

무선네트워크의 시간지연을 고려한 원격이동로봇의 안정성에 대한 연구

Mobile Robot Teleoperation to Consider the Stability over the Time-Delay of Wireless Network

노영식*, 강희준**, 서영수***, 유선국****
Young-Shick Ro*, Hee-Jun Kang**, Young-Soo Suh***, Sun-Kuk Yoo****

Abstract - When a system is teleoperated in the indoor environment through the wireless LAN, the communication time delay that is due to the inherent characteristic and surrounding environment is random and unbounded. The time delay has a significant effect on the stability and performance of the teleoperating system. In this paper, we present the method that is the image compression, measuring time delay and switching control-mode corresponding to time delay automatically, to improve stability and performance, and the simple experiment is conducted to demonstrate the feasibility

Key Words : Teleoperating, Wireless Network, Time-Delay, Image Con.pression

1. Introduction

The subject of under investigation is the teleoperation of the mobile robot with real-time monitoring remote site. The teleoperating system for the mobile robot consists of server, client and communication. The communication between server and client is accomplished with wired or wireless link. In the teleoperating system for the mobile robot, the Wireless communication is more flexible than wired one. The wireless LAN(Local Area Network) has been adopted in our system, but there is the communication time delay in the wireless LAN. The reason of the time delay is that the communication depends on the characteristics of antenna, the surrounding environment, the buffer of router and the protocol. The time delay can cause the teleoperating system to be unstable[1-3].

Section 2 of this paper introduces the architecture of the implemented system and summarizes the issues related to the communication protocol and the image compression. Section 3 presents the method for measuring the communication time delay and switching control-mode automatically. Section 4 summarizes the results of experiments.

2. The Architecture of the Teleoperating System

2.1 Hardware Architecture

Fig. 1 shows the system that has been implemented with the internet and the infrastructure that consists of the mobile server, the teleoperator(client) and the AP(Access Point). The mobile server is equipped with a PC camera and eight ultrasonic sensors

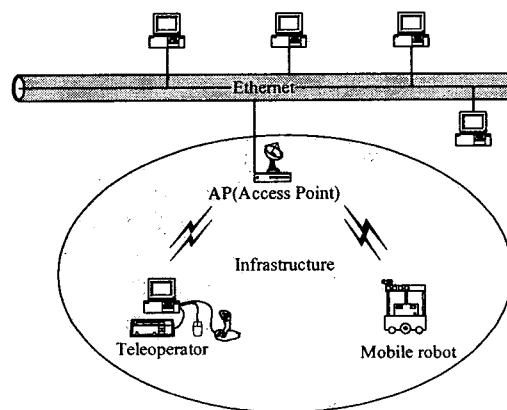


Fig. 1. The architecture of the teleoperating system

2.2 Network Protocol and Image Compression

TCP(Transmission Control Protocol) and UDP(User Datagram Protocol) are supported in 802.11b. TCP provides a full duplex stream service, with automatic error handling, retransmission, packet re-ordering, and guarantee of safe delivery. However, from the point of view of a real-time application, this protocol has the drawback of

저자 소개

- * 노영식: 울산대학 전기전자공학부 교수
- ** 강희준: 울산대학 전기전자공학부 교수
- *** 서영수: 울산대학 전기전자공학부 교수
- **** 유선국: 연세대학 의공학과 교수

having unpredictable arrival time of the data. This limitation can be overcome by using UDP, which does not require any acknowledgement message between sending and receiving processes, and therefore it is not blocking. However, UDP does not guarantee data delivery, since it provides no feedback about lost data packets from the receiver. The TCP mechanisms ensuring data delivery cannot be skipped, and therefore real-time applications cannot be implemented using the TCP. On the other hand, UDP is a possible protocol for real-time applications, since it is designed for single-datagram exchange and offers a faster access to the network.

The CCIT and ISO collaborated to develop the most popular and comprehensive continuous tone, still-frame compression standard, called the JPEG standard. JPEG supports both lossy and lossless compression. The lossy methods are based on the DCT (Discrete Cosine Transform). The compression is performed in three sequential steps: DCT computation, quantization, and variable-length code assignment. The second step is to quantize the DCT coefficients. The purpose of this step is to achieve further compression by quantizing high-frequency components with a larger step size (i.e., more coarsely). This is because high spatial frequencies require less detailed coding. This step discards visually unimportant information and thus makes the approach "lossy".

In our system, the size of still-image is 160x120 and 8bit gray-level, that is, 19200 bytes and captured with 20 frames per second. The MTU (Maximum Transmit Unit) of wireless LAN is 1420 bytes. The transmit speed of wireless LAN is specified with 11 Mbps, but the actual speed is less than 1 Mbps. For above constraints of network, the still-image must be compressed and sent to the local site by using UDP. In this paper, each frame is compressed by using the four times of typical normalization matrix and 20 frames are transmitted to the teleoperator at every second. The time to compress and reconstruct has been shown in the section IV.

