APPLICATION OF ROBUST CONTROL OF NONLINEAR SYSTEMS IN MECHANICAL ARMS

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ABSTRACT: To study the robust control problem of singular systems with uncertainties, we must consider the elimination of the pulse and the regularity and robust stability of the closed-loop system, so it is more complicated than the robust control of the normal uncertain system. In this paper, the application of a new nonlinear system robust control algorithm in the control of two-link mobile joint robot is discussed. The model tracking problem when the terminal is holding an indefinite load is discussed. The simulation results show that the robot closed-loop system has better dynamic response when the manipulator clamps the uncertain load motion, indicating that the system has strong robustness. Through the two joints, the robot performs an algorithm test on the robust control of the neural network. When the motion trajectory value is 0.5, the actual trajectory value is 0. Therefore, the actual trajectory of each joint of the robot arm can track the reference trajectory well with a probability of 98%.

KEYWORDS: Nonlinear system; robust control; mechanical arm

1. INTRODUCTION

When the structure and parameters of the robot are known, the dynamic characteristics of the system can be used to describe the complete dynamic characteristics of the system, so that various automatic control theories can be applied, and the model-based controller can be designed to realize the trajectory tracking control of the robot, and the position of the robot, variables such as speed and acceleration have ideal tracking states. Robot dynamics is actually a system with high nonlinearity and uncertainty [1]. Therefore, the processing of nonlinear uncertainty of the system is a very important research content in robot trajectory tracking control. Among the various control theories of robot nonlinear uncertainty, adaptive control and robust control are the two most representative ones. The adaptive control can identify and learn according to the parameter changes of the controlled object and the actual output, so as to adjust the control law structure and parameters to achieve certain control performance indicators [2]. However, the online control method of adaptive control is computationally intensive and has poor real-time performance. It cannot guarantee the stability of complex systems with non-parametric uncertainties. It is mainly applicable to the case where the parameter uncertainty is uncertain and the unknown parameters of the system can be linearized. Robust control enables effective control when there are uncertainties such as unmodeled dynamics and external disturbances. The greatest advantage of robust control is the suppression of unmodeled dynamics and interference, but it is without the ability to learn and adapt, usually assuming that the gain is bounded, the upper bound is unknown, etc., so that the controller of the design is too conservative [3].

Therefore, in view of the characteristics of both adaptive control and robust control, relevant scholars at home and abroad further put forward adaptive robust control strategy. The purpose is to combine the advantages of the two algorithms, robust control and adaptive control, to eliminate their shortcomings and inadequacies, and play a role in promoting strengths and avoiding weaknesses. The design idea of adaptive robust control is based on the robust controller to ensure the dynamic performance of the system under the action of parameterized uncertainties and disturbances, and adaptive control technology is used to reduce the steady-state error caused by unstructured uncertainties and improve the control accuracy of the system [4].
2. METHODOLOGY

Based on the robust control structure, Wang assumes that the system only has parameter uncertainties, and introduces an adaptive algorithm to estimate the upper bound of the unknown parameters, effectively reducing the conservativeness of the robust gain [5]. Furthermore, for the system with both parameter uncertainties and non-parametric uncertainties, Zhang combines robust adaptive control with fuzzy logic control to propose a robust adaptive fuzzy tracking control strategy for mechanical systems. Through Lyapunov stability theory, the stability of the system is clarified and the tracking error is asymptotically convergent. The control method is robust to the uncertainty of the system [6]. Fan uses the adaptive control technology to identify the nonlinear dynamic characteristics of the robot, and proposes a robot adaptive robust control based on passive control. When there is no model error and external disturbance, the asymptotic stability of the system tracking error can be ensured, and the parameters of the identification system can be guaranteed to be bounded [7]. In order to ensure that the adaptive parameters are bounded in the case of bounded interference, the adaptive law is further improved, and variable structure control items are added to the controller structure to ensure that the system trajectory tracking can reach the sliding surface.

In the innovation of the article, a trajectory tracking strategy based on adaptive robust control is proposed. For the uncertainty of the robot and the external disturbance, the robust controller is used to eliminate the approximation error of the neural network controller, and then the adaptive law adjusts the unknown parameter value of the robust controller to ensure the system has good robustness and dynamic performance, and proved by simulation experiments.

3. EXPERIMENTAL METHOD

Robust control and adaptive control are studied as two independent fields. Scholars try to obtain the desired control performance through separate robust control or adaptive control, but the effect is not obvious [8]. Therefore, this chapter combines adaptive control with robust control, and utilizes the advantages of the two control methods to design an adaptive robust control algorithm for the robot to ensure the system has ideal trajectory tracking performance [9].

