On Time Delay Telerobot System Control Model Research

JIN HE, YULIN WANG, CHUNFEN LV
Department Physics & Electronic Engineering
Yunnan Nationalities University
12.1 Street, Kunming, 650093, Yunnan
P. R. CHINA

Abstract: - This A new optimization of event-based control model is presented in the time-delay problem. Considering the waiting defect in the traditional event-based teleoperation, the paper presents to feedback the simulated force to the teleoperator directly. The buffer sequence mechanism is accepted at telerobot end. The command execution in sequencing event is ensured. The experiment results show that the control effect is satisfactory.

Key-Words: - Teleoperation, Time Delay, Manipulator, Event-Based Control Model, telerobot, Control System.

1 Introduction

Bilateral research of teleoperation system, for example, studying to manipulation Force, sense of touch measured by the robot sensor, etc., is the main developing direction. Because of the time delay influence, it proposes an extremely incisive question to the control method, namely the time delay existence causes the system performance decreasing and the entire teleoperation system instability, and to make synchronism difficult. At the same time, the time delay has the time-variable characteristic, so the research of time delay robot control model is extremely necessary.

2 Control Model

By analysis the existed robot telerobot system control model based on the wave variable or the scattering theory control method, we concluded that rational of system control model is passive theory. When system power input is bigger than the output, this system is stable. But this method did not consider the system internal characteristic and the structure. A model was designed by the input and the output computation in order to eliminate the network transmission time delay. But this model changed the system characteristic and cause the time delay to be bigger [1, 2, 3, 4].

The control method key based on event is evasion of network transmission time to evade, makes the whole system no longer to be influenced by time, keep the stability of the original system. From stable theorem based on the event that we know the system stability needs two premises. First original robot assembly system itself is stable and controllable. Secondly it is not related time that designed reference model s. this model function must be the monotone increasing along with time t and guarantees controls and feedback use a same event reference. To guarantee controls and feedback to us same event reference, reference model s must meet the requirement mentioned above. For instance, it may put operation distance or sequence number as reference. In paper [1] $s \in [1,2,3,\ldots\ldots]$, actually this method is time delay discretion. It can maintain the original system's stability. But because of existence of time delay, still there is very different between far-end operator and the local operator. For fixed-length time delay, may say the track performance is quite better; but in actual network the time delay is variable; sometimes even lose bag or overtime. At the moment difference between master-slave manipulator position and the force track quite is big [5, 6, 7, 8].

Flow chart robot teleoperation bidirectional force feedback control system based on event was shown in Figure1. In this system, the master teleoperator had the force feedback function control handle in order to obtain the telepresence. Slave teleoperator is the manipulator. In order to cause master-slave manipulator to track well, It adopted the speed control way. Two flow charts shown below stand for the far-end client server and the robot server respectively. The event reference is sequence number. What we need to explain is that robot original control system in Figure1 is invariable; the robot server end has two feed back information: One is feedback the force, the other were the image information. In the figure 1 the feedback force and the image fed back together to the operator is to maintain the image and the bilateral uniformity. In fact, the standard picture frame frequency is 25/second, therefore the feedback times of the robot image data must be more than the force feedback times. The data quantity is extremely huge, needs to consider the more effective compression algorithm and the transport protocols.