3. The switch of control-mode

3.1 Real-time measurement of communication time delay

The still-image was compressed and transmitted to the local site for the internal constraints of the wireless LAN in the previous section. There are also external constraints such as the characteristics of antenna and the wall of office. Because of these constraints, the communication time delay is taken place randomly or becomes unbounded. The stochastic model that has been reported for the time delay could make the mobile server dangerous. To avoid this dangerous situation, the method to measure the

RTT (Round Trip Time) on real-time is needed and the teleoperating system have to be controlled. The equation (1) is for the RTT from the network model shown in Fig. 2 and the equation (2) is to measure the RTT on real-time. The mobile server checks periodically if a probe data is received after sending it and the RTT is measured with equation (2).

$$\tau(t) = \tau_{ds}(t) + \tau_{dr}(t) + \delta(t) \cong \tau_{ds}(t) + \tau_{dr}(t) \quad (1)$$

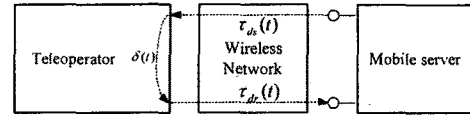


Fig. 2. Network model for teleoperating system

$$\tau(t) = \tau_r(t) - \tau_s(t) \quad (2)$$

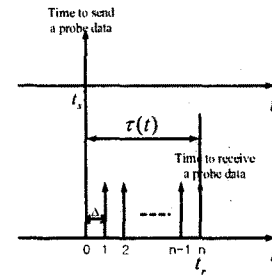


Fig. 3. The method for real-time measuring the RTT

The control-mode is switched to the direct or the behavior control-mode according to the measured RTT. A human operator can control the velocity of the mobile server in the direct control-mode and the position of it in the behavior control-mode. The controller of the switch to take the time delay into consideration is devised as the equation (3) that decreases the velocity as the RTT is increased, and converges to 0 as it is over the maximum allowable RTT.

$$\begin{bmatrix} v' \\ w' \end{bmatrix} = h(\tau(t)) \begin{bmatrix} 0 & a \\ -b & 0 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \quad (3)$$

$$h(\tau(t)) = \begin{cases} 1, & \tau(t) \leq \tau_{\min} \\ \frac{\tau_{\max} - \tau(t)}{\tau_{\max} - \tau_{\min}}, & \tau_{\min} < \tau(t) \leq \tau_{\max} \\ 0, & \tau(t) \geq \tau_{\max} \end{cases}$$

4. Experiments

4.1 Environment

To illustrate the usefulness of the method that is presented to improve the stability of teleoperating system, we have demonstrated the teleoperation of the mobile

server in the laboratory and the lobby for about 30 minutes. In this environment, the wall exists between the laboratory and lobby or laboratories. Because of it, the probability that the long communication time delay occurs is very high. Therefore, we thought that this environment was fit to prove the feasibility of the presented methods. The maximum velocity of the mobile server was limited to 400mm/s for the safety, and the frame rate was fixed to 20frames per second. τ_{\max} (=200ms) and τ_{\min} (=100ms) were determined by trial and error.

4.2 Results of experiments

The compression rate, RTT and time to take for the compression and the reconstruction were measured. The results of experiments were summarized in the table 1.

Table 1. The results of the experiments.

	RTT	Compression	Reconstruction	Total
Average [ms]	6.44	33.19	20.44	60.07
Standard deviation[ms]	1.88	0.86	0.33	2.09

The original image of the mobile server site and the reconstruct image of the teleoperator site are shown in Fig 4. The Comparison of Fig. 4 reveal the difference of resolution between them, but a human operator is likely to recognize the reconstruct image.

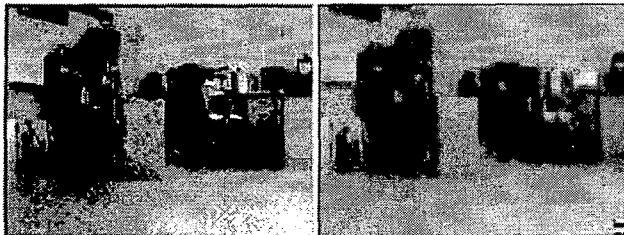


Fig. 4. The Original image of the mobile server and the reconstruct image of the teleoperator

When the mobile server was teleoperated in the laboratory and the lobby, the RTT and the position and the heading were depicted in the Fig 5. We started to teleoperate the mobile server with the joystick by the direct control-mode, and the maximum speed of the mobile server was decreased as the communication time delay, RTT, was increased. When the time delay was over threshold τ_{\max} , the mobile server could not be teleoperated by the direct control-mode anymore and it could be teleoperated by the behavior control-mode, that is, the control-mode was switched.

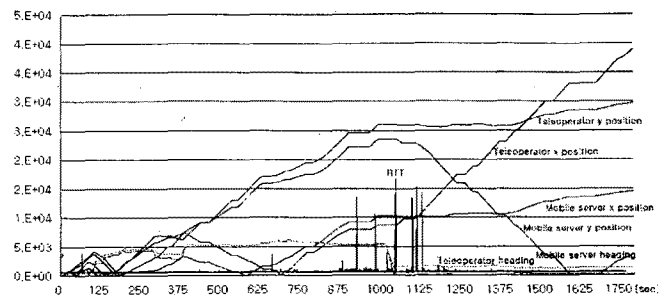


Fig. 5. The position, heading and RTT

5. Conclusion

In this paper, we have implemented the teleoperating system with the wireless LAN and used the image compression, JPEG, to reduce the number of the communication data and the UDP protocol to monitor with real-time. And also to improve the stability of the teleoperating system, the mobile server has measured the RTT on real-time and has automatically switched the control-mode according to it. We have demonstrated to improve the stability of the teleoperating system with the wireless LAN from the resultsof the experiments, and think that these methods could be used to the similar application.

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