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RBF Nerve Network Tuning PD Control Scheme for Tele-operation Robot Servo System

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Abstract

In the bilateral hydraulic servo control system of a construction tele-robot with in-situ force sensing, the p-f type force feedback architecture is liable to result in an impact on the operator hand, and its high amplitude will cause the control unstable. In order to solve this problem an improved force feedback control method with the feature of a T-S fuzzy feedback coefficient, which could be modified online nonlinearly and continuously, is proposed. And a RBF-PID force controller is also designed, and formed a bilateral hydraulic servo control system. The experimental results indicate that the new improved control method reduced the impact of the feedback force; the compliance and transparency of the tele-operation of construction tele-robot system are enhanced.

Keywords: *fuzzy feedback coefficient, force feedback, construction tele-robot*

1. Introduction

Since the tele-robot came out, it has got widespread attention, and has important position in top science research and production. In the recent years, as the rational exploitation and utilization of the resource of sea-floor, underground and astrospace, it is needed to work in limit environments such as high temperature, high pressure suffocation etc [1-3]. So the operator in safety zone controlling the robot to enter the hazardous regions by remote operation is developed and used as a kind of effective method.

Operators in a safe place that only a true and accurate force tele-presence information, they can control engineering task robot to accurately complete the operation. Pairs of force tele-presence tele-operation robot control system design projects, to ensure system stability, reliability, and tracking performance, So effective control methods, rational design of the controller is the critical to ensure the reliable operation of control systems [4-8]. Authors based on the existing control methods and their application in the field of robotics research, combined with force tele-presence tele-operation robot works bi-directional hydraulic servo control system characteristics, relying on electro-hydraulic proportional valve controlled by the master, from the hydraulic swing motor experimental platform consisting of tele-presence. Force feedback servo-control for bi-directional feedback exists in the impact force the issue, proposed to improve the force feedback control method to increase the smoothness.

In this paper, PID control strategy is applied to improve its performance in the two-way force servo on the basis of two-way force servo tele-operation technology，taking into account the parameter characteristics of two-way force servo system are likely to change in actual working conditions, the traditional PID parameter tuning method already can not satisfy the real-time, accurate control conditions. The PID algorithm was done various improvements. Emerging selective control PID-PD, control I-PD control and adaptive PID control algorithm [9], especially in recent years with the research of the intelligent control and development of the so-called intelligent PID controller was formed from combining intelligent control and conventional PID control ,the controller has caused widespread concern and great interest and has been successfully applied [10], scholars has researched some intelligent PID algorithm and controllers,such as parameter fuzzy PID controller [11, 12], PID controller based on genetic algorithm [13, 14], neural network PID controller [15, 16], PSO-PID controller [17] and so forth, and achieved good control effect.

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Radial basis function neural network is a forward neural networks with good performance it has a good ability of generalization and Small amount of calculation, its learning speed is also much faster than the other algorithms, so it has been widely used in system identification and parameter estimation [18]. It use a self tuning method of PID control parameters based on RBF neural network, combining the neural network with PID on the basis of conventional PID performance, using the adaptive capacity of neural network to fine-tune the control parameters of the system, so that a stable PID controller with self-tuning capability was construct to adapt the changes of work parameters under servo of the bilateral force servo control, to get better control effects. Experimental results show the effectiveness of the method [19].

2. Description of System

2.1. Structure of Construction Robot

The construction robot is based on the boom of the excavator; the bucket is replaced by an single degree of freedom end-effector to form an four-DOF series joint type manipulator, as shown Figure 1. The end-effector opens and closes to grasp the object by a pair of mesh gear, and there are in sections on the tooth surface to enhance the reliability of grasping the object. In order to bear greater working load, the arm of the construction robot are driving by hydraulic power, four cylinders are used to control the four-DOF of the robot. The hydraulic system is composed of hydraulic station, oil circuit, electronic-hydraulic controlled proportional reversing valves and their controllers and cylinders. The proportional reversing valves and their controllers are the core of the electro-hydraulic control subsystem, which realize the flow control of the cylinders, namely speed control and reversing control.

