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Decorators Help Teleoperations

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1. Introduction

The wide bandwidths of the communication and advanced bilateral robot control technologies have led us to realize multi-sensational teleoperation systems that provide auditory, visual, and haptic information of remote site to its operator simultaneously. Such teleoperation system is expected to be applied to medicine, education, work in hazardous environment, online game or other use. Especially, haptic sensation is extremely required to improve its operability and safety in medical operations. In this chapter, a teleoperation system is assumed to consist of three components, i.e., audio, video, and haptics transmission systems. In addition, each transmission system can be distinguished into local site and remote site.

When the distance between the remote site and the local site of a teleoperation system is far enough, the performance of its communication line becomes crucial factor to decide the operability of the teleoperation. In general, since the data rate of video information is higher than the bandwidth of communication line, data compression is indispensable. Moreover, data compression and decompression are considered as time consuming processes. As a result, video transmission system must be delayed in principle. In multi-media context, audio transmission system should be delayed artificially so as to keep its playout delay to be the same as that of video transmission system. For example, lip sync is necessary for its operator to feel the audio and video contents in naturally. From this point of view, the bandwidth of its communication line is the only requirement for realize video and audio transmission systems. Even if these transmission systems are used to make a conversation for its operator with a remote person, it is said that 200ms delay is allowable. This requirement is rather negligible in the Internet in nowadays. On the other hand, a haptics transmission system requires short and stable performance of delay for communication line. This is because the achievable bandwidth of haptic sensation is limited by the round trip time of communication line since haptics transmission controller includes the delay inside of its closed control loop. In fact, a human being can feel the sense of touch at the tip of a finger up to about 400Hz. To recognize this bandwidth of haptic sensation, its sampling period must be higher than 800Hz according to Shannon's sampling theory. Thus, the round trip time of communication line must be shorter than 1ms. This value is much shorter than the allowable delay of audio and video transmission systems. In short, haptics transmission system requires short delay while video transmission system requires wide bandwidth for communication line.

If haptics transmission system and video transmission system are constructed individually, these systems will not synchronize at all. The operator may hope these two systems synchronize although the operator may feel strangeness with such unsynchronized teleoperation system. If the haptics transmission system is delayed artificially in order to synchronize video transmission system, the bandwidth of haptic sensation will also be limited accordingly and the overall system's operation will deteriorate. Likewise, if the delay of video transmission system occurs to synchronize haptics transmission system, the quality of video, such as, resolution, depth of color, and frame rate, will be reduced drastically. Therefore, it is impossible to realize both of high quality of each service and synchronization at the same time with infinite bandwidth communication line. This is the underlying issue of this chapter.

This chapter proposes decorators to lessen the strangeness of such unsynchronized teleoperation system. The latter part of this chapter is organized as follows: Section 2 overviews related works to this issue. Section 3 includes our proposed decorators. A target task designed for operability evaluation of teleoperation and its experimental equipments are shown in Section 4. Section 5 explains the implementation of proposed decorators. Experimental results are shown in Section 6. Finally this chapter is concluded in Section 7.

2. Related Works

Many researchers and developers have been trying to improve the operability of teleoperations since several years ago. Their development can be classified into three categories of approach.

The first category focuses on haptics transmission system. In the field of control theory, (Ferrell, 1965) showed the transmission delay deteriorates the stability and the performance of remote manipulation and (Hannaford, 1989) opened up a new field in haptics. To stabilize a controller against unknown delay, a communication disturbance observer is proposed (Natori, 2008). In the field of applied technology, (Sato & Yakoh, 2000) implemented 1ms sampling loop as a network based control system, and (Oboe, 2001) realized web-based force feedback system. (Tsuji, 2004) evaluated the performance of a bilateral operation system between Slovenia and Japan approximately 9000km distance via the Internet. So the theory and the implementation technology have been researched well. However, it is still difficult to transmit keen haptic sensation through long delay or high jitter communication line.

The second one is about network QoS (quality of service) to improve the performance of information transmission systems. To reduce the jitter, several methods have been studied. Network delay consists of transmission delay, switching delay, queuing delay, and retransmission delay, and their magnitude vary greatly according to the network conditions (Gutwin et al., 2004). Some researches also focused on solutions based on network communication, either at a transport-layer, a network-layer, or an application-layer in the form of framing update messages (Shirmohammadi & Nancy, 2004) (Dodeller & Georganas, 2004). Some researches focused on the delay of transmission of position information of virtual object on Collaborative Virtual Environment (CVE) (IEEE 1995). The method of Synchronous Collaboration Transport Protocol (SCTP) sets the communication priority of information needed for synchronization of local and remote site (Boukerche et al., 2006). Thus, there are many researches to solve the problems of the network delay and the communication delay of the feedback information in the systems. However, there are no crucial solutions for the problems.

The third category is about the expression method to increase the accuracy of its operator's perception of remote site situation. Decorators were proposed to improve the operability of teleoperation system (Gutwin et al., 2004). Most of them have been studied in the field of CVE. They present supplementary information for teleoperation system. For example, the decorators indicate magnitude of delay, jitter, round-trip time, network lag and end-to-end delay by changing the color of pointing cursor (Gutwin et al., 2004) (Boukerche et al., 2006). They are useful because the operator can recognize the change of delay at a glance. Another decorator indicates the past tracks, the present position and predicted future position of the virtual object. Thus, decorators are different from the communicated environmental audio-visual information that indicates the situation of the remote site in teleoperation.

