Design of Longitudinal Nonlinear Control Circuit System for Small Disturbance Robot

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Keywords: Small disturbance robot; Longitudinal nonlinear control; Circuit design

Abstract: The purpose of this paper is to study the design of longitudinal nonlinear control circuit of small disturbance robot in order to improve the stability and operation accuracy of robot in complex environment. By deeply analyzing the development status of small disturbance robot and the importance of longitudinal nonlinear control circuit, this paper puts forward a new circuit design scheme. Based on nonlinear control theory and stability analysis, the scheme aims to optimize the dynamic response and anti-interference ability of the robot. The research method combines theoretical analysis and experimental research, and verifies the performance of the circuit design through simulation and actual test. The experimental results show that the newly designed control circuit has obvious advantages in stability and dynamic response, and can effectively deal with small external disturbances and improve the overall performance of the robot. The research in this paper not only promotes the progress of control circuit technology of small disturbance robot, but also provides more reliable technical support for the application in related fields.

1. Introduction

With the rapid development of science and technology, robotics has been widely used in various fields [1]. Among them, small disturbance robot, as a kind of robot system that can maintain stability and accuracy under small disturbance, has been widely concerned by researchers in recent years [2]. This kind of robot has great application potential in precision operation, environmental monitoring, medical surgery and other fields [3]. However, the control circuit design of small disturbance robot is the key to its stability and performance, especially the design of longitudinal nonlinear control circuit, which is very important to improve the dynamic response and anti-interference ability of robot [4].

At present, there has been some research foundation on the control circuit of small disturbance robot, but most of the research focuses on linear control strategy, and there is relatively little research on nonlinear control circuit [5]. However, in practical application, the robot system is often faced with the challenges of nonlinear factors and uncertainties, so it is very important to study the nonlinear control circuit to improve the performance of the robot [6]. The purpose of this paper is to study the design of longitudinal nonlinear control circuit of small disturbance robot in order to improve the stability and operation accuracy of robot in complex environment. By optimizing the design of the control circuit, we can better cope with small external disturbances, thus improving the overall performance of the robot. This is not only of great significance to the development of robot technology, but also will provide more reliable technical support for the application in related fields.

The main research contents of this paper include: the development status of small disturbance robot and the importance of longitudinal nonlinear control circuit are deeply studied; Based on the nonlinear control theory, a new longitudinal nonlinear control circuit is designed. The performance of the circuit design is verified by experiments.

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2. Theoretical basis

2.1. Robot control technology foundation

Robot control system is the core of robot technology, which is responsible for receiving instructions, processing information and controlling the movement of the robot [7]. The basic principle of robot control system includes sensor information collection, information processing and control algorithm realization, actuator driving and so on. Among them, the control algorithm is the key to realize the precise movement of the robot. In the control circuit, the nonlinear control circuit can better adapt to the nonlinear characteristics of the robot system and improve the dynamic response and stability of the robot. The basic theory of nonlinear control circuit includes state space description, stability analysis, controller design and so on.

2.2. Small disturbance theory and its application

Small disturbance refers to the small impact on the system, which may come from the change of external environment, uncertainty or noise in the system and other factors. In robot control, small disturbances may have a significant impact on the stability and performance of the robot [8]. Therefore, it is of great significance to study the small disturbance theory and its application for improving the performance of robots.

The application of small disturbance in robot control is mainly reflected in the optimal design of control system. By analyzing and predicting the influence of small disturbance on the robot system, we can design the control circuit in order to reduce the influence of disturbance on the robot performance. And the small disturbance theory can also be used to guide the trajectory planning and dynamic modeling of robots.

2.3. Theoretical framework of longitudinal nonlinear control circuit

Longitudinal control refers to the control of the robot along its moving direction. In longitudinal control, the design of nonlinear control circuit is very important, because it can better adapt to the nonlinear characteristics and uncertainty of robot system [9]. The theoretical framework of longitudinal nonlinear control circuit mainly includes the following aspects: The dynamic model of the robot is established to describe its motion characteristics and nonlinear factors. A nonlinear controller is designed based on the dynamic model to realize the precise control of the robot. The performance of the controller is verified and optimized by stability analysis and optimization algorithm. In this process, we need to consider the dynamic response, stability, anti-interference ability and other aspects of the robot.

