Synchronization and Control of Supermedia Transmission Via the Internet *

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Abstract

The growth of the Internet has been accompanied by an increase in its application. Many new Internet based applications have been introduced during the past decade. One of the most interesting of these is teleoperation, where the Internet is used as a bridge between operators and machines. The operator sends commands and receives visual and haptic feedback. Collectively, we refer to all those streams as supermedia.

Teleoperation over the Internet comes with several problems: delay, lost packets and disconnection. All of these limitations may cause instability and desynchronization in teleoperation systems especially if those systems include haptic feedback. Most of the previous work in Internet based teleoperation rests on many limiting assumptions; for example, time delay is constant or has an upper bound, control is not in real-time. This paper presents a new real-time haptic feedback system that deals with these limitations and difficulties without any assumptions made regarding the time delay. The approach is based on Event Based Control, which has been implemented on a mobile robot and a mobile manipulator over the Internet

1 Introduction

All real-time control systems used over the Internet share several similar difficulties. The greatest difficulty faced is delay. This delay, although not desired, does not constitute a major problem for data transmission. However when the Internet is used as an action super-highway, via which control commands are sent and haptic feedback is received in real-time time delay becomes an important factor in the stability and efficiency of the system.

Several Internet based robots have been developed and studied (Tarn and Brady [1], Pai [2], Stein [3], Simmons [4] and others). These robots perform different tasks, ranging from manipulating objects and navigation to manipulating camera views. However, except for video, no other sensory feedback was used in these experiments.

The role of supermedia systems is to link the operator's senses to the real or virtual environment. The general form of such systems is seen in Fig.1; the operator sends commands, such as velocity, and the remote machine feeds back force and video information. To capture all those streams flowing in both directions we present the notion of *supermedia*, which includes operator's commands, multimedia feedback and haptic feedback. The resulting supermedia system couples the operator with the remote environment and gives him a sense of telepresence. This significantly increases the safety and efficiency of the telerobotic system [5].

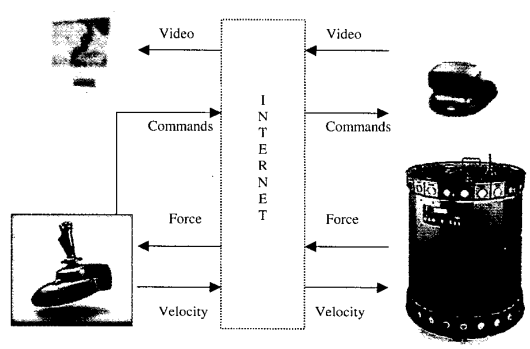

Figure 1: The general structure of the haptic system used in this study.

Several studies have been made relating to haptic systems in general and specifically, force reflection un-

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der time delay [6]-[10]. But each of these approaches has its limitations in regards to delay. Delay is taken to be fixed and not random, it is considered to be the same in both directions or considered to have an upper bound beyond which the system becomes unstable or stops operating. These assumptions are usually not true while dealing with teleoperation over Internet. When it comes to the Internet no assumptions should be made regarding the time delays, because they can be random (with no specific simple statistical model) and there is no upper bound on them. The main effects of these delays are, instability and desynchronization. This desynchronization occurs between the different supermedia streams, which implies that the commands get desynchronized which respect to the feedback. This paper presents a new approach that overcomes these problems in teleoperation systems that have haptic feedback.

2 Non-Time Based Control For Teleoperation With Haptic Feedback

Delay in communication links has several effects on the stability and synchronization of the system. And on the synchronization of the different supermedia streams. These effects are resulting from the use of time as the reference variable; therefore, if a non-time based reference is used the system would become immune to delay. This suitable action or motion non-time reference variable is called event. The event-based controller design was first introduced in [11]. Then several studies and applications followed [12] [13]. The planning and control of the traditional time-based and the event-based schemes is shown in Fig.2.