3.1 Rigid Robot Dynamics Modeling

This section will establish the dynamic model of rigid robots, and explain the basic characteristics of the robot model and related preliminary knowledge, and provide the necessary theoretical support for the subsequent research on rigid robots. Figure 1 shows a typical two-joint robotic arm:

![Typical two-joint robotic arm](image)

**Fig. 1 Typical two-joint robotic arm**

In it, $m_1$ and $m_2$ are the masses of the two joints of the robot arm; $l_1$ and $l_2$ are the length of the mechanical boom; $q_1$ and $q_2$ are the angle of rotation of the two joints. The Lagrangian method is the simplest and most effective modelling method by calculating the kinetic energy and potential energy of the manipulator system to establish the dynamic equation. The rigid manipulator dynamics model is established below to clearly determine the dynamics of the manipulator for further analysis and application [10].

As the number of robot joints and degrees of freedom increases, the coupling between the joints becomes stronger which is making the robot dynamics model more complex [11]. In addition, in practical applications, robots inevitably have various factors such as friction, uncertain disturbance, load change, etc., specifically, such as viscous friction between joints, coulomb friction, etc.; Unknown environmental interference experienced by the robot during the execution of the operational mission; Operating load changes in parameters such as size, weight, and inertia; And artificial simplification of the dynamic model of the system, and so on. That is to say, the actual robot model has complex dynamic characteristics such as strong coupling, time-varying and highly nonlinear, which will bring difficulties and inconvenience to the control of the robot. Therefore, for the dynamic model of the actual robot system, it should not only be a description of the nominal model with known parameters, but also a description of the various uncertainties that the system has. The mathematical model of rigid robot considering
various uncertain factors is generally expressed as:

the dynamics model of the n degree of freedom
rigid linkage robot system can be described as:

\[ M(q)\ddot{q} + C(q; \dot{q})\dot{q} + G(q) = \tau + d \] (1)

First, take the nonlinear system described by
the expression as an example to illustrate the
relevant mathematical basis in the equation, x is
an n-dimensional state vector, and f is an n
dimensional nonlinear function whose structure is
related to the time variable t. Our control goal is
to make the position tracking error and speed
tracking error of the robot tend to zero, that is, the
operator moves steadily from any initial position
to, define the state variable to be \( x_1 = q \), \( x_2 = \dot{q} \).

Early robot control methods usually
linearized the nonlinear part of the robot dynamics
near the target trajectory, called the local
linearization method. However, the robot system
has strong coupling, time-varying and nonlinear
characteristics. Local linearization often cannot
guarantee the global convergence of the system.
In the further study of nonlinear robot systems, a
global linearization method, namely feedback
linear method, is proposed. The basic idea is to
introduce differential geometry. The coordinate
transformation of state space makes the
relationship between input-state or input-output
of nonlinear system equivalent to linear system,
and then applies the mature control theory of linear
system to make the system meet certain
performance. The feedback control is required to be:

\[ u = M_0(q)^{-1}[\tau - N_0(q, \dot{q})] \] (2)

A variety of uncertainties in the actual system
may degrade the performance of the control
system and may even cause system instability.
Robust control is precisely the modern control
theory that is generated to make control objects
with various uncertainties meet the control
requirements. In the design of robot dynamic
control system, the robust controller not only
considers the nominal dynamic model of the robot,
but also considers the influence of uncertainty on
system performance.

3.2 Adaptive Fuzzy Robust Controller
Design

It can basically meet the design requirements
when the uncertainty has the most serious impact
on the system performance quality or is the worst.
Robust control is to control the state of the system
under the uncertainty \( \varphi(x) \) and effect \( f(x) \) of
the robot system described in the above equation, \( x(t) \)
is for any non-zero initial value, \( x(0) \) can gradually
asymptotically zero and stabilize at zero, that is
\( \lim_{t \to \infty} x(t) = 0 \).