3. Decorators for Teleoperations

As mentioned in Section 1, a haptcs transmission system requires short delay communication line while a video transmission system requires wide bandwidth communication line. It is then natural to design the communication lines separately according to the required performance in such a teleoperation system. In this case, haptic information reaches first, and visual information appears last. Consequently, its operator may experience a strange feeling due to the time lag among those sensations. This is a problem targeted in this chapter.

This study proposes two decorators to overcome this issue. Though the word 'decorator' is derived from the field of CVE, the proposed decorators are different from the original ones. The proposed decorators are kinds of artificial cross-modal modification. One decorator, named visual decorator, generates a visual image of remote objects with haptic information and superimposes it onto the screen of a visual transmission system. Since haptic information reaches earlier than transmitted visual information, the decorator is fresher than the image of remote site. Additionally, the decorator image is synchronized to haptics transmission system in principle. So it is expected to resolve the strangeness of unsynchronized teleoperation system. Another decorator, named auditory decorator, generates artificial sound based on haptic information and mixes it with the sound of audio transmission system. Since auditory transmission system delays audio information artificially so as to realize lip sync, the audio decorator is also fresher than the sound of remote site. So it is expected to relax the strangeness too.

4. Teleoperation System

In this study, one task is set as the representative teleoperation. On the haptics transmission system (the detail is described in section 4.1), a stick is set as master and the rail is set as slave. They can rotate around a rotating shaft and the slave rail rotates following the master stick. So the operator controls the position of the rail by handling the master stick. Based on the system, a target task is controlling the position of a ball to stay close to the center of the rail. The ball is able to move freely on the rail. At the both ends of the rail, stoppers are set to prevent the ball from falling off the rail. Fig. 1 illustrates our setup

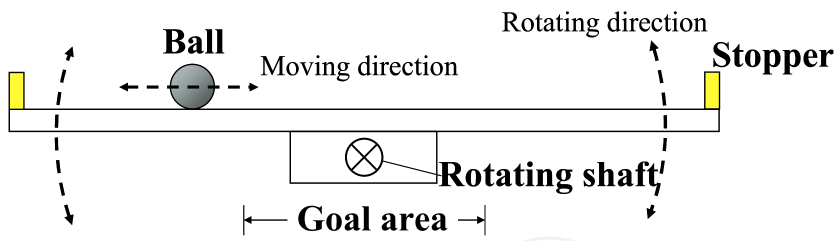

Fig. 1. Ball, slave rail and rotating shaft which are used for the target task

This task of controlling the position of the ball is designed as simples as possible so as to enable its operator achieve only with of audio, video or haptic sensations. The operator manipulates the stick by watching the ball and the rail, hearing the sound of the ball moving and perceiving the weigh of the ball. Moreover, even if the one or two kinds of information are lost, it is still possible to achieve the task with the other information. Thus, the task depends on the auditory, visual and haptic information, and these contributions are independent. That is why the task is suitable to set as the representative teleoperation. In this study, the rail is 950mm long. The ball is 32mm in diameter and the range of the goal area is within 40mm from the center of the rail.
For this task, an experimental tele-oepration system is constructed. Fig. 2 shows the overview of the teleoperation system. According to the above-mentioned background, auditory, visual and haptics transmission lines are set separately.

