시간 지연을 가지는 수동성 양방향 텔레오퍼레이션 시스템

Passivity Bilateral Teleoperatio System with Time Delay

장창레이*, 정길도**
Changlei Zhang, Kil-to Chong

Abstract - This paper presents a force-reflecting teleoperation scheme with time delay. In reciprocal systems, to improve the stability and performance of the tleleoperation system, the network provides a wide bandwidth, no congestion. However, as use of Internet increases, congestion situation of network increased and transmission time and packet loss increased accordingly. This can make system unstable at remote control. In this paper, we present a passive control scheme for a force reflecting bilateral teleoperation system via the Internet and we investigated how a varying time delay affects the stability of a teleoperation system. A new approach based on a passive control scheme was designed for the system. The simulation results and the tracking performance of the implemented system are presented in this paper.

Key Words : force-reflecting, passive, teleoperation, time delay

1. Introduction

As an ever-growing communication medium, the Internet includes more than 100 million hosts and it gives all of its users the possibility of reaching and commanding any device connected to the network. With the rapid growth of the Internet, Internet based robotics has received considerable attention in recent years and is expected to be the merging point between modern developments in computer network, robotics and control theory. The potential applications of teleoperation include network robotics, telesurgery, and space and seabed telemanipulation.

In order to operate remote system in real-time through the Internet, it is necessary to provide sufficient channel bandwidth, small transmission delay time, low packet loss, and various other conditions. However, UDP that use usually is no congestion control so RTP and TFRC were developed. These protocols provide congestion control algorithm in application layer. But, these methods could not resolve the stability problem if the time delay is getting longer or there exists a large packet loss. Although the Internet provides a readily available communication medium for teleoperation, there are some problems that need to be resolved, of which the time delay and packet loss are the two most important factors..

In this paper, we proposed passive bilateral teleoperation schemes[1][2], which are based on the control laws that address the issue of energetic interactions between the manipulator and the environment while considering the time delay and packet loss in signal transmission. Moreover we consider force reflecting effect because when a teleoperator operates a robot remotely, it is desirable that the contact force information be transferred from the slave to the master in order to kinesthetically couple the operator to the environment.

This paper focuses on the analysis of passive bilateral control schemes, and in particular, addresses the stability and tracking performance of systems with varying time delays caused by the communication network[3][4]. In our approach, the differential of the time delay can be calculated adaptively by the system itself and used to adjust the output wave variables automatically, reducing them for increasing time delays and amplifying them for decreasing time delays. The proposed approach not only guarantees the passivity of the system, but also its stability, while also affording acceptable performance levels. This will be demonstrated using mathematical equations and simulations.

* 張昌雷: 全北大學 制御計測學科 碩士
** 丁吉道: 全北大學 電子情報學科 敎授・工博

2. Passivity Bilateral Control

2.1 Passivity

The passivity formulation represents a mathematical expression of the intuitive physical concepts of power and energy. If a system is passive, the following will be true:

$$\int_0^t P d\tau = \int_0^t x^T y d\tau = E(t) - E(0) + \int_0^t P_{diss} d\tau \geq - E(0) = Const \quad (1)$$

where P is denoted as the power entering into the system, x is the input vector and y is the output vector. P is a scalar product of vector x and vector y. The energy, E, defines the lower-bounded energy storage in the system and P_{diss} represents a none negative power dissipation. The notion of wave variables is closely related to the passivity formulation. Fig. 1 shows the wave transformation scheme of a standard bilateral teleoperation system.

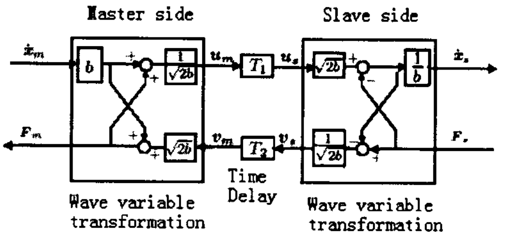

Fig 1. Wave Transmission Scheme

The above figure depicts a transformation between power variables and wave variables as follows,

$$u_m = \frac{1}{\sqrt{2b}}(F_m + b\dot{x}_m) \quad u_s = \frac{1}{\sqrt{2b}}(F_s + b\dot{x}_s) \quad (2)$$

$$v_m = \frac{1}{\sqrt{2b}}(F_m + b\dot{x}_m) \quad v_s = \frac{1}{\sqrt{2b}}(F_s + b\dot{x}_s)$$

substitute the above equatio into Eq. (1), and the related wave scattering passivity equation is obtained as follows

$$\int_0^t P d\tau = \int_0^t \frac{1}{2}(u_m^T u_m - u_s^T u_s + v_s^T v_s - v_m^T v_m) d\tau \geq - E(0) \quad (3)$$