4. EXPERIMENTAL RESULT

The basic idea of robust controller design and
implementation of robust control method based on
signal compensation is: for the controlled object
with uncertain characteristics, the nominal
controlled object is introduced, and the difference
between the actual controlled object and the
nominal controlled object is regarded as
equivalent interference. Firstly, the nominal
controller is designed for the nominal controlled
object, so that the input and output characteristics
of the closed-loop system composed of the
nominal system satisfy the given performance;
then the robust compensator is designed to
compensate the generated robust compensation
signal or the effect of equivalent interference on
the nominal closed-loop system is suppressed to
achieve the desired robust control performance.
In a real system, each joint is typically driven by a
separate drive. When applying the signal-based
robust control method to the control of the robot
arm system, a decentralized control strategy can
be adopted, that is, a controller that requires only
local state feedback is designed for each joint
subsystem. Design, stability analysis and
simulation results of decentralized robust tracking
controller based on signal compensation.
Simulation experiments are carried out on a two-
joint rigid robot to verify the effectiveness of the
neural network robust control algorithm designed
in this section. The specific simulation parameters
of the robot dynamics model are as follows:

\[ M(q) = \begin{bmatrix}
 m_1*l_1^2 + l_1*[m_1 + m_2 + 2l_1*m*cos(q_1)] & 1*m_1 + l_1*l_2 \\
 1*m_1 + l_1*l_2*cos(q_2) & m_2*l_2^2
\end{bmatrix} \] (3)

In it, \( q_i \) (i=1,2) represents the angular
position of the joint, \( m_i \) (i=1,2) is the
joint mass, \( l_i \) (i=1,2) is the joint length (m).
The physical parameters of the manipulator model
are set as the length of the connecting rod \( l_1=l_2=l \),
the quality of connecting rod \( m_1=m_2=2kg \).
The reference motion trajectories of joint 1 and joint 2
are selected as \( qd=0.5*sin(t) \), \( sin(qd)=0.5*sin(t)+0.5*cos(t) \) respectively.
The initial value of the joint position is \( q(0)=[0,0]^T \),
the input variables, hidden layers, and output variables are
5, 5, and 1 respectively. The center point of the
Gaussian function is evenly distributed, and the basis function width is set to 0.5. The initial network weight of the neural network is set to 0.5, and the adaptive law gain is r=50. The position tracking effect of the mechanical arm joint is shown in Figure 2, where red is the desired motion trajectory and blue is the actual tracking trajectory.

Figure 2

![Joint 2 position tracking](image1)

**Fig. 2 Joint 2 position tracking**

It can be seen from the simulation results that the actual trajectory of each joint of the robot arm can track the reference trajectory well. From the position tracking curve of the joint of Fig. 2, it can be clearly seen that the system has only slight tracking error in the initial stage, and can quickly adjust the controller parameters so that the actual output coincides with the desired running track. Figure 3 shows the tracking error curve of the two joints, which more intuitively shows the fast convergence of the tracking error of the two joints.

![Joint 2 tracking error curve](image2)

**Fig. 3 Joint 2 tracking error curve**

It can be seen from the simulation experiment results that the actual output of the system can track the reference trajectory well and has good position tracking and speed tracking performance. The position tracking error and the speed tracking error become zero after a very short period of time. The effects of system uncertainty and external disturbances are eliminated by the robust controller. The simulation results demonstrate the effectiveness of the proposed adaptive fuzzy robust controller for dealing with uncertain nonlinear systems.

![Membership function of fuzzy logic system](image3)

**Fig. 4 Membership function of fuzzy logic system**

Among the various control theories of robot nonlinear uncertainty, adaptive control and robust control are the two most representative ones. The adaptive control can identify and learn according to the parameter changes of the controlled object and the actual output, so as to adjust the control law structure and parameters to achieve certain control performance indicators. However, the online control method of adaptive control is computationally intensive and has poor real-time performance. It cannot guarantee the stability of complex systems with non-parametric uncertainties. It is mainly applicable to the case where the parameter uncertainty is uncertain and the unknown parameters of the system can be linearized. Robust control enables effective control when there are uncertainties such as unmodeled dynamics and external disturbances. The greatest advantage of robust control is the suppression of unmodeled dynamics and interference, but it is without the ability to learn and adapt, usually assuming that its gain is bounded, the upper bound is uncertain, etc. which is making the controller of the design too conservative.

5. CONCLUSION

In this paper, the global asymptotic stability of a class of nonlinear dynamic systems is firstly investigated. Then, based on the results of
nonlinear robust control, the robot continuous state feedback controller is given, and the control effect is better which is easy to implement, robust control has the advantage of suppressing interference and compensating for unmodeled dynamics, but without the ability to learn. When designing a robust controller, it is generally assumed that the uncertainty of the system belongs to a descriptive set, such as gain bounded, upper bound known, etc., but the exact boundary function is difficult to calculate. In fact, most of the uncertainty is bounded. It is estimated by the designer based on prior knowledge and subjective judgment. In order to ensure the stability of the system, conservative estimates are generally taken. Therefore, robust control is a conservative control theory. For individual elements in a set, robust control may not get the best control effect.

6. REFERENCES