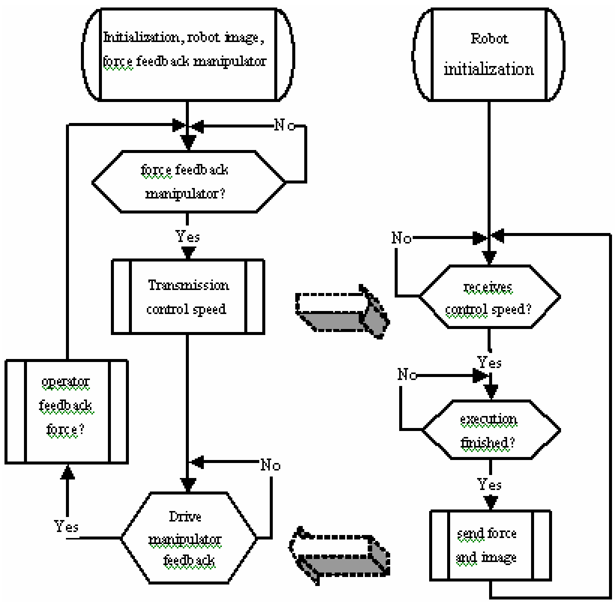

Fig.1. *Flow Chart of Event-Based Teleoperation System with Bilateral Force Feedback.*

2.1 Optimized control model

Control model based on event adopted reference model that is no related with time and took it as control basis. Its basic way was to shields the time and guaranteed the system stability, but the time delay influence still existed in the system. When system realized control way based on time, it must need to use the transmission-waiting the way. Each operation to need waiting time. So the key idea of the new improvement algorithm is to reduce waiting time.

2.1.1 Optimizing controls the model based on the event

Based on the question mentioned above, this article had designed one kind of new control model, namely control network based on the event designed event reference model s, which can slow down or the smooth influence of time delay. According to examination network real time state (QoS), the new control model joins one kind of forecast mechanism so as to enable the operator respond to the sensation operation force fast. After actual force, position and image feedback, it simultaneously renovates the force and the image. The design system is shown in Fig.2.

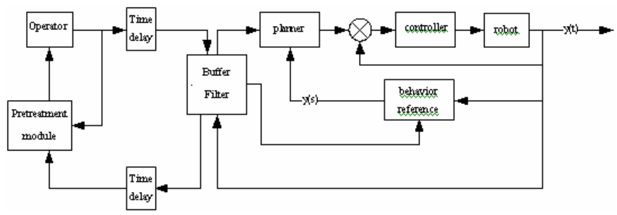

Fig.2. *Enhanced Event-Based Teleoperaiton System.*

In the actual operation process, the remote operator needs to carry on the judgment and decide next step movement according to the vision (image) and the feeling (force feedback handle). Therefore we had considered the vision into our design. Because the visual information is quite big on the one hand, it can cause time serious delay, on the other hand, it is the very difficult to establish model. Supervisor control mode based on event is the same as [2]. In the actual operation system is asked to be operated well by master control operator. The operation is completely carries out according to operator's request, the system does not only respond fast but also is asked to be well autonomous.

This model increased a simulation predictor in operator's end. Its goal is to directly simulate the position or the force which must be operated according to network time delay (including statistical network jam condition, band width situation and QoS). If model received the actual feedback form far-end robot, the actual data is adopted, otherwise fed back simulation result directly feedback to the operator. After actual position or strength information was fed back in time, they were input to the predictor and processed. This function has two points: First revises the simulator, feedbacks real result and simulation result given operator after smooth handle; secondly, according to in the returns result to order the sequence and the group information, renews transmission instruction queue. This process is counter process of the far-end robot sequence processing module.

2.1.2 Predictor model

(1) The position predictor is adopted as the following way:

$$p(t) = p^{d}(h(t)) \qquad (1)$$

In which $p^d(h(t))$ is expectation position according to time delay model $h(t)$.

(2) Computation force or force in the mixture control way is hard to compute. The position and the speed state predictor in [2] have been designed. The model in this article, the simulation force computation asked system performance is high. Because the system dynamic model is complex, client end procedure is limited to a kind of robot. Because of network reason, when system doesn't respond, it can give the user a false strength, and causes the user to take for the system network not to have the problem. If the forecasting model is not ideal, then the influence on the system can be bigger.