3. Design of longitudinal nonlinear control circuit for small disturbance robot

3.1. Circuit design scheme

When designing the longitudinal nonlinear control circuit of small disturbance robot, the design requirements and target performance should be clear at first. This mainly includes the following aspects: stability requirements, dynamic response performance and robustness. In the design process, this paper also considers some constraints, such as circuit size, power consumption, cost and so on. These constraints will affect the selection and configuration of circuit components. At the same time, the direction of optimization is also defined, including improving stability, accelerating response speed and enhancing robustness. After defining the design requirements and target performance, you can start designing the circuit scheme. The overall design idea is as follows:

Establish a mathematical model: In order to accurately describe the motion characteristics of the robot and its inherent nonlinear factors, a detailed dynamic model needs to be established first. This model will help us to better understand the behavior of the robot and provide a basis for the design of the control circuit. In the process of modeling, this paper analyzes the mechanical structure, kinematic constraints and possible external forces and disturbances of the robot in detail. By using Lagrange equation modeling method, a set of differential equations describing the dynamic behavior of the robot can be obtained. These equations include the robot's position, velocity, acceleration and other state variables, as well as possible nonlinear terms and uncertainties.

Selection of control strategy: After establishing the mathematical model of the robot, the next key step is to select the appropriate control strategy according to the design requirements and target performance. In this design, the adaptive control strategy is decided. The advantage of this strategy is that it can dynamically adjust the control parameters according to the real-time state of the robot, thus achieving stability and ensuring good dynamic response and robustness. The core of adaptive controller design is to adjust the parameters of the controller to minimize the tracking error and deal with the uncertainty and external disturbance of the system. This can be expressed by the following equation:

$$\dot{\theta} = \lambda\theta + K_a\left(yd - y\right) \tag{1}$$

Where θ is the parameter of the controller, yd is the expected system output, K_a is the adaptive gain matrix, and λ is a regularization term to ensure the stability of parameter updating. Adaptive law for online updating control parameters;

$$\dot{K}_a = \varnothing(e,t)K_a \tag{2}$$

Where e is the tracking error and $\varnothing(e,t)$ is a design function based on error and time.

Design circuit structure: Based on the selected control strategy, design the corresponding circuit structure. The goal of this paper is to build a circuit network that can realize adaptive control strategy. In the design process, we fully consider the complexity and realizability of the circuit. Through reasonable component selection and layout, the circuit can meet the control requirements and has good reliability and stability. At the same time, special attention is paid to the power consumption and heat dissipation of the circuit to ensure its long-term stable operation.

Configuration of circuit parameters: The last step is to configure the parameters in the circuit according to the requirements of mathematical model and control strategy. This includes resistance value, capacitance value, inductance value and gain of the controller. The goal of this paper is to find an optimal parameter configuration, so that the circuit can achieve the best control effect while meeting the requirements of stability, dynamic response and robustness. In order to achieve this goal, this paper uses particle swarm optimization algorithm to search the optimal parameter configuration. Through this algorithm, we can search efficiently in the parameter space and find the best parameter combination that meets all design requirements and target performance.

3.2. Simulation experiment and result analysis

After the circuit design is completed, this section uses simulation software for preliminary verification. By building a simulation model and inputting corresponding control instructions, we can observe the changes of the robot's motion trajectory, speed, acceleration and other parameters. These simulation results will help us to evaluate the feasibility and performance of the design. In the simulation experiment, different disturbance conditions are simulated to test the stability and robustness of the circuit. Table 1 shows the stability and robustness of the circuit after introducing disturbance by changing the initial position, speed or acceleration of the robot.

Table 1 Influence of dynamic change of robot on circuit stability and robustness

Initial position change	Initial velocity change	Initial acceleration change	Stability evaluation	Robustness evaluation
Δx=0.1m	Δv=0	Δa=0	Stable	Tall
Δx=0.2m	Δv=0	Δa=0	Stable	Middle
Δx=0	Δv=0.1m/s	Δa=0	Stable	Tall
Δx=0	Δv=0.2m/s	Δa=0	Slight oscillation	Middle
Δx=0	Δv=0	Δa=0.1m/s²	Stable	Tall
Δx=0	Δv=0	Δa=0.2m/s²	Slight oscillation	Low

Initial position change: When the initial position change is small (Δx=0.1m), the circuit remains stable and the robustness evaluation is high. When the initial position change increases (Δx=0.2m), the circuit is still stable, but the robustness decreases to medium. This shows that the circuit has a high tolerance to position disturbance, but its robustness will decrease with the increase of disturbance.

Initial speed change: When the initial speed changes slightly (Δv=0.1m/s), the circuit remains stable and has high robustness. When the initial speed change increases (Δv=0.2m/s), the circuit oscillates slightly and the robustness decreases to medium. This shows that the circuit is highly sensitive to the speed change, and the stability of the circuit may be affected when the speed disturbance is large.