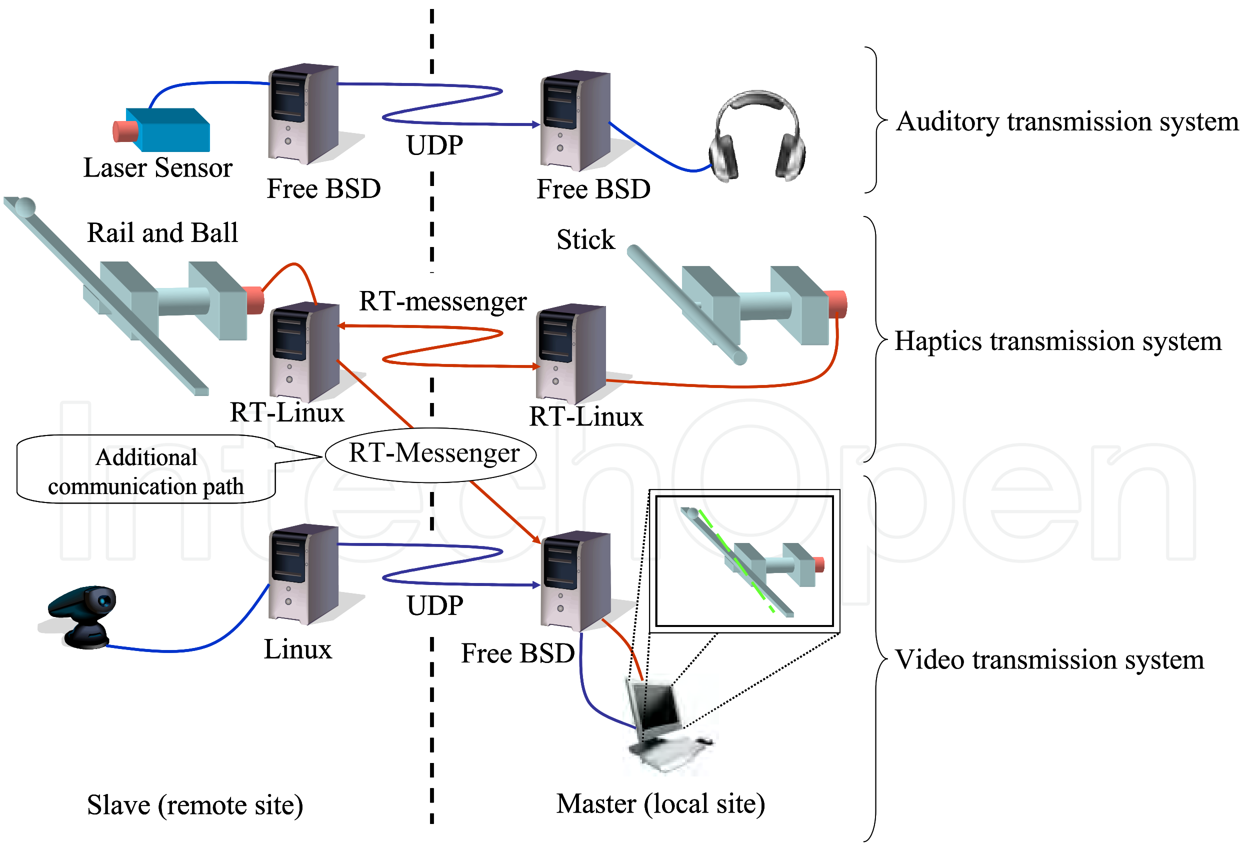

Fig. 2. Overview of experimental teleoperation system

4.1 Haptics Transmission System

Haptic information is transmitted through the center line in the Fig. 2 with real-time communication framework. The master stick at a local site and a slave rail at the remote site are controlled bilaterally (Iida & Ohnishi, 2004) so as to move as if those rotating shaft are connected directly. Because the haptics transmission system is controlled bilaterally, when the ball moves to the right of rail, the torque hanged on the master stick clockwise. Fig. 3 and 4 show the master stick and slave rail. Fig. 5 shows the implementation of the haptics transmission system.

Fig. 3. Master stick at local site

Fig. 4. Slave rail at remote site

Fig. 5. Implementation of the haptics transmission system

RTLinux is used to support real-time operation of the haptics transmission system. In addition, RT-Messenger is used to enable the haptic system to communicate between local site and remote site with Ethernet protocol (Sato & Yakoh, 2000). The basic idea of RT-Messenger is to skip processing in software protocol stacks to minimize processing delay. This puts a packet directly into the head of hardware Tx queue in transmitting phase, and picks the packet directly from a Rx queue in receiving phase. Fig. 6 shows packet flow in transmission of RT-Messenger.

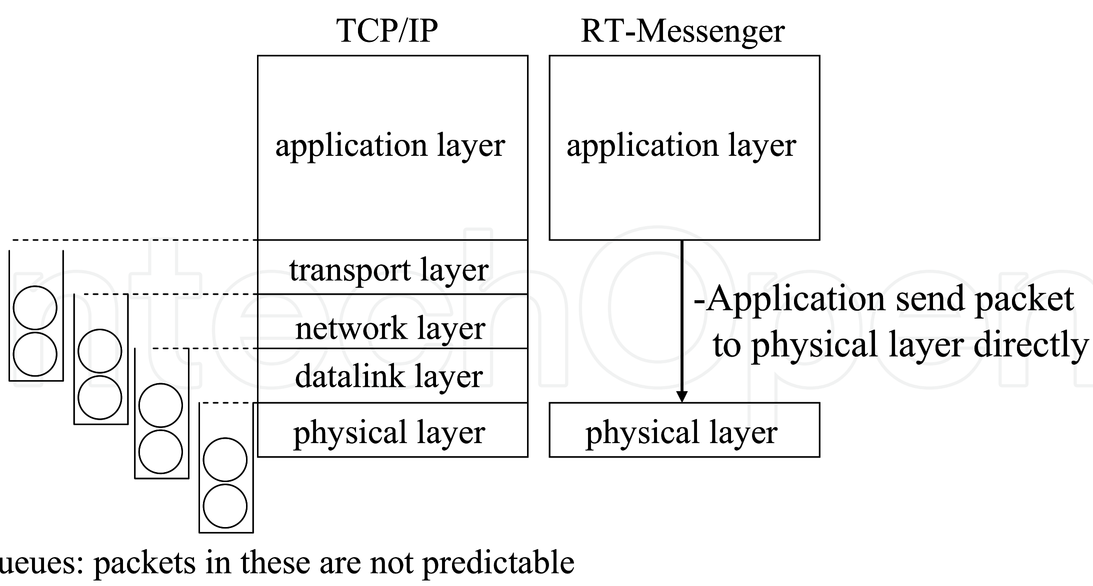

Fig. 6. Packet flow in transmission phase of RT-Messenger

Table 1 shows the specifications of the haptics transmission system.

Controller	
CPU	HT technology Pentium4 Processor 640 3.0GHz clock 2Mb cache
Motherboard	800MHz FSB
memory	1GB
NIC	Intel PRO/100 S Desktop Adaptor
OS	RTLinux-3.1 Linux Kernel Version 2.4.20

Control Device	
Motor, gear-head	MAXON MOTOR RE40,GP52C Torque constant 60.3 mNm/A Reduction ratio 12:1
Motor-driver	Servotechno PMA6 MAX. 110V
Rotary encoder	CANON R-1O 81,000 pulse per rotation
D/A board	Interface PCI-3345A Resolution 12bit Conversion time 10μs
Counter-board	Interface PCI-6204 Counter 32bit Maximum input frequency 1MHz

Table 1. Specifications of the haptics transmission system.