Regarding a unknown system, the method used by this article was: calculating virtual force according to present system simplifying model, for instance, assuming each arm to have a regular, calculable physique, then carrying on the dynamic adjustability according to return robot operation force form from real environment and making less equation $\widetilde{F} \le F_C$ tenable. If simulation computation force F_C is smaller than actual force $\widetilde{F}$, it may guarantee forecasting the feedback force to enhance gradually to the actual feedback strength.

2.2 Stability analysis

Improved algorithm prerequisite stated in this section satisfied control mode stable principle based on the event. Namely the original robot assembly system was stable.

$$\dot{x} = f\big(X(t), u(t), t\big) \tag{2}$$

The event reference is Xd. the reference sequence is s(i)=1,2,3 ...... n. According to the stable condition, there is a critical value δ. It makes $\left\| X^d - X_0^d \right\| \le \delta$,

$$\lim_{t\to\infty} e(t) = \lim_{t\to\infty}\big(X(t) - X^d\big) = 0 \tag{3}$$

In the improved model, an operator end (Local) and controls end (Remote) bath have an order sequences. Both sequences are: $S_L=(X_{1L}^d, X_{2L}^d, \ldots\ldots, X_L^d)$, $S_R=(X_{1R}^d, X_{2R}^d, \ldots\ldots, X_R^d)$ respectively. The reference sequences are $S_L(i)=(1, 2, \ldots\ldots, L)$, $S_R(i)=(1, 2, \ldots\ldots, R)$ respectively, among them, $L \ge R$. Suppose time delay of the ith operation ($i \le R$) is T_{ci}, forecasting time delay is T_{pi}, but that the smallest time interval that satisfies the stability condition is T_{si}. Control method in [5] based on the event, needs $T_{si} \le T_{ci}$ to be satisfied. In improved models, if $T_{pi} \le T_{ci}$, when $T_{si} \le T_{pi}$ is satisfyied, the stability of the amended model is obvious.

It is easily known. T_{ci} changes at random, but the T_{pi} can be predicted according to the characteristic of the network time delay and QoS situation, we only guarantee $T_{si} \le T_{pi}$ and choose the prediction time delay as short as possible. System place trace performance is fine and stabilization.

2.2 The improvement controls the model procedure based on event

In real operating, order initial time and QoS execution time need to be recorded in each starting order. In this way the robot execution end gets important reference.

(1) In a telerobot end, on basis of in original the planner, model increases a queue management and the filtration module. In fact it is one kind of expansion of the planner. Regarding the remote operation robot, all far-end operation and the all result feedback must pass through the sequence/filter module. The processing step is as follows:

Step 1: Wait to receive and deal with the order, judge whether there are orders in the sequence to be handled. If there are orders it carries step 2, otherwise circulates. At this moment state is set up as vacant. After receiving dealing order and putting it into sequence, each order must be numbered.

Step 2: Obtain foremost effective order in the waiting sequence. Suppose order number is k, and send out operating order to planner. Set event state as waiting order state at the same time.

Step 3: The robot deals with correspondingly order.

Step 4: The robot returns the handling results and the order number k to the sequence.

Step 5: Basis on feedback order k and the result, processing module feedbacks robot image to code stream and does the processing result and operating order number in the group to the remote operator.

Step 6: The remote operator renews image according to the feedback processing result, adjusts position and feedback force, and carries on the following operation.

Step 7: Repeat step 1.

(2) On distant operator's one end, the processing flow is as follows:

Step 1: The remote operator through the operation contact surface, the keyboard, the mouse or the feedback force handle starts to operate the far-end the robot, sends out the position and the speed instruction to the forecast processing module queue, carries on the corresponding operation and waits far-end robot feedback result.

Step 2: The forecast processing module puts the order into queue according to the former network statistical value and the current condition, forecasts the time delay value of instruction feedback. If under this time delay, there was not the information fed back, computation simulation force was fed back to the teleoperator. At the same time, it informed the operator that current force was the simulation computation force; Let the user judge whether to operate slowly. If the actual processing result was fed back, first forecast processing module needed to judge this instruction serial number and the group instruction number, the renewed instruction waiting queue and forecast model. Simultaneously, it compares calculating force, gives the difference and value feedbacks it to the remote operator.

