In order to solve the problem that the delay of wireless network and complex operating environment affects the stability and operating performance of teleoperation system, a method of intelligent control robot based on multimedia network defined by software is proposed in this paper. In the network environment established based on the software definition, the gain of the system control is increased according to the network delay to improve the operating performance of the system, and the output of parameters is dynamically adjusted to adapt to the stability of the system in complex environment. The experimental results show that the robot control system can obtain the best control stability by continuously adjusting the relevant parameters. After the simulation test, the final setting is $k_p = 0.8, k_i = 0.001, k_d = 0$

Conclusion. Based on the intelligence of gain scheduling control algorithm, the control effect of fuzzy control can be significantly improved when the network delay is large.

1. Introduction

Mobile robot technology is a field where digital information processing technology, computer science and technology, path planning, and navigation technology converge. Its research purpose is to be able to obtain all kinds of surrounding information in the whole movement process according to the predesigned map and other information, make path navigation planning, help the robot avoid obstacles, reach the destination safely, and complete the required operations. However, due to the influence of complex and changing working environment, there are great difficulties in the autonomous work of robots, and there are still many situations that require the intervention of operators [1]. At this time, it is an effective solution to this problem to guide the robot to work artificially through the teleoperation system. Robot teleoperation technology is a highly strategic top science and technology, which is predicted by scientists as the key development direction of science and technology in the future. Since its first appearance in 1960, robot has been regarded as an important reference for the progress of human scientific level. After 50 years of gradual development, it has been widely used in all aspects of life and production [2]. The mobile robot teleoperation system is an important part of robot technology, and it is also a hot spot in the robot field. The mobile robot teleoperation system has a keen ability to perceive the external environment and its own state and a strong ability of self-organization and self-adaptive.

Robot teleoperation based on network refers to connecting the robot with the Internet, so that people can easily control the behavior of the robot at any place and at any time to meet specific services. With the growing development of mobile Internet, people’s demand for information sharing is no longer limited to pictures, words, video, and audio. In the future, the development trend will be direct interaction with remote locations to obtain objective physical information and real-time feedback operation to achieve real interaction. Robot teleoperation based on Internet provides an effective means of interaction for this demand [3]. H. 264 is a new generation of digital video coding standard. As the most advanced video coding standard in the world, it has the characteristics of high compression rate, low coding rate, and low bandwidth requirements [4].

As the most basic industrial robot, the multidegree of freedom robot arm has multiple joints, generally composed
of the base, vertical arm, horizontal arm, and hand claw, which can complete a variety of complex movements in a specific space. Reasonable mechanical structure, including the driver, servo motor, sensors, and other hardware equipment, can achieve good human-computer interaction software, with an efficient, stable, and strong control algorithm. Mechanical arm system design needs to consider all aspects of things. In order to understand the dynamic characteristics of the system, dynamic analysis and simulation are needed to understand the movement trajectory, to develop the system software and meet the software requirements; to realize the data transmission between the software and the hardware, the communication is completed according to the communication protocol.

The multifunctional robot arm can be used for the experimental teaching of fully driven robot or for the experimental research of underdriven robot. The conversion between full drive and underdrive function is simple and convenient and can be easily realized by installing and unloading the drive. However, there is not many software developed about the robot system, so we need to develop the robot intelligent control system experimental platform software that can realize full drive/underdrive conversion. The solid-height multifunction four-degree of freedom robot arm is used as the experimental platform robot. The robot has four series joints, which can complete two motion modes: uniaxial point motion and multiaxis linkage. It is mainly used to study the influence of different control algorithms on the dynamic characteristics of the robot structure. After completing the requirement analysis, over all design and implementation of the software structure is also achieved. Besides, detailed design and implementation of the software test is conducted on the robot intelligent control system and the experiment platform.