4.2 Video Transmission System (Live Video Streaming System)

For the feedback of the visual information, the live video streaming system is used. The lower communication line in Fig. 1 shows the system. This system displays 30fps video of the remote site to the master site with UDP protocol. Basically, the system is designed to minimize the processing delay (Endo et al., 2008). On top of this system, an artificial delay buffer is introduced to emulate orbitral communication delay of visual feedback. This buffer can emulate 120, 240, 360, 480ms delay. In the teleoperation system, the remote camera takes the image of remote slave and the local display shows the image. Table 2 shows the specification of the video transmission system.

Remote site	
CPU	HT technology Pentium4 Processor 640 3.0GHz clock 2Mb cache
Motherboard	800MHz FSB
memory	1GB
NIC	Broadcom NetXtreme 57xx Gigabit Ethernet Controller
VGA	NVIDIA Quatdro FX540
Camera	CIS CORPORATION VCC-8350CL Maximum resolution 60fps

Local site (monitor)	
Responsivity	8ms
Optimum resolution	1280*1024, Refresh rate 60Hz
Maximum resolution	1280*1024, Refresh rate 75Hz

Table 2. Specifications of the visual transmission system.

4.3 Auditory Transmission System

The auditory transmission system uses the upper communication line in Fig. 2. In the past research, ultrasonic sensors, which were located at the both ends of the rail measured the position of the ball and the system generated the sound according to the measurements as pseudo environmental sound. When the ball was far from the center of the rail, high frequency sine wave was given. Low frequency wave indicated that the ball was near the center. However, this method was not so effective in view of improving the operability of the teleoperation in the past experiments. In this time, therefore, the system does not provide the sound of the remote situation, but provides only additional sounds which indicate the position of the ball on the remote rail and helps the task.

5. Proposed Decorators

This study proposes visual decorators and auditory decorators which improve the operability of the teleoperation system.

5.1 Visual Decorators

This article assumes that delay of live video playout is longer than that of haptics transmission. With this assumption, the haptic information of remote site reaches to local site earlier than arrival of video information, i.e. haptic information is fresher than video information. So it is much worth visualizing haptic information. In this study, position and force information are transmitted as the haptic feedback. Based on these information, this study proposes two kinds of visual decorators which superimpose real-time remote site information on delayed remote video play backs. A position decorator shows the real-time CG image of the remote slave. In this study, the position decorator is bar and its rotation follows the remote rail. If the delay of haptic information is the same as the visual information, the graphic image will be overlapped perfectly with the remote image in the video play backs. However, since haptic information arrives earlier than video information, the position decorator indicates future position of the slave rail against the video playout. This decorator, thus, is expected to improve the operability of the teleoperation system especially when the delay of video play backs is long. This study also proposes a force decorator which visualizes the torque of the remote rail. Force itself is invisible physical abstraction. Therefore, there are many possibilities to visualize force information. This study simply uses bar-graph style appearance to visualize force information. In this study, when the ball is right side of the rail and the weight hangs on, the right bar-graph becomes long, and when it is on the left side, the left bar-graph grows.

The position decorator and force decorator are based on the haptic information. The information is already available to use because haptics transmission system transmit them simultaneously. As a result, haptic feedback system is modified so as to send position and force data also display site of live streaming system through RT-Messenger. In Fig. 2, the additional communication path is shown. SDL and OpenGL libraries were used to draw these decorators.

The effect of force decorator seems questionable compare to that of position decorator. So this article evaluates the effect of two visual decorators independently. Fig. 7 shows the implementation of the visual decorators.

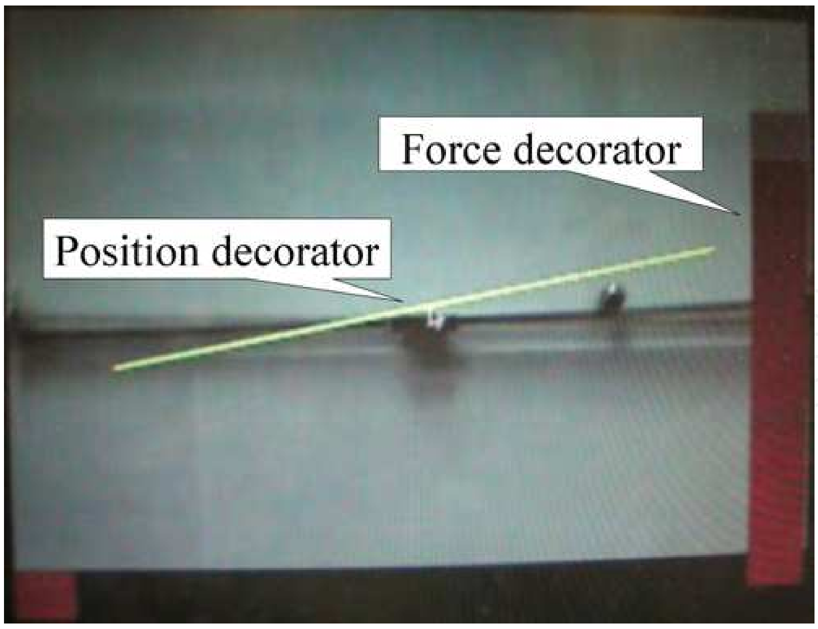

Fig. 7. The Position decorator and the force decorator

5.2 Proposed Auditory Transmission System and Auditory Decorator

The ball position is measured by a laser range finder. Fig. 8 shows tarrangement of mirrors and laser range finder. The box with a polymer reflector covered the ball, and two optical mirrors are located at the axis of the rotating shaft of the rail and the left end of it.