Step 3: Repeat step 1.

3 Simulation

We take teleoperation control system of two degree of freedom as an example.

The kinematics equation is:

$$\begin{cases} x = l_1 c_1 + l_2 c_{12} \\ y = l_1 s_1 + l_2 s_{12} \end{cases} \quad (4)$$

Among them: c_1 , s_1, C_{12}, S_{12} stand for $cos\theta_1$, $sin\theta_1$, $cos(\theta_1+\theta_2)$, $sin(\theta_1+\theta_2)$ respectively.

The kinematics equation is:

$$\tau = D(q)\ddot{q} + h(q,\dot{q}) + G(q) \quad (5)$$

We adopt PD control method,

$$\tau = D(q)J_h^{-1}(q)\left(V_1 - \dot{J}_h(q)\dot{q}\right) + h(q,\dot{q}) + G(q) + J_h^T(q)V_2$$

Based on the time and the event position, the force curve comparison was shown in Figure 3.

Six degree of freedom telerobot system simulation is adopted.

$$\tau = D(q)J_h^{-1}(q)\left(V_1 - \dot{J}_h(q)\dot{q}\right) + h(q,\dot{q}) + G(q) + J_h^T(q)V_2$$

$$x = \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = \begin{pmatrix} q \\ \dot{q} \end{pmatrix}$$

$$v = \ddot{q}^d + K_v(\dot{q}^d - \dot{q}) + K_p(q^d - q)$$

$$\tau = \alpha(x) + \beta(x)v$$

$$\alpha(x) = -D(q)J^{-1}(q)\left[J(\dot{q})\dot{q} - J(q)D^{-1}(q)\left(h(q,\dot{q}) + G(q)\right)\right]$$

$$\beta(x) = D(q)J^{-1}(q)$$

Simulation mainly verifies the simulation force, the actual force (Calculate through PUMA560 library function) and trace state of the master-slave hands under time delay forecast model. Simulation was show in fig.4 in detail. In order to contrast measuring force curve of control mode of forecast mechanism, we only lists X - direction simulation force.

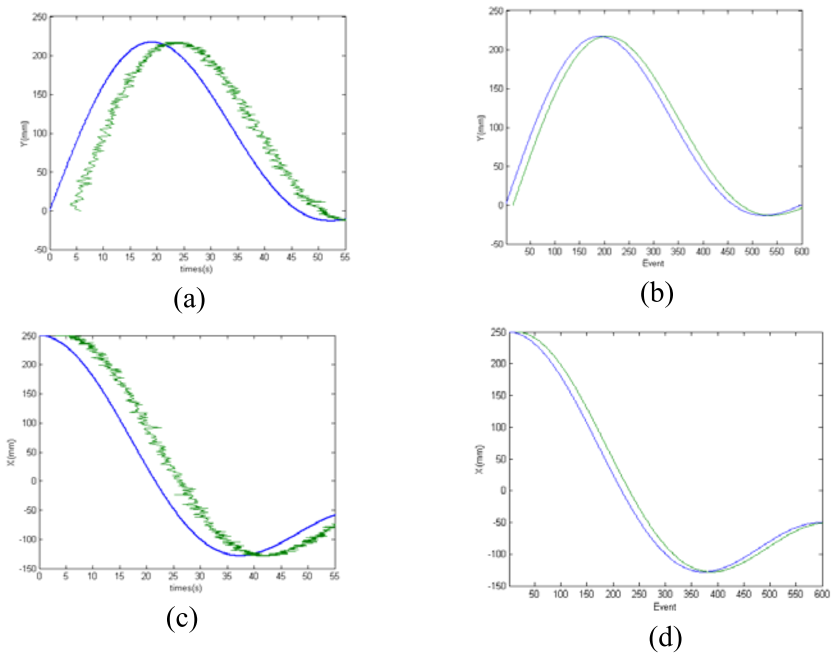

Fig.3. Simulation Curves of Two-DOF Manipulator. (a) Trace Curve for Position Based on Time; (b) Trace Curve for Position Based on Event; (c) Trace Curve for Force Based on Time; (d) Trace Curve for Force Based on Event.