Initial acceleration change: When the acceleration changes slightly (ΔA = 0.1m/s), the circuit remains stable and has high robustness. When the acceleration change increases (ΔA = 0.2m/s), the circuit oscillates slightly, and the robustness is obviously reduced to low. This shows that the disturbance of acceleration has a more significant influence on the stability of the circuit.

By adding noise signal to simulate the influence of external environment, the stability and robustness of the circuit are obtained as shown in Table 2 and Figure 1.

Table 2 Influence of external environmental noise on circuit stability and robustness

Noise type	Noise intensity	Stability evaluation	Robustness evaluation
White noise	Low	Stable	Tall
White noise	Middle	Slight oscillation	Middle
White noise	Tall	Obvious oscillation	Low
Ruido Rosa	Low	Stable	Tall
Ruido Rosa	Middle	Slight oscillation	Middle
Ruido Rosa	Tall	Oscillatory instability	Low

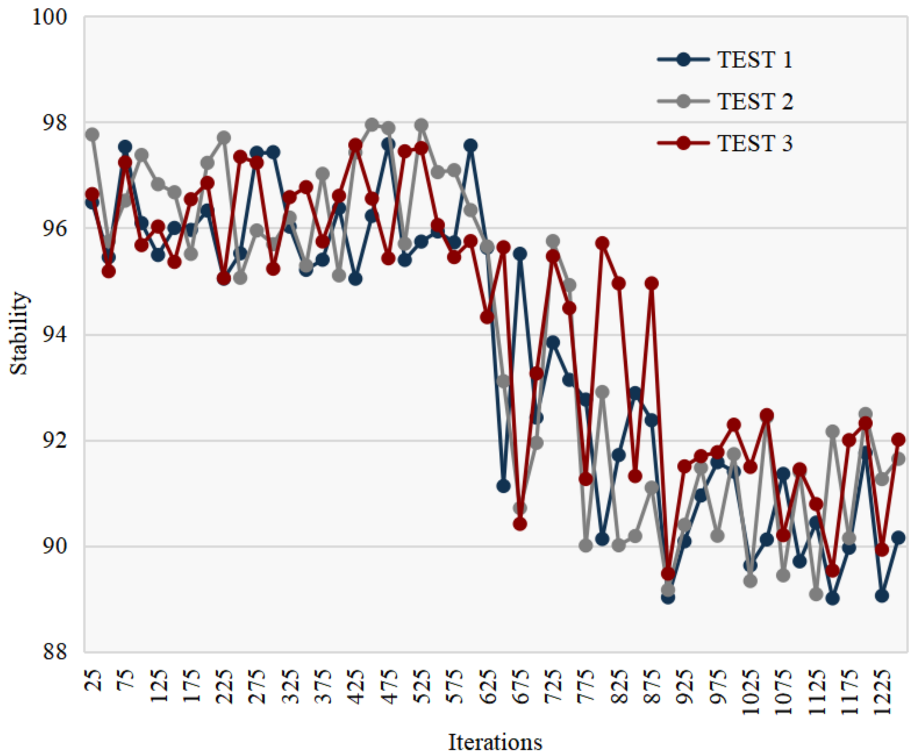

Figure 1 Stability result of circuit

White noise influence: Under the interference of low-intensity white noise, the circuit remains stable and has high robustness. With the increase of noise intensity, the circuit oscillates slightly to obviously, and its robustness decreases accordingly. This shows that the anti-interference ability of the circuit to white noise decreases with the increase of noise intensity.

Influence of pink noise: Similar to white noise, low-intensity pink noise has little influence on the stability of the circuit, and the circuit remains stable and robust. However, with the increase of pink noise intensity, the circuit develops from slight oscillation to oscillation instability, and its robustness is significantly reduced. This shows that pink noise has more serious influence on circuit stability, especially at high intensity.

Stability of the circuit: From the results, the circuit can remain stable in most cases. This shows that the designed circuit has strong anti-interference ability and stability.

4. Conclusion and prospect

After in-depth research and experimental verification, this paper successfully designed a longitudinal nonlinear control circuit for small disturbance robot. The circuit design is excellent in stability and dynamic response, which can effectively deal with small external disturbances and ensure the stable operation of the robot in complex environment. Through comparative experiments, it is found that the newly designed control circuit has higher anti-interference ability and faster response speed than the traditional linear control circuit. These advantages make the design have obvious practicability and effectiveness in practical application, especially in the scenes that require high precision operation and high stability, such as precision manufacturing, medical surgery assistance and other fields. With the continuous progress of robot technology, higher requirements are put forward for the control circuit of small disturbance robot. In the future, the development of control circuit technology of small disturbance robot will pay more attention to intelligence, adaptability and high integration.

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