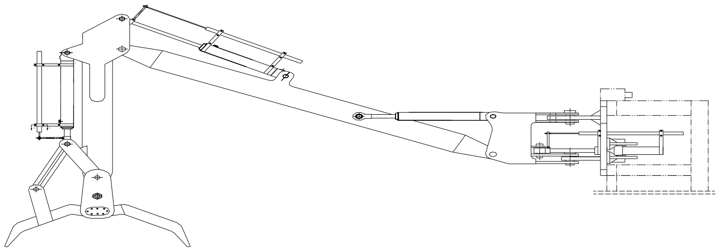

Figure 1. 4DOF Engineering Robot Structure Chart

2.2. Tele-operation Robot System

In a tele-operated manipulation system, the operator needs not only a visual representation but also a force representation of a system existing in a remote place. Those devices of sense of force, at present, have problems, such as insufficiencies in the display functions and complications in their constitutions.

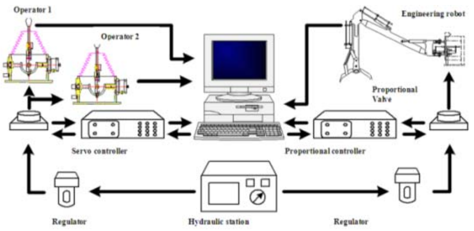

Figure 2. Master-slave System for Remote Control

A conceptual illustration of a tele-operated manipulation system for this study is given in Figure 2. The figure shows that the system is constructed as a master-slave system and that both manipulators for the master and the slave consist of 4-DOF type actuators. Moreover, it is illustrated that a machine tool for grinding is implemented at the end-effecter of the slave manipulator. In a tele-operated master-slave system as shown in Figure 1, the master has to play two roles, firstly as a reference input device to the slave, and secondly as a sense of force device. Here, the term “sense of force” means a function that allows the operator to feel a force that is fed back to him from the slave [20-22].

3. Improved Bi-directional Force Feedback Servo-control Method

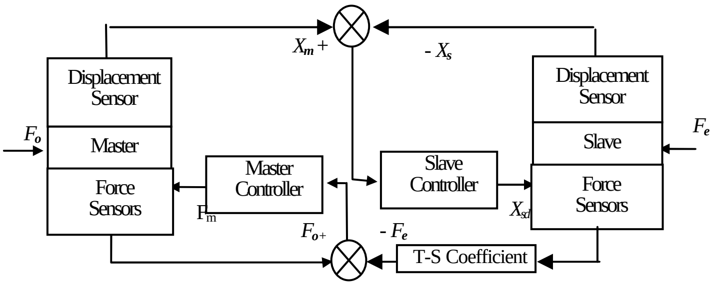

Figure 3. Structure of Improved Force Feedback tele-robot Control System

The choice of the feedback coefficient, the usual practice is based on specific system feedback force range, select an appropriate ratio constant. However, this approach will force when feedback is small, the transparency of the system decreased significantly. The feedback coefficients should be expected of such a nature, force feedback when the feedback coefficient and a small number in order to enhance the sensitivity of force feedback. When the feedback force is large, the feedback factor should be smaller to ensure that force feedback can be put in the scope of the manpower in order to reduce the impact effects. In this paper, TS-type fuzzy model is constructed using non-linear changes in a continuous feedback coefficient to improve the force feedback control method.

The improved control system schematic shown in Figure 3, the main features of the control is the location of the Slave hand depend on the main and the secondly hand's position deviation between the control, the main force hand feedback force by the product of F_e, K_{ef} and the operation of force bias control, the control law as follows:

$$F_m=K_f(F_o-K_{ef}*F_e), \quad X_{sd}=K_s(X_m-X_s) \tag{1}$$

Where:
F_m--Drive Master Hand Vector;
K_f--Main hand gain matrix;
F_e--force vector from the secondly hand and the environment;
F_o--The operator control force vector;
X_{sd}--Expect position vector of the Slave hand;
K_s--Displacement gain matrix of the Slave hand;
X_m--Main hand displacement vector;
X_s--Slave hand displacement vector;
K_{ef}--Feedback coefficient.

3.1. Design of Feedback Coefficient

In the T -S model, the general form of fuzzy rules as follows:

R: IF x is A and y is B Then Z = f (x, y)

Where, A and B is the antecedent of the fuzzy set, $Z = f(x, y)$ is a precise function or after the pieces of constant [20].