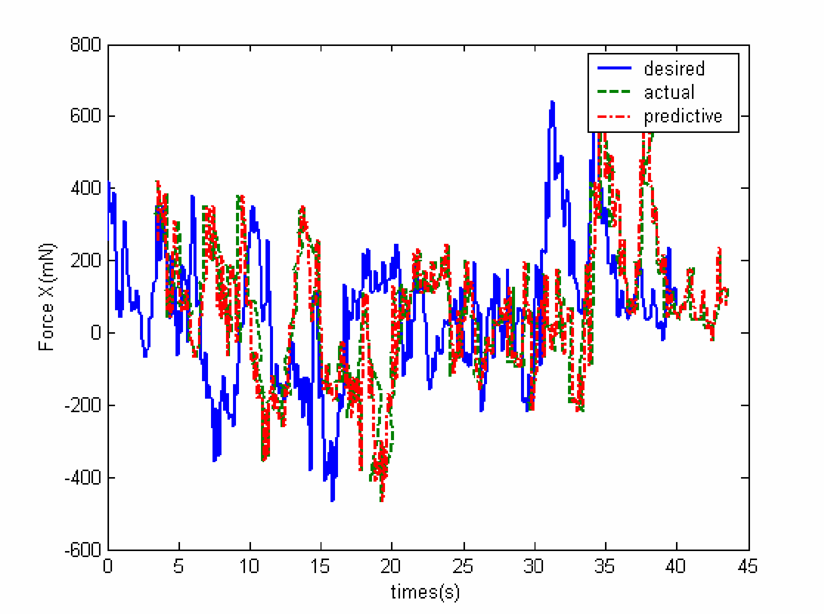

Fig.4. *Event-Based Curves of Manipulation with Predictive Model.*

4 Conclusion

The time delay is a question which needs to be faced and solved. This article first analyzed the control method existed teleoperation system. A buffer mechanism processing method was put forward on the basis of existing telerobot based on event. At the same time, a design was put forward according to event-based reference state S. Finally, analysis and the simulation test of changed fixed-length time delay were carried on.

References:

[1] Imad Hanna Elhajj, Supermedia Enhanced Internet-based Real-time Telerobotic operations [Ph.D], Michigan State University, 2002.

[2] Hu, X.D, Yu, H., Chen, Y., Web-based Data Acquisition, Journal of Zhejiang University SCIENCE, Vol. 3, No.2, 2002, pp.135-139.

[3] Brady, Kevin Joseph, Time-delayed Control of Telerobotic Manipulators[D.Sc], Washington University, 1997.

[4] LI Xiao-ming et al, Hybrid Event Based Control Architecture for Telerobotic Systems Controlled Through Internet, Zhejiang University SCI 2004, Vol. 3, Nol.5, 2004, pp. 296-302.

[5] Dana Cobzas, et al, IEEE Virtual Reality 2003 Tutorial 1: Recent Methods for Image-based Modeling and Rendering, 2003, pp.955-110.

[6] Georgios Akrivas, MPEG-4 Authoring Tool Using Moving Object Segmentation and Tracking in Video Shots Petros Daras, 2004, pp.121-127

[7] Mihail Lorin Sichitiu, Control of Data Networks: Models, Stability and controllers [Ph.D], University of Notre Dame, 2001.

[8] Ortega, R., Chopra, N. and Spong, M.W., A New Passivity Formulation for Bilateral Teleoperation with Time Delay, In Advances in Time-Delay Systems, Workshop CNRS-NSF, Paris France, 2003, pp. 22-24.