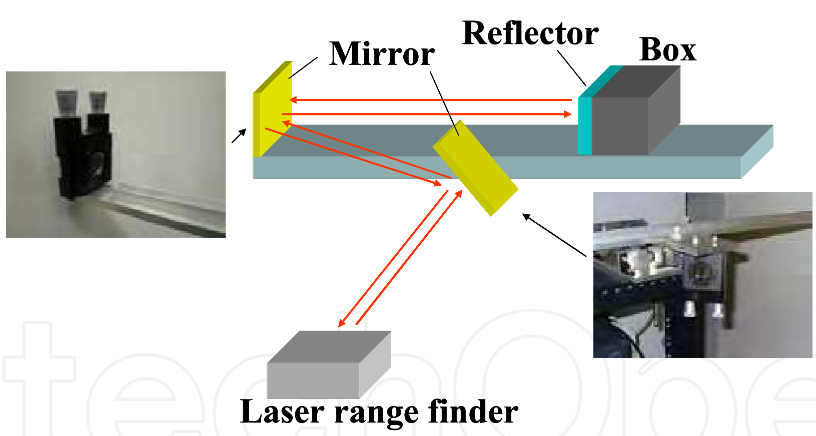

Fig. 8. Measurement of the weight position by laser sensor and optical mirrors

Table. 3 shows the specifications of the laser range finder.

Laser sensor	SICK DME5000
Sampling rate	2ms
resolution	1mm

Table 3. Specification of the laser range finder.

According to the measurements, the additional guiding sounds are generated. The sounds are nonverbal beep which can be perceived at once. In our past research, the pseudo sound indicates the ball position by the frequency this time. However, the method was not so effective to improve the operability of teleoperation. So the system varies the volume according to the ball position. The frequency of the sound is set 1000Hz. This is as much as that of siren, and human being can perceive easily the variation of the sound. Moreover, there is a context effect in our perceptual characteristics. The context effect is alternation in perception of the stimulus by the previous or next one. If the volume varies continuously, the volume is fluctuated by little and little when the ball moves slowly. In that case, the operator gets used to the sound by the context effect and hard to perceive the variation. So the volume variation of the guiding sound should be varied discretely for the operator to perceive the variation and the position of the ball easily. This system sets 4 levels of volume. When the ball is close to the end of the rail, the guiding sound is generated at the loudest volume. The minimum volume indicates that the ball is near the center of the rail, and when the ball is in the goal area, the sound is off. In addition, human being has the ability of sound localization which is used recognize the direction of the sound source. Based on the ability, in case the ball is right side on the remote rail and the stick is rotated clockwise, the right speaker gives the tone and other may around. Fig. 9 shows the correspondence of the indicating position and the volume of additional guiding sound.

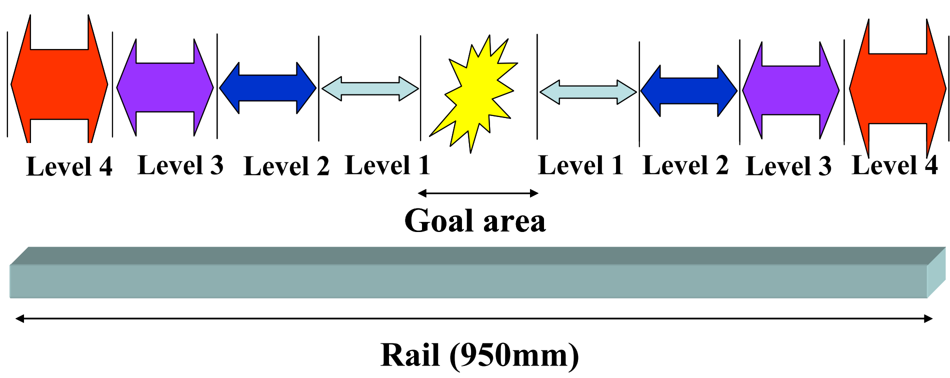

Fig. 9. Correspondence of the indicating position and the volume of additional guiding sound in the auditory feedback system

In addition to the auditory feedback system, auditory decorator is implemented. When the ball is in the goal area, the auditory decorator gives the other beep sound. Its frequency is higher than that of guiding sound of auditory feedback system.

6. Experiments and Results

To evaluate the operability of teleoperation system and the efficiency of the proposed decorators, task achievement time is measured under several conditions.
As mentioned in section 4, controlling the position of the ball to be center of the rail is set as the target task. The initial time, the ball is put on the left end of the rail and the operator starts to manipulate the stick. When the ball locates in the goal area of the rail stably, the operation is finished. The elapsed time is used as an index of usability, i.e. shorter operation time, higher usable condition. Artificial delay time of the live video streaming and the combination of used decorators are used as condition parameters. Delay time are selected as 120, 240, 360, and 480ms.