In this paper, the measured value of feedback strength for Fe antecedent to feedback coefficient for the latter parts K_{ef}. First, in the Fe-normalized value | Fe | on the domain defined three fuzzy sets: BIG, MID, SML; fuzzy subset of the membership function selection for the entire overlapping continuous linear trapezoid, shown in Figure 4 show. Fuzzy mapping rules as follows:

R^{l}: IF Fe is BIG Then K_{ef1}=2
R^{2}: IF Fe is MID Then $_{Kef2}$ = 1
R^{3}: IF Fe is SML Then $_{Kef3}$ =0.5

U sing algebraic product - the fucus of France fuzzy inference rules, the availability of TS-type fuzzy feedback coefficient K_{ef} non-linear curve of Figure 5.

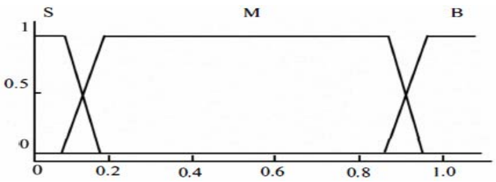

Figure 4. Membership Function of | Fe |

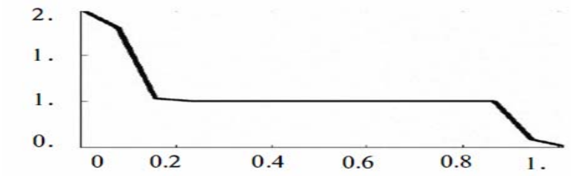

Figure 5. Curve of Feedback Coefficient

4. The Structure of System

The tele-operation system with force tele-presence includes following components: the manipulator, electro-hydraulic servo drive system, displacement servo control system, visual tele-presence system, wireless communication system and force sensors, displacement sensors etc, shown in Figure 6.

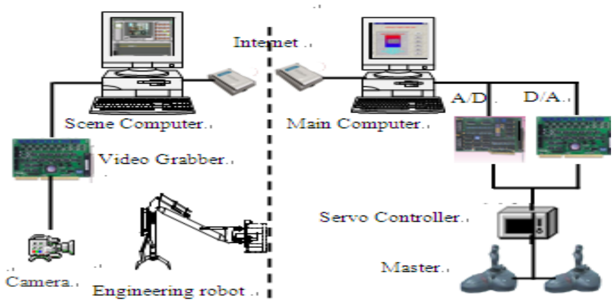

Figure 6. Master-slave System for Remote Control

This research deals with a remote-control system applicable to the machining fields, such as grinding, polishing, assembling, and shaping. In machining works that require high speed, high power, and high rigidity in the operation, the attributes of hydraulic actuators make them suitable for these applications. In this study, we deal with a master-slave system composed of serial links by hydraulic cylinders. First, the serial links treated here are assumed to be of 1-DOF, and then of 4-DOF for general use, because we mainly are concerned with developing a new sense of force device.

At the first control stage, the remote control computer handclasps with the worksite one, and then the worksite computer reads the information of the joints' displacement and velocity through the A/D continuously, and transmits all these information to the remote control computer to initialize the graphic robot and make the operator present the worksite robot's state. Simultaneously, the worksite computer and the graphic computer receive the control instructions in the manner of event-driven. The graphic computer refreshes the virtual robot motion state on real time. The worksite computer explains the operator's instructions into the motion angles of every joint by arithmetic, where the sampling and controlling interval is ten mms. The process is shown in Figure 7.

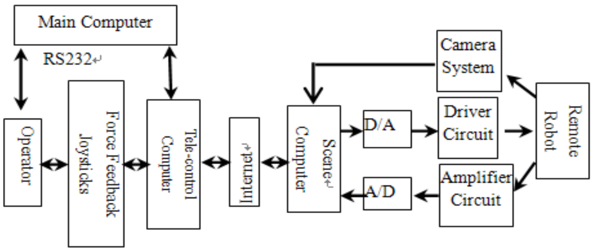

Figure 7. Remote Robot Control System Principle

When the operator operates the remote worksite robot facing to the simulation robot, the video information is needed to be watched on real time because the model errors between the graphic robot and the virtual environment are inevitable [8], and the worksite environment can also not be predicted. All these were completed by the equipments fixed on the remote robot such as camera, video emitter, video receiver and so on [23, 24].

Comparing with the tele-operation which is operated only by the video pictures transmitted from the worksite, the operation with high tele-presence prompt manner may enhance the work efficiency by 30%~50%. Simultaneously, it is not only favor for conquering the influence of time delay, but also can provide friendly graphical user interface. The operator can change video point and video angle of the conceals level forward feeds network [25-26]. It is non-linear from input to the output mapping, but it is linear from the conceals level space to the output space mapping, thus speeds up the study speed greatly and avoids the partial minimum problem.