Business requirements are the guide to action for the whole system, describing the purpose of developing the system and what goals to achieve from a macro perspective. For the software of the robot intelligent control experiment platform, it is the requirement of the robot intelligent control system for the software. As an important link of the robot intelligent control system, it is hoped to establish a bridge of information transmission for the operation users and the control system and realize the unity of control simulation and physical control. This is in the global level of the robot intelligent control experimental platform software put forward the target requirements.

User needs, that is, the needs established from the perspective of users, use the needs that the product has to provide to achieve the work objectives. For the robot intelligent control experimental platform software, the user demand is the task that users must achieve when using the software. Specifically, the software must be able to realize the performance parameters of each joint of the arm, the mechanism back to zero, and other operations and must be able to control the arm to complete various movements. Implement corresponding control and collect joint position information through the underlying hardware and perform data conversion. The component technology calls the simulation software to realize the control simulation of the mechanical arm and realize the transmission between the simulation experiment data and the physical experimental data, as well as the preservation of the experimental data and other related processing. This level of demand is extremely important. Since most requirements are recessive, incomplete, and variable, this raises high requirements for the needs of collecting users.

2. Literature Review

Mahboob and others adopted the Java Based Teleoperation mode to realize the image stream transmission of robot image based on JMF. The encoding method is based on MPEG4 standard, and the client needs to install plug-ins in advance, such as RealOne or Microsoft’s media player [5]. Slawinski and others applied augmented reality technology in human robot communication. Since the operating environment of the remote robot is unstructured, and the computer is obtained through stereo vision, the use of augmented reality technology can greatly reduce the requirements of the system for video refresh rate [6]. The most typical application is the application of virtual reality in the Mars rover. Carvalho and others used the event-based intelligent control method to control the robot 1000 miles away from the Internet to grasp objects and avoid obstacles [7]. Carvalho and others directly control the car in unknown environment through Internet time-delay force feedback handle and VR helmet. A linear feedback observer with time delay is designed for Internet. Internet puts forward a network control model based on dissipative theory [7]. Assad UZ Zaman and others analyzed the transmission characteristics of robot image and control information according to the real-time requirements of robot teleoperation. The network protocol adopted RTP/RTCP/UDP to solve the problem. In addition, the transmission problem of low frequency and narrow bandwidth network is also a key research direction, which is also not limited to the application of robot teleoperation [8]. Solanes and others put forward several measures for fault tolerance and improving data reliability by analyzing the characteristics of video stream, which can be used as an effective means for robot image and other data transmission in robot teleoperation [9].

The wireless network time delay is sometimes variable and random, which not only reduces the control performance of the wireless network-based telerobot but also leads to the robot misoperation and inevitable losses. In order to solve the influence of wireless network delay on the controllability of telerobot, a gain scheduling control algorithm based on parameter model is proposed in this paper. According to the network delay, the gain of system control is increased to improve the operation performance of the system. At the same time, the output of parameters is dynamically adjusted by module control and the self-learning ability of neural network to adapt to the stability of system operation in complex environment.
3. Research Methods

3.1. Software Definition Network. Since the birth of the Internet, its technology and demand have been increasing day by day. The Internet is no longer satisfied with simple data forwarding. Higher and more intelligent services need to be supported by an intelligent network. These demands lead to the enhancement of network scale and carrying capacity, but limited by Moore’s law, the update of hardware infrastructure is far from keeping up with the growth of demand. At present, the tens of thousands of demands of the Internet bring a large number of computing, storage, transmission, virtualization, and centralized control demands, which make the traditional network face great pressure [10].