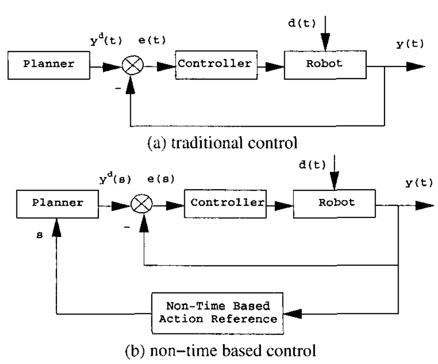

Figure 2: The comparison between traditional time-based and event-based planning and control.

3 Implementation

The implementation can be divided in two parts, hardware and software. As seen in Fig.3, the system consists of various operating systems and configurations. So the problem of interconnection had to be studied carefully. The joystick used is a programmable Microsoft SideWinder Force Feedback Pro. with 3 degrees of freedom. The mobile robot is a Nomadic XR4000. The video part consisted of an on board Sony EVI-D30 camera with a Matrox Meteor frame grabber and an over head Logitech Quickcam camera, which is connected to another remote PC.

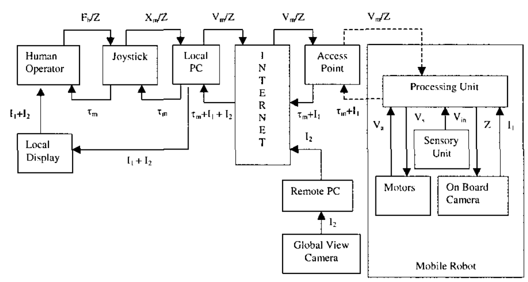

Figure 3: Hardware structure of system.

The software developed or used can be divided into four parts: motion server, camera server, client and the video conferencing tool VIC. The servers run on the robot, the client runs on the local machine and VIC runs on the robot, the remote PC and the local PC.

Motion Server: The service is moving the robot and sending feedback. This is mainly what the motion server does; except that the server does not execute the request blindly, it first checks the sensors and based on that a decision is made according to an obstacle avoidance algorithm.

After the velocity to be set is decided, it is sent to the motors for execution. Then the server checks the actual velocity of the robot and subtracts that from the original desired one and sends it back to the client as force feedback. To overcome the problem of disconnection, the server would execute the velocities for $250ms$; after which, if no new command is received, it would time out and stop moving waiting for the next command.

Camera Server: This program provides the ability to control the on board camera using Visca commands. The operator sends pan, tilt and zoom commands, and the server relays these to the camera. This gives the operator the ability to change the field of vision to allow close coupling to the environment.

Client: This program runs on the local machine and communicates with both servers and the joystick. The client sends commands either to the motion or camera server and sends force commands back to the joystick once feedback is received. The client communicates the joystick using DirectX technology and with the servers over the Internet.

VIC (Video Conferencing Tool): This video conferencing application was developed by the Network Research Group at the Lawrence Berkeley National Laboratory in collaboration with the University of California, Berkeley. VIC was used to transmit video feedback from the onboard and the overhead camera to the operator.

4 Experimental Results

Several experiments were done during the duration of the project; included here is the one done over the Internet with Hong Kong. For this experiment the operator is sending velocity commands to a mobile robot and receiving haptic and visual feedback. The haptic feedback in this case corresponds to the distance to obstacles detected in the environment. So the operator is able to sense the obstacles in front of the robot before hitting them. To understand the system operation let us consider Fig.4.

In the top row a plot of time versus s, the event, is given. The other plot in the top row is the desired rotational velocity. The second row is the desired velocities in x and y directions. The third row displays the actual velocities in the both directions. Next we give the force that is played by the joystick in both directions. The last row displays the same plot, which is the closest distance detected to obstacles in the environment. To get an idea about the performance and behavior of the system let us consider all these plots together. Looking at the actual velocity we see that it is changing according to the distance detected, for example if the distance gets closer the actual velocity decreases, when this happens we see that the force increase, which is what we expect. Thus a close object causes the robot tracking error to increase by that telling the operator that an obstacle exists. Whenever the robot gets to the critical distance of $0.5m$, the actual velocity becomes zero in both x and y directions. When the robot gets further away from obstacles the actual velocity starts tracking the desired one again, by that reducing the tracking error and therefore the force.