5. Control Algorithm Realization

5.1. RBF Nerve Network Model

The Radial Basis Function nerve network is proposed by J.Moody and C.Darken in the end of 1980s, it is has three conceals level forward feeds network [27]. It is non-linear from input to the output mapping, but it is linear from the conceals level space to the output space mapping, thus speeds up the study speed greatly and avoids the partial minimum problem. RBF network architecture shows in Figure 8.

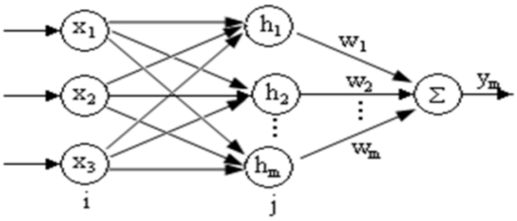

Figure 8. RBF Nerve Network Frame Chart

5.2. RBF Nerve Network PID Control Algorithm [28]

PID control to simple structure, robustness, good, able to adapt to the complex system control, etc., in the control engineering has been widely used [29, 30]. But the parameters of conventional PID control system by setting a hard-line adjustment of the non-linear and non-deterministic system control result is not very satisfactory. To do this in cooperation with the Ziegler-Nichols method of digital simulation to determine the PID parameters of stable operation of the system K_p, K_i, K_d, after the initial value. Designed to use RBF (Radial Basis Function) neural network model for online identification system, and adjust the PID parameters, the formation of RBF-PID controller to meet the remote operation of robot control system engineering nonlinear and uncertain requirements, its block diagram as follows in Figure 9.

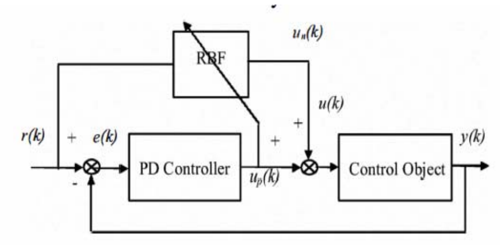

Figure 9. RBF Nerve Network PD Control

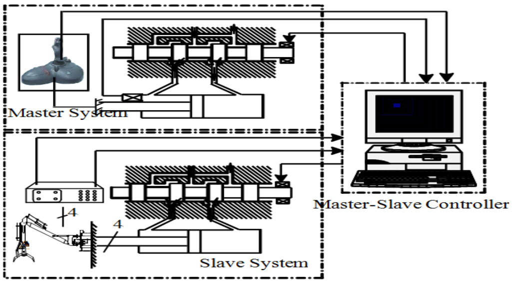

Figure 10. Diagram of Experimental Apparatus

RBF network is a three-layer feed forward network, from input to output mapping is nonlinear, while the hidden layer space to output space mapping is linear, thus speeding up the learning speed and avoid local minima problems [31, 33]. This design network model has six input nodes, eight hidden layer nodes, three output nodes.

According to the system model equation, to be ts as the sampling period, matching all the pole-zero conditions, to obtain the discrete model of the system:

$$\begin{aligned} y(k) = a_1 y(k-1) + a_2 y(k-2) + a_3 y(k-3) + \\ a_4 u(k-1) + a_5 u(k-2) + a_6 u(k-3) \end{aligned} \tag{2}$$

Where:
$y(k)$—the output of the system of k time
$u(k)$—the control input of K time
a_i —known constants of System model

$$X = [x_1, x_2, x_3, x_4, x_5, x_6]^T \tag{3}$$

Then the RBF network input vector：
Where:
$x_i = y(k-i)$ $i=1,2,3$
$x_j = u(k-j+3)$ $j=4,5,6$
Hidden layer nodes to take Gaussian kernel function:

$$h_j = \exp\left(-\frac{\|X - c_j\|^2}{2b_j^2}\right) \qquad j=1,2,\ldots 6 \tag{4}$$