6.1 Evaluation of Visual Decorators

To examine the stability of the operation, the reaction force of the remote rail is measured in the experiments of visual decorators. When the ball is far from the center of the rail, the torque becomes large because of the weight of it, and the reaction force becomes large. If the reaction force is small, the ball is near the center and the operation is stable. Used combinations of decorators are position and force (P+F), position only (P), force only (F), and no decorators (Non). For each sixteen combinations of all video delay and decorators, 5 participants operated the task twice, and averages of 10 times of measurements are used as the usability index of each condition.

A. results of the task achievement time

Table 4 shows the task achievement times of the experiments of visual decorators

	Combination of decorators			
Video delay [ms]	Non [s]	P[s]	F[S]	P+F [s]
120	33.90	21.43	27.46	32.5
240	38.75	30.62	35.87	32.1
360	50.00	37.46	41.81	42.5
480	56.62	36.53	50.84	44.8

Table 4. Average task achievement time for each experimental circumstance of visual decorators

From table 4, no decorator use, the most left column, shows the longest value for each row. From this result, the decorators were effective at any values of the delay. Especially, the position decorator was very effective and shortened the task achievement time. The position decorator indicated how the operation of the master stick is followed by the manipulation of the remote rail, and operator may understand that at glance. The result in 120ms shows that position decorator was effective. However, the effect is less than it in case of the delay is long. When the delay is 480ms, the task achievement time can be shortened for 20 seconds compared to the case without decorators. To locate the ball stably, the operator manipulated little by little while taking the feedback of the action of the rail. Therefore, the difference between the position information of the rail in the video playout and the bar of position decorator was small when the delay of the playout was short. Therefore, the position decorator is less effective when the delay is short.

When the delay of the visual feedback is set as 120ms with position decorator, the task achievement time shows the shortest value. On the other hand, when the delay is 480ms without decorators, the time indicates the longest value.

In cases of the delay is 480ms, regardless of presence and the combination of the decorators, the task achievement time has grown. The examinee said the operability is worsened extremely in the cases. Also, it is said that the examinee got used to operate under the other three delay values, 120, 240 and 360ms.

Next, the experimental result of force decorator is discussed. The force decorator cannot shorten the task achievement time significantly compare to the position decorator achieves. It means that the force decorator is less effective than position decorator in the teleoperation. The purpose of force decorator is to show the position or movement of the ball on the remote rail from the torque information, and to indicate to which site of the torque is large. However, the examinee says that it is difficult to pay attention to the moving of force decorator besides the slave on the monitor because they concentrate on the action of the slave rail. In addition, it is not useful to visualize the force infomation to shorten the task achievement.

B. stability of the operation

To mention the stability of the operation, this article considers the results of the reaction force of the remote site by the view point of the combinations of the decorators.

Fig. 10, 11, 12, 13 show the representative results of the reaction force and the achievement time of each combinations of the decorators.

When no decorators are used or the force decorator is used, the reaction force fluctuated greatly in the cases of the video delay are 360ms and 480ms. It is because that the manipulation of master became large by not stabilizing the position of the ball and the operation.

These results show that the force decorator is not able to give the positive effect of improving the operation about 20 seconds from the beginning of the task in cases of the delay are 360 and 480ms. However, the reaction force converged after the state which the reaction force and the position of the ball are not steady (for example, II in the Fig. 11 shows the state). This is because the movement of the ball is not steady, the bar-graph of force decorator became long and the effect was appeared. So, the reaction force converged after 20 seconds from the beginning of the task. Force decorator is effective when the operation is not stable.

On the other hand, when only the position decorator is used, the swinging of the reaction force is small (for example, I in Fig. 10 shows the swinging range). As a whole regardless of the delay of live video streaming, the operations can be done stably. Especially, steady operations are done when the delay are 240, 360, 480ms compared with the cases that decorator are not used, and the effectiveness of position decorator is shown.

When two decorators are used, the operations are stable. These results suppose that the position decorator helped the teleoperation