Compared with the traditional network, the most prominent feature of SDN is the separation of data plane and control plane. The goal of SDN network is to simplify forwarding and centralize control. In the traditional network, because the network is transparent to users, users and service providers cannot obtain the internal information of the network, so the usual optimization methods are estimation and feedback. The former estimates the internal network traffic or packet loss rate by using windows or other means to count the relevant network information at the source end. The latter is to judge whether there is congestion in the network according to the feedback received from the user and then adjust the transmission bit rate from the source [11]. Although this indirect method can also solve the problem to some extent, it is ultimately limited by the network architecture. With the increasingly complex and intelligent application, some information observed at the terminal is completely insufficient to support the requirements of the entire application layer. In contrast, the centralized control layer of the SDN network can realize the comprehensive control of the data layer and can observe the network status in real time, providing sufficient information for the upper level decision-making.

As shown in Figure 1, SDN system architecture mainly includes infrastructure layer (i.e., data plane), control layer, and application layer. The infrastructure layer is mainly composed of programmable routers or switches, and OpenFlow switches are one of them. Deploying the routing and forwarding function through software can also save the hardware cost to a certain extent. The SDN network data plane follows the principle of simple forwarding. Each SDN router does not have the routing learning function, but guides the routing by accepting the “flow table” issued by the SDN controller to complete the data forwarding, replacing the forwarding based on the IP address in the traditional network, and the programmable feature enables the router to complete different functions. Compared with the simple data plane, the centralized control plane is responsible for the management and control of the entire network and the connecting task [12–14]. The SDN controller communicates with the switch through the “control data plane interface,” and the flow table distribution and data upload are all realized through the South interface. On the other hand, the SDN controller provides a programmable interface API for the application layer, and the supply layer realizes various network applications.

After the establishment of the network system, the next problem to be solved is its implementation and deployment. Although there are mature and stable programmable switch equipment available to build the prototype system, considering the large network scale and experimental stability in the research problems in this paper, this paper will adopt the hardware in the loop simulation to realize the network architecture [15]. Network simulation has been a mature technology. There are many well-known network simulation tools, such as NS2, NS3, and Mininet. The network simulation tool used in this paper is Mininet. As a lightweight software development platform, it supports OpenFlow, supports user-defined topology, and provides external interfaces. Most importantly, the Mininet simulator has good hardware portability, so the experimental results obtained in the simulation environment created by Mininet are very convincing [16].

The control system of a typical type of pipeline detection robot has been studied. According to the working characteristics and use requirements of the robot, a three-layer structure model of the control system is established and designed from hardware, software, and communication aspects, respectively. Finally, the developed software completed the test and analysis of the control system functions and verified the feasibility and practicability of the pipeline detection robot control system. We study an indoor wheeled mobile robot based on differential drive control and develop control system software. According to the design and implementation of the robot control task deployment software, the transmission and receiving of the timing update instructions were completed through the CPU timing interrupt service program, and we communicated with the server driver through the ECAN module following the CANopen protocol standard. The designed robot control system has good navigation and control effect, and the positioning accuracy can reach within lcm.

3.2. Design of Teleoperation Robot System Based on Wireless Network. The teleoperation robot system is a basic application of PID control. The teleoperation robot system is shown in Figure 2.

In Figure 2, the teleoperation robot system mainly includes the following parts: robot teleoperation console, remote operation computer, wireless AP, wireless network card, field control computer, and robot. As the communication medium between the remote control subsystem and the field control subsystem, the wireless network mainly carries the transmission of control signals and feedback signals. The control signals are transmitted from the remote control subsystem to the field control subsystem, and the feedback signals are fed back from the field control subsystem to the remote control subsystem [17]. The two transmission processes are carried out at the same time. If there is a delay in the signal transmission process, it is likely to lead to mis-operation of the robot.

The communication efficiency of wireless communication network determines the working accuracy and precision of teleoperation robot. The wireless communication network consists of local area network, wireless AP, and wireless
network card deployed on the remote operation computer and field control computer. At the same time, wireless AP is used to connect the remote control subsystem and field control subsystem. After the system is started, the wireless AP deployed in the remote control terminal system within the working range of the field control subsystem is started, waiting for the connection of the field control subsystem. When the field control subsystem is connected to a specific wireless AP and logged in with the corresponding password, Figure 3 shows the workflow of the remote operation robot.