Where: The first j nodes hj center vector $c_j = [c_{j1}, c_{j2}, \ldots c_{j6}]^T$; the base width $b_j = [b_1, b_2 \ldots b_6]^T$; knot vector $H = [h_1, h_2, \ldots h_6]^T$. Take the network weight vector $W = [w_1, w_2, \ldots w_6]^T$, using gradient descent method c_{ji}, b_j, w_j, h_j of the iterative algorithm is as follows:

$$y_m(k) = w_1 h_1 + w_2 h_2 + \cdots + w_6 h_6 \tag{5}$$

$$w_j(k) = w_j(k-1) + \eta\left(y(k) - y_m(k)h_j + \alpha\left(w_j(k-1) - w_j(k-2)\right)\right) \tag{6}$$

$$\begin{aligned} b_j(k) = b_j(k-1) + \alpha\left(b_j(k-1) - b_j(k-2)\right) \\ + \eta \Delta b_j \end{aligned} \tag{7}$$

$$\begin{aligned} c_{ji}(k) = c_{ji}(k-1) + \alpha\left(c_{ji}(k-1) - c_{ji}(k-2)\right) \\ + \eta \Delta c_{ji} \end{aligned} \tag{8}$$

Which take learning rate η=0.2, Momentum factor α=0.05.

$$\frac{\partial y(k)}{\partial u(k)} = \frac{\partial y_m(k)}{\partial u(k)} = \sum_{j=1}^{m} w_j h_j \frac{c_{ij} - u(k)}{b_j^2} \tag{9}$$

Incremental PID coefficient adjustment method is as follows:

$$E(k) = R(k) - y(k) \tag{10}$$

Where: *R(k)*—The system reference input.
E(K)—System error.

$$\Delta k_p = -\eta \frac{\partial J}{\partial k_p} = \eta E(k) \frac{\partial y(k)}{\partial u(k)} \left(E(k) - E(k-1)\right) \tag{11}$$

$$\Delta k_i = -\eta \frac{\partial J}{\partial k_i} = \eta E(k) \frac{\partial y(k)}{\partial u(k)} \tag{12}$$

$$\Delta k_d = -\eta \frac{\partial J}{\partial k_d} = \eta E(k) \frac{\partial y(k)}{\partial u(k)} \left(E(k) - 2E(k-1) + E(k-2)\right) \tag{13}$$

$$\begin{aligned} u(k) &= u(k-1) + K_p\left(E(k) - E(k-1)\right) + K_i E(k) \\ &\quad + K_d\left(E(k) - 2E(k-1) + E(k-2)\right) \end{aligned} \tag{14}$$

6. Experiment Results

To realize a tele-operated manipulation system as shown in Figure 3. It is necessary to constitute a master-slave system, in which the master and the slave correspond, respectively, to a sense of force and an actuating manipulator. In this section we therefore discuss a master-slave hydraulic system equipped with the new sense of force proposed.

6.1. System Constitution

In Figure 10, a schematic diagram of the experimental apparatus for the present study is shown. The total system consists of a master system and a slave system. The operator's force Fop, detected by a force sensor, is sent to the computer in order to actuate a master-side piston. In the slave system, a spring of stiffness k is attached at a frame of apparatus for simulating a load-force of operation. To detect the load-force, a force sensor is set at the inertial load through a plate spring. Two displacements of pistons in master and slave xm, xs, and two forces Fop = Fm, Fs are detected by each sensor and then sent to the computer. Subsequently, two control inputs u_m and u_s for actuating the master and the slave are calculated in the computer, according to a bilateral algorithm. For an algorithm of each controller for the master and slave, a proportional control algorithm was adopted. The sampling time was chosen to be 1 ms. In the experiment, two kinds of load, that is tires and hardwood, were tested. With respect to servo-valves and cylinders for constructing two servo-systems in the master and the slave, different types were adopted intentionally between the two systems. Namely, the master-slave system was tested in the experiment for a system with rather different dynamic characteristics between the master and the slave.

It is adopted that a bilateral control methodology for controlling the master-slave system. Concerning system constitutions for bilateral control, the following two types are well known as representative ones: (a) Force reflecting servo type and (b) Parallel control type.

6.2. Experimental Results

In the master-slave system shown in Figure 11, two types of bilateral controls are adopted, that is, a force reflecting servo type and an improved parallel control method. By comparing the force functions between two types of systems, we investigate experimentally the applicability of the proposed system. In the experiment, time responses of two forces Fm and Fs were measured together with those of two displacements X_m and X_s.