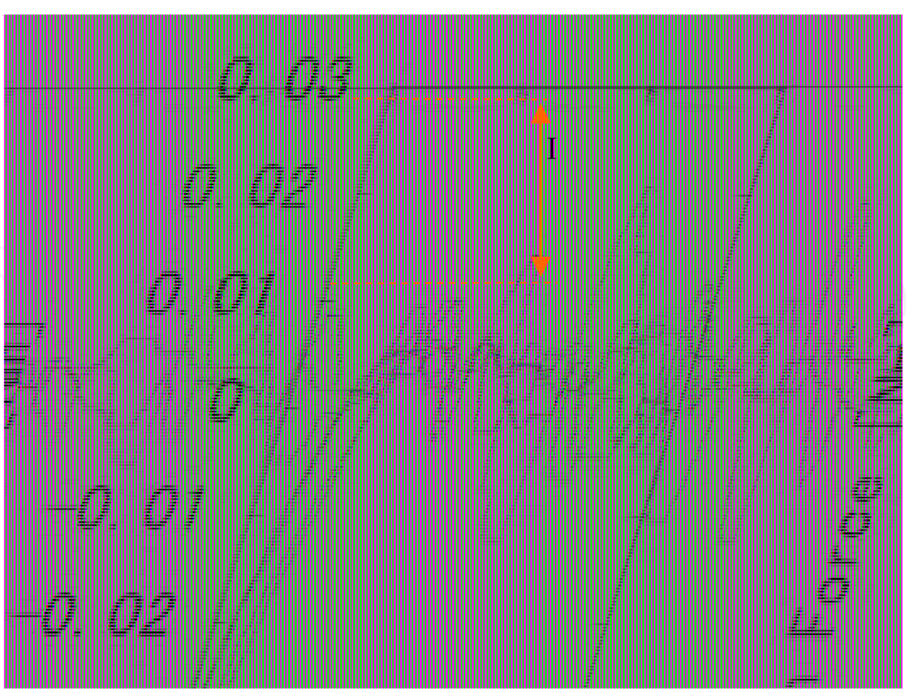

Fig. 10. Reaction force response when no decorators are provided

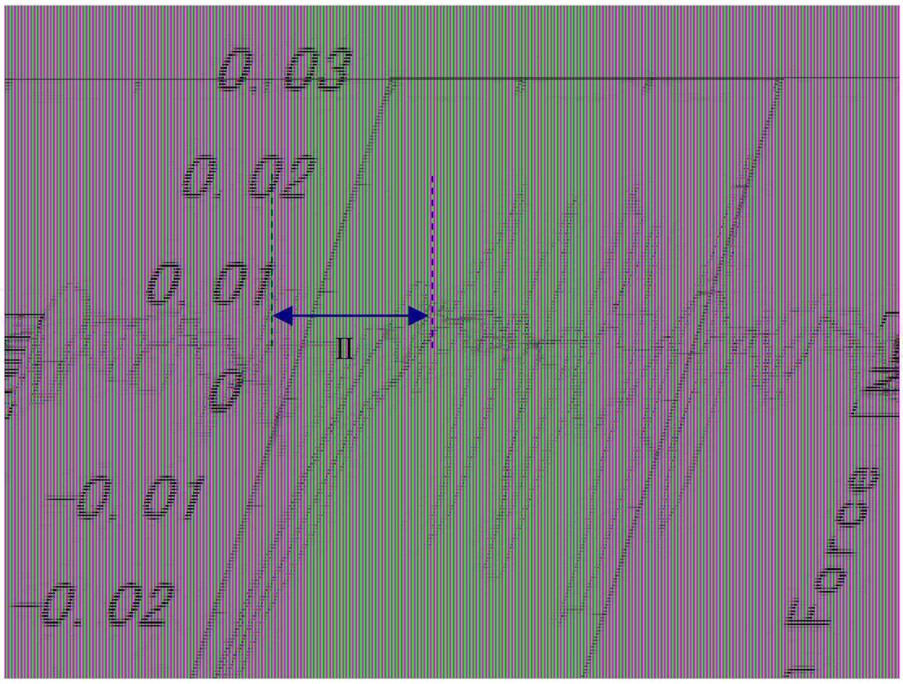

Fig. 11. Reaction force response when force decorator is provided

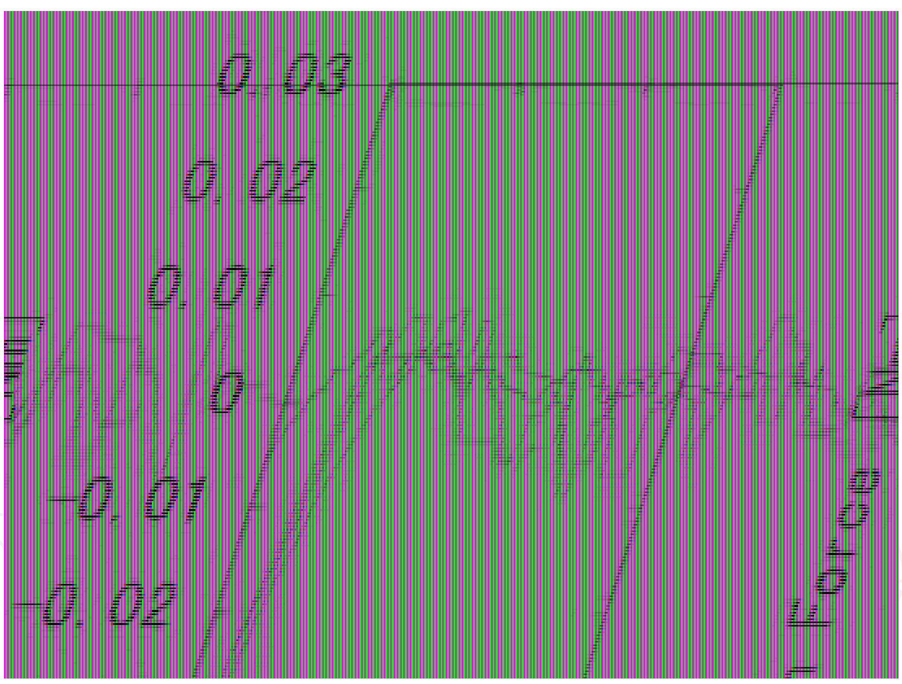

Fig. 12. Reaction force response when position decorator is provided

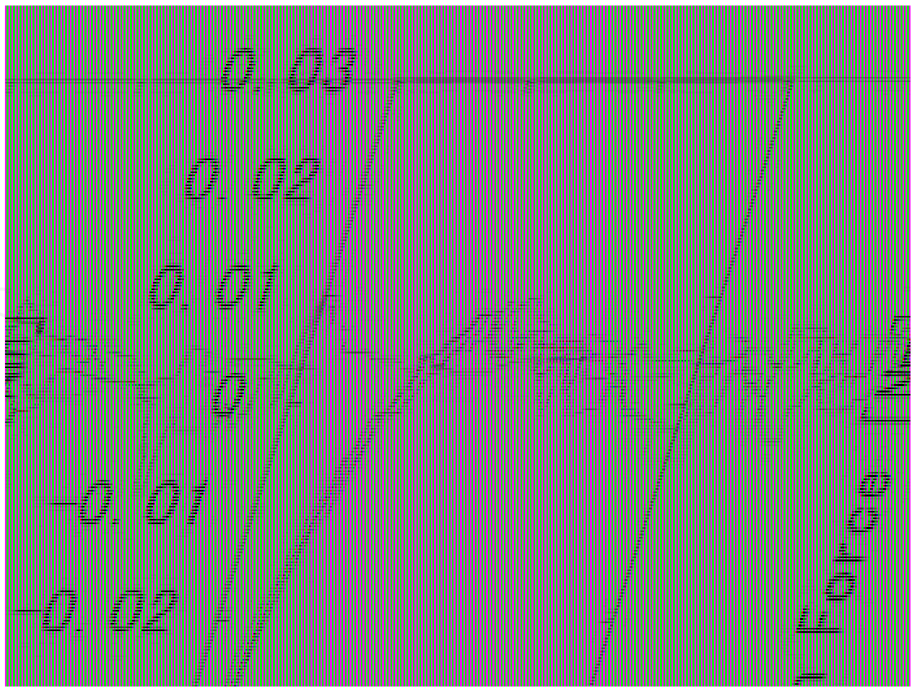

Fig. 13. Reaction force response when position decorator and force decorator are provided

6.2 Evaluation of Auditory Decorators

In the experiments which evaluate the proposed auditory transmission system and decorator, three kinds of experimental conditions are set. No auditory feedback (Non), with auditory transmission system and no decorator (T), with auditory transmission system and decorator (T+D). For each twelve combinations of all video feedback delay (120ms, 240ms, 360ms and 480ms) and auditory feedback, 5 participants operated the target task.
Table 5 shows the task achievement times of the experiments of auditory transmission system and decorator.

Video delay [ms]	Non [s]	F [s]	F+D [s]
120	31.4	33.0	32.5
240	41.3	35.2	32.1
360	45.1	43.9	42.5
480	54.7	44.8	44.8

Table 5. Average task achievement time for each experimental combination of auditory transmission system and decorator

Table 5 shows that the averages are rarely different in case the video playout delay is 120ms. It is believed that the video delay did not cause the deterioration of the operability of the teleoperation in that case. Other results show that proposed auditory transmission system and decorator shorten the task achievement time by 9-24%, and it means that the results are independent from whether the auditory decorator is provided or not.
Moreover, the task can be done without video playout, but with the haptics and auditory transmission systems. The average of the task achievement time without video playout is 69.7 s.

7. Conclusion

This study proposed to introduce decorators to overcome the difficulty of teleoperation system through delayed communication line. The proposed visual decorators indicated some information superimposed on delayed video playout. Since the delay of information decorator used is shorter than that of video, decorator can indicate future information over video playout. This future information is expected to improve the operability of teleoperation system. The experimental results showed that the proposed decorators are useful in the case that delay is long. Especially, position decorator showed significant effect to the teleoperation system and improves the operability. Position decorator