2.2 Time Delay in Bilateral Teleoperation

Time delays can result from either the physical layer or the logical algorithms. It is well -known that even a small delay between the master and slave may result in a system which would otherwise remain stable becoming unstable. In the case of a time delay, the scattering of variables between the master and slave at any time is denoted as

$$u_s(t) = u_m(t - T_1(t)), \quad v_m(t) = v_s(t - T_2(t)) \quad (4)$$

Then the total energy expressed in Eq. 3 related to communications during the signal transmission at any time can be written as follows:

$$\int_0^t P d\tau = \frac{1}{2}\int_0^t u_m^T u_m d\tau - \frac{1}{2}\int_0^t u_m^T(t - T_1(\tau)) u_m (1 - T_1(\tau)) d\tau \quad (5)$$
$$+ \frac{1}{2}\int_0^t v_s^T v_s d\tau - \frac{1}{2}\int_0^t v_s^T(t - T_2(\tau)) v_s (1 - T_2(\tau)) d\tau$$

This can be rewritten by denoting $t - T_1(\tau) = \alpha$ and $t - T_2(\tau) = \beta$ as follow:

$$\int_0^t P d\tau = \frac{1}{2}\int_0^t u_m^T u_m d\tau - \frac{1}{2}\int_0^{t - T_1(t)} \frac{u_m^T(\alpha) u_m(\alpha)}{1 - T_1{}'(\alpha)} d\alpha \quad (6)$$
$$+ \frac{1}{2}\int_0^t v_s^T v_s d\tau - \frac{1}{2}\int_0^{t - T_2(t)} \frac{v_s^T(\alpha) v_s(\alpha)}{1 - T_2{}'(\alpha)} d\beta$$
$$= \frac{1}{2}\int_{t - T_1(t)}^t u_m^T u_m d\tau - \frac{1}{2}\int_0^{t - T_1(t)} \frac{T_1'}{1 - T_1{}'(\alpha)} u_m^T(\alpha) u_m(\alpha) d\alpha$$
$$= \frac{1}{2}\int_{t - T_2(t)}^t v_s^T v_s d\tau - \frac{1}{2}\int_0^{t - T_2(t)} T_2'($$

From the above equations, it is evident that the passivity of a system is determined by the differential of the time delays, T_1' and T_2', in the forward and backward communication networks, respectively. If the delay is constant, the differential of the time will be zero ($T_1' = T_2' = 0$) and the total energy can be expressed as follows:

$$\int_0^t P d\tau = \frac{1}{2}\int_{t - T_1'}^t u_m^T u_m d\tau + \frac{1}{2}\int_{t - T_2'}^t v_s^T v_s d\tau \quad (7)$$

Obviously, a constant delay system will be passive, independent of the magnitude of the delay. However, passivity cannot be guaranteed in a varying time delay system since there are two negative integrators in the power equation. Thus, the system may not satisfy the passivity condition when either the time delay is increasing or the differentials T_1' and T_2' are positive.

3. Proposed Parameter Adaptive Passivity System

A block diagram of the proposed systems shown in Fig.2, which illustrates the additional transmitted data required for integrating and differentiating u_m and v_s

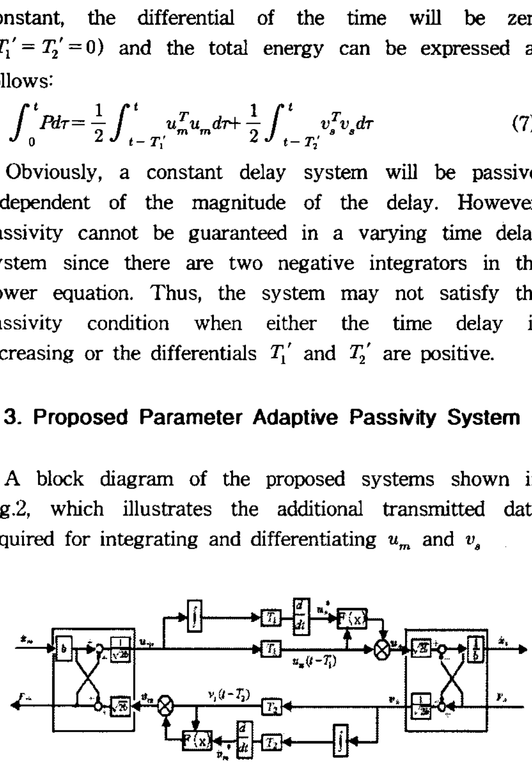

Fig 2. Proposed wave scattering transmission scheme

The new variables and shown in the figure can be expressed by,

$$u_s^*(t) = \frac{d\left(\int_0^{t - T_1(t)} u_m(\tau) d\tau\right)}{dt}, \quad v_m^*(t) = \frac{d\left(\int_0^{t - T_2(t)} v_s(\tau) d\tau\right)}{dt} \quad (8)$$

The above equation can be rewritten as follows:

$$u_s^*(t) = \frac{d\left(\int_0^{t - T_1(t)} u_m(\tau) d\tau\right)}{dt} \frac{d(t - T_1(t))}{d(t - T_1(t))} = u_m(t - T_1(t))(1 - T_1'(t)) \quad (9)$$

From the Eq. 10, the $u_m(t - T_1(t))(1 - T_1'(t))$ can be obtained. It is possible to obtain $T_1'(t)$ from the values of $u_m(t - T_1(t))(1 - T_1'(t))$ and $u_m(t - T_1(t))$.

