Internet Teleoperation of a Robot with Streaming Buffer System under Varying Time Delays*

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It is known that existence of irregular transmission time delay is a major bottleneck for application of advanced robot control schemes to internet telerobotic systems. In the internet teleoperation system, the irregular transmission time delay causes a critical problem, which includes instability and inaccuracy. This paper suggests a practical internet teleoperation system with streaming buffer system, which consists of a buffer, a buffer manager, and a control timer. The proposed system converts the irregular transmission time delay to a constant. So, the system effectively transmits the control input to a remote site to operate a robot stably and accurately. This feature enables short control input intervals. That means the entire system has a large control bandwidth. The validity of the proposed method is demonstrated by experiments of teleoperation from USC (University of Southern California in U.S.A.) to HYU (Hanyang Univ. in Korea) through the Internet. The proposed method is also demonstrated by experiments of teleoperation through the wireless internet.

Key Words: Internet, Teleoperation, Streaming Buffer, Time Delay, Robot

1. Introduction

Recently internet is used for a transmission media for teleoperation of a robot or for remote control of appliances because of low cost and easy accessibility. A teleoperation of a robot requires a proper transmission of the commands from the master operator to the slave robot. However, the internet has a problem of time delay which is nonuniform and this causes instability or unacceptable performance of the teleoperation system. A simple task-based command transmission may not be affected significantly by the irregular delay, but the continuous signal like the reference input form the master is significantly affected by the irregularity and the amount of the delay.

Kosuge et al. proposed virtual time delay to adapt the irregular delay but this method requires the pattern of the delay in advance. Sliding mode control was also used to overcome the nonsmoothness of the signal due to the transmission delay. Many others have tried to overcome the delay problem with the internet. However, the delay is inherent in internet and its size is variable depending on the traffic of the internet nodes. In addition, the amount of the delay is not predictable so the many control schemes for solving time delays are not effective for internet transmissions.

In this paper, we propose a streaming buffer system to regulate the time delay uniform. With a constant time delay, the command from the master arm can be transmitted at a fixed sampling rate and the slave robot will receive the clean reference input. Thereby, the many teleoperation techniques developed for delayed systems can be employed through internet. In cases, the data stored in the buffer may be depleted and then the system may be put in the state of disconnection. For this case, the buffer manager was devised and implemented. The buffer manager also has a function of selecting an adequate size of the buffer in the initial stage of internet connection depending upon the traffic condition. In order to show the effectiveness of the proposed system, a number of experiments were conducted for short-range and
long-range teleoperation.

In the second section, the basic feature of the developed system will be described. The detailed architecture and the buffer manager of the buffer system will be explained in section 3. The experimental results will be presented in section 4 and the conclusion will be drawn in section 5.

2. Features of the Internet-Based System

The main idea of the paper lies in that the streaming buffer will make possible to implement constant time delay, uniform sampling time, and precise transfer of the reference input. As shown in Fig. 1, the time delay is maintained constant and this scheme is applicable to any type of internet devices like wired internet, wireless internet, Bluetooth, etc.

Since the internet is in the public domain, there is always a traffic changes and it causes variable delay in transferring data packets. The data sent out at a uniform period arrive at the destination irregularly as shown in Fig. 2. To avoid confusion of terminologies before proceeding description of the system, we define packet delay as the delay of the packet transfer. The time difference between arrivals of packets is called a jitter. The total delay between the master and the slave is defined a system delay.

When the master sends out data at a fixed interval, the jitter is variable, i.e. the slave receives them irregularly depending on the network condition. The jitter may become temporarily large or small. If the buffer on the receiver side stores the data and sends them to the slave at a constant rate, the jitter will be constant.

3. System Architecture

The master side of the teleoperation system consists of a human operator, a master robot (input device), and an internet connection unit. The slave side includes an internet connection unit, the streaming buffer system and a slave robot.

The input signal given by the operator is transferred to the slave by a TCP/IP based asynchronous socket which is a connection-oriented protocol and can send data reliably and fast. The connection managers on the master and the slave have network-related functions such as sending and receiving data, maintaining connection, and user approval. The received data on the slave is stored in the streaming buffer system and retrieved at a constant time interval for a reference input.

The streaming buffer system is composed of a buffer, a buffer manager, a control timer, and a control command generator as shown in Fig. 3. The arrived data is directly stored in the buffer of the streaming buffer system not in the TCP/IP based buffer. The buffer manager initializes the buffer and sets up the buffer size. It also continuously monitors the state of the buffer and adjusts the buffer size as necessary.