rotates like the stick and rail, so it is easy to recognize the information given by position decorator for operator. On the other hand, the action of force decorator was different from that of the experimental task. In addition, the task requires much concentration. Therefore, the operator cannot pay attention to force decorator. Decorator indicates the supplemental information for the teleoperation system and encourages the operator to manipulate properly. Thus, it needs its operator to manipulate immediately for the problems of the network delay and the communication delay of the feedback information. To do the immediate manipulation, the visual information is the most effective. In the view point of "immediacy", it is important whether the optical cue can be recognized easily and user can reflect the information from it to the manipulation momentarily. Therefore, the visual information like position is effective to use as decorator because it is easy to recognize and understand. That is why, position decorator is much useful than force decorator. The visual decorators which are optical cue are useful to the real object and the teleoperation system, and especially, the decorator which indicates the position information of the object is useful.

The proposed auditory transmission system and decorator also shorten the task achievement time, and improve the operability of the teleoperation.

The conclusion of this study is that the manipulation aid by visualizing the haptic information and the guiding additional tone are effective, thus the decorators helps teleoperation. As the future work, designing the other kinds of decorators and discussion which methods is much effective should be done. In addition, the quantitative evaluation of the effects of the decorators should be proposed.

Acknowledgments

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Any book which presents works about controlling distant robotics entities, namely the field of telerobotics, will propose advanced technics concerning time delay compensation, error handling, autonomous systems, secured and complex distant manipulations, etc. So does this new book, Remote and Telerobotics, which presents such state-of-the-art advanced solutions, allowing for instance to develop an open low-cost Robotics platform or to use very efficient prediction models to compensate latency. This edition is organized around eleven high-level chapters, presenting international research works coming from Japan, Korea, France, Italy, Spain, Greece and Netherlands.

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