in Figure 8.

5. Conclusion

The time and space of the linear and nonlinear spatio-temporal fractional convection-diffusion equations are approximated, respectively, and their numerical discrete forms are obtained. Theoretical results show that the two numerical schemes are stable and the space-time convergence order is second order. The linear and linearized systems derived from these two numerical formats, respectively, have a coefficient matrix structure that can be represented at each time step in the form of an identity matrix plus a dense Toeplitz matrix. Aiming at this structure, a Strang loop preprocessor is designed to solve such systems quickly. Numerical experiments verify that the two numerical discrete schemes can indeed achieve second-order convergence in space and time. For a class of nonlinear systems with state time-delay, an adaptive dynamic programming algorithm based on neural network is used to propose an optimal control method, which ensures the stability of the system and makes the performance index extremely small. The HJB equation of the system is obtained through Bellman's principle, and the optimal control strategy of the system is obtained. The stability conditions of the system under the optimal control law are obtained by using tools such as Lyapunov's second method and linear matrix inequality, and the time-delay parameters are obtained. According to the action sequence of the logistics automation transmission system, the reasonable driving mode and control mode are determined to improve the reliability of the control system. The layout of the conveyor is determined according to the requirements of the conveying line, and the model and transmission mode of the conveyor are determined by the parameters such as the size and weight of the automatically conveyed goods, so as to design a reasonable sorting mechanism. The sufficient conditions for neural network convergence are obtained by constructing Lyapunov functions. The optimal state regulation problem is transformed into an optimal tracking problem, and the optimal tracking control of a class of time-delay nonlinear systems is realized. The simulation results verify that the algorithm has a good control effect.

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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