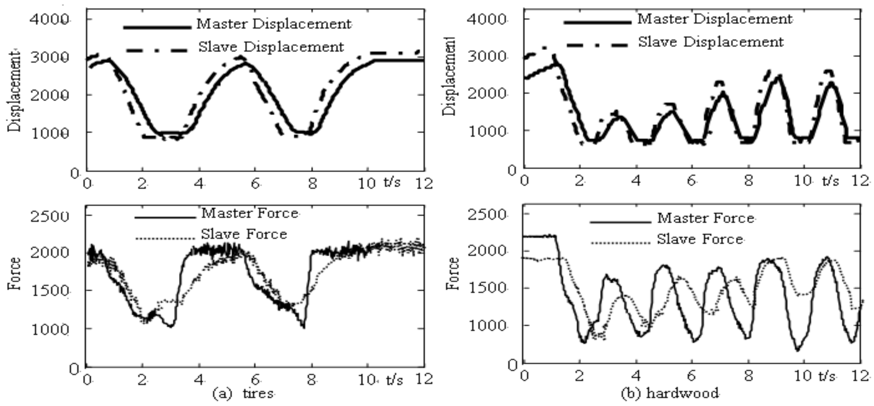

Figure 11. Experimental Results of Force Reflecting Servo Type

First, response curves for the force reflecting servo system are shown in Figure 11(a) and (b). These figures correspond, respectively, to the results for the tires and the hardwood. Observing Figure 11(a), it is shown that the slave force Fs is detected almost at the instant that the slave touches the tires. Subsequently, the force Fs is controlled in good agreement with the master force Fm is shown in the figure. In this experiment, the operator was able to feel a softness of tires through the sensing function of the sense of force. On the other hand, Figure 11(b) shows that the response curve of Fs is accompanied by a tendency toward vibration. The vibration appears from the instant that the slave touches at the tires. In addition, the tendency of such a vibration affects the waveforms of displacements Xm and Xs . In this experiment, it was difficult to control the system stably.

Secondly, the same kinds of results as seen in Figure 11 are shown in Figure 12 (a) and (b) as a result of the parallel control. Through comparing Figure 12(a) and Figure 11(a), it is shown that both results coincide well with each other. The operator in this experiment was able to feel a softness of tires as in the previous experiment in Figure 11(a). Furthermore, the result for the hardwood from Figure 12(b) is improved distinctly compared with the result in Figure 11(b). The system was kept stable in this experiment under various system conditions. As a result, the operator was able to feel a hardness of wood. Correspondingly, it is observed in Figure 12(b) that the amount of piston dis-placement is smaller than in Figure 12(a), in spite of the fact that a larger force than that in (a) is given to the system.

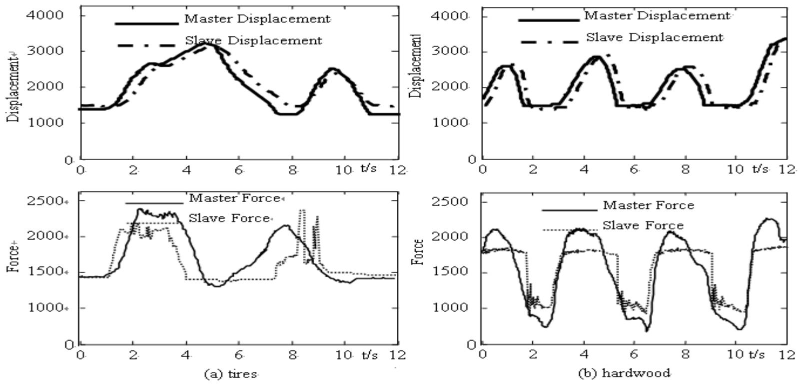

Figure 12. Experimental Results of Parallel Control Method

7. Conclusion

In view of the novel force feedback bilateral servo control system, it was proposed that one kind of RBF nerve network tuning PD on-line from study, adaptive control strategy, which can approach willfully the continuous function characteristic using the RBF nerve network by the free precision, through optimizing two parameters of PD by RBF nerve network, it can improve dynamic characteristic of master-slave control system. Through simulation and experiments, we can obtain that: (1) It can be theoretically proved that this control algorithm of novel force sense bilateral servo system is practical and feasible. (2) It effectively reduces the force feedback from the impact of the phenomenon, significantly improved the system's force feedback control smoothness, enabling the operator to obtain the real force tele-presence, transparency improved. (3) It can realize master-slave position tracking and let the operator feel "the force sense" well from feedback, improves the human and the environment interaction characteristic and enhances the working efficiency. (4) Moreover, this control arithmetic has taken on control briefness, constringency rate rapidness, real-time well, strong robustness, self-adapted and the rapidity.

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