Let, $u_s(t) = u_m(t - T_1(t))(1 - T_1'(t))^{\frac{1}{2}}$ and

$v_m(t) = v_s(t - T_2(t))(1 - T_2'(t))^{\frac{1}{2}}$. substituting these into Eq. 3 and assuming no initial energy,

$$E = \frac{1}{2}\int_0^t u_m^T u_m d\tau - \frac{1}{2}\int_0^{t-T_1(t)} u_m^T(\alpha) u_m(\alpha) d\alpha \qquad (9)$$
$$+ \frac{1}{2}\int_0^t v_s^T v_s d\tau - \frac{1}{2}\int_0^{t-T_2(t)} v_s^T(\beta) v_s(\beta) d\beta$$
$$= \frac{1}{2}\int_{t-T_1(t)}^t u_m^T u_m d\tau + \frac{1}{2}\int_{t-T_2(t)}^t v_s^T v_s d\tau$$

4. Simulation and Result

The passivity approach provides an easy way to analyze the stability of a system, yet it cannot always guarantee stability for varying time delays, particularly when the time delay is increasing. However, the proposed approach based on the passivity concept is a reinforced approach which ensures the stability of the system. In this section, computer simulations will be performed to validate the proposed scheme for various cases in which the positions of the master and slave are tracked.

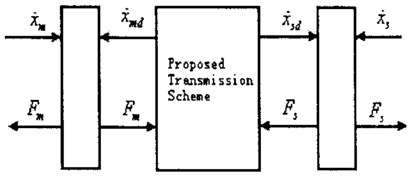

Fig. 3 Simulation system with velocity input control

Fig 4 and 5 show the result of tracking performance with varying time delay.

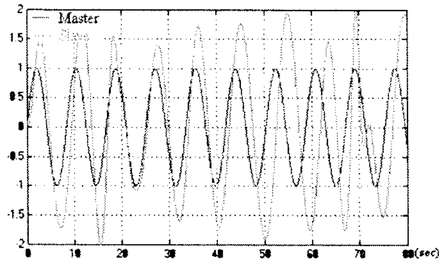

Fig 4. original scheme tracking with varying time delay

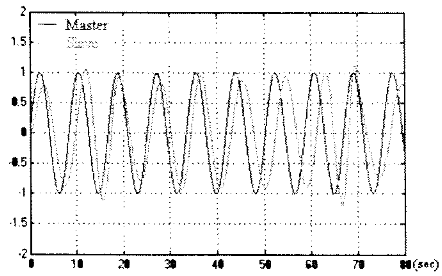

Fig 5. proposed scheme tracking performance

To verfiy the proposed approach, a 1 DOF teleoperation system has been set up(master-joystick and slave-moving bar) via the Internet. In Fig . 6 the performance of position is presented. and fig. 7 is the velocity between master and slave. This compensated for the Internet based teleoperation can archive an acceptable tracking performance.

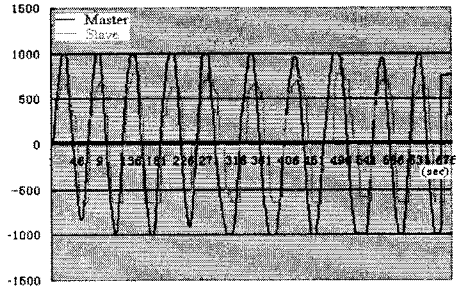

Fig 6. Position tracking via the Internet

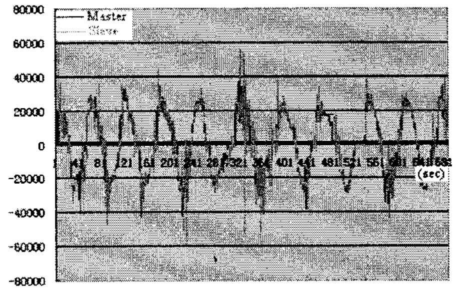

Fig 7. Velocity between master and slave

5. Conclusion

Passive controls for a time delay system were discussed in this paper. A new adaptive approach was proposed to overcome the instability of varying time delay systems. This approach was based on parameter estimations made in real time and aimed at maintaining passive control and providing acceptable tracking performance. The proposed scheme could adjust the output of the system adaptively and achieve a stable and acceptable tracking performance.

참 고 문 헌

[1] R. J Anderson and M. W. Spong, "Asymptotic stability for force reflecting teleoperations with time delay," IEEE Int. Conf. Robotics ans automation, 1989.

[2] Niemeyer G, Slotine J.J.E. "Stable adaptive teleoperation," IEEE J. of Oceanic Engineering, 16(1), 1991.

[3] Lozano R, Chopra N, and Spong M.W, "Passivation of Force Relecting Bilateral Teleoperators with Time varying Delay," Mechatronics'02, 2002.

[4] Leeraphan S., Maneewan T. and Laowattana S. "Stable Adaptive Bilateral Control of Transoperation through Time-Varying Delay", IROS 2002