In the above workflow, it can be seen that most of the communication delay between the remote control subsystem and the field control subsystem will occur in the wireless communication node. For the robot, it is necessary to receive the instructions from the remote control terminal in real time to complete the relevant work. For the remote operator, it is necessary to obtain the feedback of the robot in real time to adjust the subsequent operation. Once a large network delay occurs, it will bring inevitable losses to the system. Therefore, it is necessary to adopt a specific algorithm to deal with the delay problem of wireless network.

### 3.3. Gain Scheduling Control Algorithm Based on Parameter Model

#### 3.3.1. Basic Principle of Gain Scheduling Control

Gain scheduling control is a nonlinear control algorithm. Its basic idea is to use an auxiliary variable to determine the change of
The auxiliary variable according to the change of the environment or the controlled object itself in the past period of time, that is, "gain," and then use the change of the increase to adjust the output of the controller, so as to reduce the instability of the controlled object caused by some uncertain factors.

For the teleoperation robot system in this paper, because the wireless network is deployed in a relatively bad field environment, the direct consequence is that the network delay will cause a sudden change in the delay due to the change of the environment. For example, the obstruction of obstacles may bring a large delay, which is sudden and unpredictable. Therefore, the traditional PID control method cannot guarantee the stability and accuracy of the system control. The main idea of the gain scheduling control based on the parameter model is to add a gain α to the output of the conventional PID controller, which is dynamically adjusted for the network delay calculation of the monitoring wireless network [18].

The experimental platform software needs to record the position changes of the robotic arm at different times and collect the corner data of the robotic arm joint, while the periodic collection of the data requires a timer to achieve. In the process of windows message processing, the timing work is completed by processing the timer message requests in the message queue. Considering the priority of the message queue and the system clock frequency, the timing accuracy may not be accurate, and the "second loss" phenomenon often occurs. There are many ways to solve this problem, but the simplest and most effective way is to use high-precision timing technology. General software provides a unified working framework, the same management ideas and modes, and completes the practical management process of real management according to the fixed business process. For customers without too many personalized needs, general software can fully provide functions to meet all customer expectations. Give customers a standardized and standardized mode for operation. For the customers who have urgent needs in terms of personalized needs, the software that does not take into account the personalized needs is easy to cause the phenomenon of “acclimation” in the process of use. Therefore, in order to meet individual needs, software systems are designed according to specific situations and requirements, and customized development providing corresponding personalized services is widely used.

The operation interface is the interface for users to interact with the experimental platform. Users complete various functions through the operation interface, such as the initialization of the card, back to zero operation, and calling the simulation module. The system modeling module completed the establishment of the dynamic model of 2R robot and the expression of MATLAB language, which lays for the subsequent construction of fuzzy PID control module. The fuzzy PID control simulation module completes the motion control simulation including full drive and underdrive. COM component module is used to make the modeling and simulation module written in MATLAB language into dll or exe components identified by VC to facilitate VC program calling, communication, and data management module to realize the communication between host and motion controller, data transmission, and management of various data files.

In the teleoperation robot system, the communication between the remote control subsystem and the field control subsystem requires a gain scheduling link, that is, gain α. In the actual operation process, gain α is not a specific value, but a proportion, which is calculated by a specific calculation function $\mu(k)$ to obtain a pure delay $\tau_k^{ca}$, where $\mu(k)$ is defined by the following formula:

$$\mu(k) = k_p \text{error}(k) + k_i \sum_{j=0}^{k} \text{error}(j) + k_d (\text{error}(k) - \text{error}(k-1)).$$

(1)