As seen, the actual velocities are tracking the desired ones as long as the distance to obstacles is less than a critical distance. Therefore, the system output stability is illustrated. In addition, the change of the desired and actual velocity direction is occurring at the same event, thus the system is synchronized.

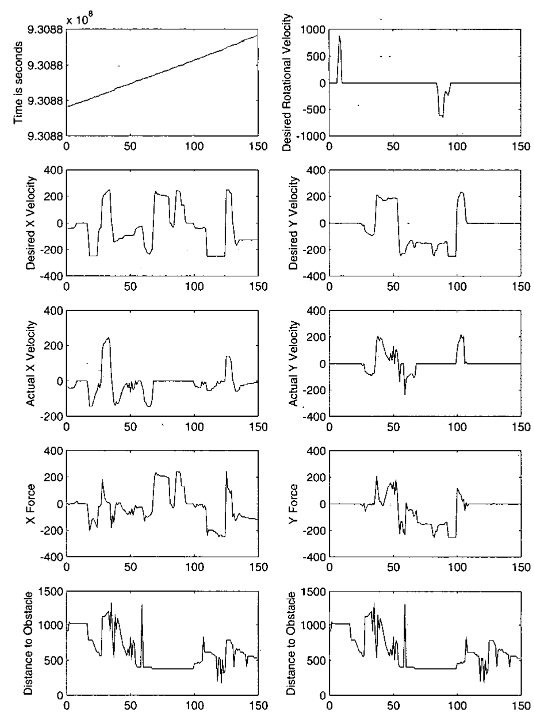

Figure 4: The behavior of the system during the control from Hong Kong.

Fig.5 presents the experimental results and the performance of the visual feedback. This figure shows a plot of the frame rate and the bit rate of both the overhead and the onboard camera. The overhead camera has a significantly lower frame rate than the on board one, most probably a result of having the overhead camera connected to USB port, which is slower than the frame grabber used in the robot. These plots show that the frame rate is increasing as the bit rate goes down, which might seem at first illogical. However, when there are few changes in the view, VIC does not need to send much data to obtain an up-to-date image. For large changes in the view, such as a robot movement, more data must be sent to achieve even a

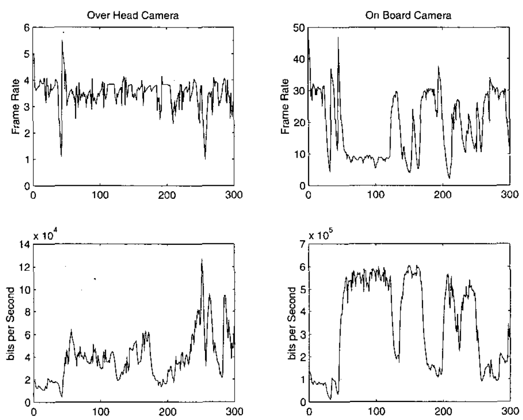

Figure 5: The frame rate and bit rate of the overhead and on board camera.

low frame rate for the video.

In comparing force and video, the large difference in the transmission rates (average rate for video $45KB/sec$, Average rate for force $140B/sec$) makes force a very attractive feedback option. Additionally, force conveys very helpful information and does not consume significant resources. For cases where slow networks are used, such as ISDN with maximum bandwidth of about $8KB/sec$, the video update rate would slow considerably but the force performance would still be acceptable. However, very slow frame rates do not exclude video from being essential in a haptic teleoperation system.

5 Conclusions

This study presents a new event-based control method for teleoperation systems with haptic feedback, which overcomes the effects of time delay. This approach is immune to any kind of time delay; no upper bound is assumed and the delay can be random or fixed. Therefore, it is ideal for Internet applications. In addition, the event-based control method is independent of the system model, specifically the network.

The notion of supermedia was presented. Supermedia includes commands, multimedia and haptic information, all of which have to be synchronized in order to achieve stable and efficient operation. This was accomplished by using event-based planning and control.

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