Then, the retrieved data is provided to the slave robot as a reference input with a constant time delay. While the delayed time remains within the capacity of the buffer, the teleoperation system can perform a task stably. If it goes beyond the capacity, the buffer manager intervenes to adjust the buffer size to minimize the chattering due to the abrupt jump in the signal. The flow chart of the buffer manager is shown in Fig. 4.
4. Experimental Results

The teleoperation system used for implementation consists of an input device, a computer on the master (client), a computer on the slave (server), a motion controller, and a 6-DOF robot. The experiments were conducted for a short range and a long range. The short range is from Hongik University to Hanyang University in Seoul. They are apart 40 km. The long range is from USC in California to Hanyang University with a distance of 15,000 km as shown in Fig. 5. For simplicity, only 2 axes of the robot were given reference inputs with other axes fixed.

In the case where there is no buffer, the desired trajectory was not delivered to the slave in its original shape. As a result, the actual trajectory of the slave robot has chattering as shown in Fig. 6 (a). Although this was the short-range test and the packet delay was relatively small as 60 ms, the system was unstable yielding severe chattering as seen in Fig. 6 (d).

With the same setup, the buffer system was employed and the results in Fig. 7 show that the slave robot follows the desired trajectory almost identically with time delay of 50 ms. Note that the traffic condition was not good and the packet delay was irregularly high during the period of 6.4 s to 8.3 s. Nonetheless, the slave was controlled well with smooth trajectories.

For the long-distance test, the data path was

![Map of experiments between USA and Korea](image-url)

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Fig. 6 Test results for short distance without buffer

(a) Trajectory  (b) Packet delay

(c) Angular velocity  (d) Output voltage

Fig. 7 Test results for short distance with buffer

(a) Trajectory  (b) Packet delay

(c) Angular velocity  (d) Output voltage

15,000 km long ranging from University of Southern California to Hanyang University via University of Hawaii, Japan XP, and Korean XP. Without the buffer (Fig. 8), the slave could not follow the trajectory exactly with significant chattering as in the case of the short distance.
Fig. 8 Test results for long distance without buffer

Fig. 9 Test results for long distance with buffer
When the buffer system was used, the sampling period was set to 10 ms with the initial buffer size of 10 (100 ms). The initial packet delay was 122 ms. The results in Fig. 9 show that the slave was controlled smoothly with the system delay of 222 ms. Although the packet delay was erroneously varying from 100 ms to 240 ms, the slave robot was consistently following the desired trajectory.

The proposed buffer system was extended to a wireless internet system of IS-95B provided by KTT. The currently commercialized wireless internet IS-95B has transmission speed of 64 kbps but the actual speed is around 9–25 kbps. Due to the limited capacity of the wireless modem driver, the sampling period cannot be below 18 ms. Thus, the period was set to 20 ms and the buffer size was selected at 5 (100 ms).

The long packet delay of the wireless system prohibited proper teleoperation of the robot without buffer. When the buffer system is utilized, the initial packet delay was 212 ms and the resultant system delay was 312 ms. Although the delay was relatively long, the slave robot was following the trajectory exactly as shown in Fig. 10. As the transmission speed of the wireless system is improved in the future, the delay will be shortened.

5. Conclusions

For teleoperation of a robot through the internet, a streaming buffer system was proposed. This can solve the problem of irregular time delay that severely degrades the performance of the teleoperation. The streaming buffer system maintains the delay uniform under varying traffic conditions of the internet. Thereby, the reference command from the remote operator can reach the slave robot without signal distortion.

The buffer manager was also introduced to decide the buffer size at the initial contact. It can also adjust the buffer size on monitoring the transmission condition.

In order to show effectiveness of the proposed control scheme, the buffer was implemented on a robotic teleoperation system. Several tests were conducted for a short distance, a long distance (inter continental), and a wireless internet system. In all the cases, the streaming buffer system regulated the time delay at a constant size. As a result, the command signal from the master arrived at the slave controller in its original shape. Accordingly, the resultant control performance was superior to the system without the buffer.

The local controller for the slave robot can use
any feedback control method for position control such as PID controller, sliding mode controller. In this paper, however, only the position command was transmitted to the slave robot from the master arm. Force reflection should be incorporated to improve stability and tele-presence of the teleoperation system. The teleoperation schemes developed for systems with constant time delay such as robust control, predictive control can be employed together with the proposed streaming buffer system. Thereby, the streaming buffer system is expected to enable the non internet-based teleoperation method applicable to internet-based teleoperation.

With the advance in the network technologies, the buffering technology will be enhanced and the transmission speed will be also improved. Then the buffer size can be reduced yielding a shorter time delay. Time-series commands will be more effectively transmitted from the host to the server. As a result, numerous applications will be generated in home automation and other remote control systems.

References