In order to control the precision of the teleoperation robot more accurately, theoretically, each pure delay $\tau_k^{ca}$ should be used as the next feedback adjustment parameter of the next PID controller. However, because the delay adjustment is too frequent, it is necessary to sample the pure delay [19]. As can be seen from Figure 4, gain α is the key to gain scheduling control.
3.3.2. Determination of Gain. As can be seen from Figure 4, the total network delay of each feedback adjustment is \( \tau_k = \tau_k^{sc} + \tau_k^{yr} \). Suppose that during the first iteration is as follows:

\[
G'_o(s) = G_o(s) \alpha \tau_k^{yr} G_p(s).
\]  

Therefore, the delay transfer function from the first closed loop \( y_r(k) \) to \( y(k) \) is as follows:

\[
cs \tau \frac{G'_o(s)}{1 + G'_o(s)}.
\]

Therefore, the expression of \( G'_0(s) \) is as follows:

\[
G'_0(s) = \frac{\alpha G_o(s)G_p(s)}{\left(1 + (\tau_k s/n)\right)^{\alpha}}.
\]  

The delay transfer function of the system can be approximately expressed in the form of rational fraction, so the different network delays \( \tau_k \) in the teleoperation machine system are the root locus with the gain \( \alpha \) as the parameter [20].

According to equation (9), the method to obtain the maximum gain by using the root locus function can be obtained, that is, the method to obtain the maximum gain \( \alpha_{max} \) through the finally calculated delay space. In order to determine the optimal gain, it is necessary to find the optimal gain in the spatial range of the gain. In this paper, a multilevel optimization strategy similar to the pruning algorithm is used to gradually reduce the spatial range of the optimal gain and finally determine the range space of the optimal gain. In order to determine the advantages and disadvantages of different gains, it is necessary to define a measurement standard, that is, the cost function, where the cost function is the following equation:

\[
J_0 = \sum_{k=1}^{M} e(k)^2,
\]

where \( e(k) = y_r(k) - y(k) \) represents the error between the network delay sampling input and output, \( J_0 \) represents the sum of squares of errors at all sampling times, when the reference gain cost function is \( \alpha = 1 \), it is set as \( J_{0,k} \), and \( J_0/J_{0,k} \) is used to measure the excellence of the gain. When \( J > 1 \), it represents that the gain is worse than the reference gain; otherwise, the gain is better than the reference gain [21].
4. Result Analysis

In order to verify the effectiveness of the gain scheduling control algorithm in the teleoperation robot system, this paper applies the algorithm to the actual system. During the experiment, the delay sampling period of the teleoperation robot system is 20 ms. In this paper, PID control, gain scheduling control, and fixed parameter control are compared to compare their advantages and disadvantages [22]. During the experiment, the robot control system obtained the best control stability by continuously adjusting the relevant parameters. After the simulation experiment test, the final value obtained under the parameters of $k_p = 0.8$, $k_i = 0.001$, $k_d = 0$ was set as the best. This parameter will not be adjusted in the subsequent experiments. As mentioned above, all operation commands in the teleoperation robot system need to be transmitted between the two industrial control computers of the two remote control subsystems and the field control subsystem through the wireless network. The signal has a certain delay in the remote control process, and the impact of the delay alignment accuracy and accuracy must be overcome [23]. The experimental results are step response curves, as shown in Figures 5(a) and 5(b).

It can be seen from Figures 5(a) and 5(b) that the deviation amplitude of the two curves under the gain scheduling control is much smaller than the oscillation amplitude of the PID control curve. Therefore, it can be seen that the effect of gain scheduling control based on parameters is obviously better.

5. Conclusion

In order to meet the control accuracy and precision of tele-robot in wireless environment and avoid the damage to the system due to network delay, this paper introduces a parameter based incremental scheduling control algorithm. By analyzing the basic principle of gain scheduling control, this paper also analyzes how to determine the gain in the process of gain scheduling control, which can make the control accuracy meet the best state. Finally, the experiment verifies the improvement of the accuracy of the algorithm proposed in this paper compared with PID control.

Data Availability

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

Conflicts of Interest

The author declares that they have no conflicts of interest.

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