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A TCP/IP-based remote control system for yard cranes in a port container terminal

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SUMMARY
If one operator in a remote operating room can operate 4 ∼ 5 cranes remotely, which are yard cranes for container loading/unloading in a port container terminal, the port loading/unloading efficiency will dramatically be improved through productivity increase, cost reduction, and so on. This study presents a remote crane control system for container loading/unloading yard cranes of port container terminals. First, a wireless web-based video and audio transmission system to transmit the images and the sounds of a craneyard is designed by using 3 web cameras and a microphone. Next, a TCP/IP-based remote crane control system is presented on the basis of the delay performance simulations of TCP (Transmission Control Protocol) and UDP (User Datagram Protocol) for real-time remote control. The simulation results show that TCP is more advantageous for remote crane control on a local network.

KEYWORDS: Remote operation; Remote control; Yard crane; Wireless web-based video/audio transmission; TCP; UDP.

I. INTRODUCTION

A modern harbor is aiming at high automated, information-oriented, and intelligent integrated management system. It is not easy to secure competitiveness in international shipping market without harbor automation, and so many countries are investing in automation for harbor advancement. The researches and developments related to port container terminals were mainly carried out in the areas of terminal or facility operation,[1–5] and remote control and operation.[6] They are chiefly for improving harbor efficiency rather than a full automation of a port or a crane due to realistic difficulties.

On the other hand, a remote control system to operate and control far-off equipments through a communication network like the internet can be applied to control industrial machinery and equipments remotely by using an interface controller between the controlled equipment and a network equipment. Recently, the remote control of an industrial equipment like web-based rectifier control, or web-based monitoring and control by using a camera is being much performed. However, the field of remote control of industrial equipment which need precise control has still many problems to solve such as real-time control or restoration of load loss.[7,8]

This study presents a remote crane control system to operate 4 ∼ 5 yard cranes remotely in a remote operating room by one operator, which transmits the images and the sounds of a craneyard by radio, and controls the cranes targeting on container loading/unloading yard cranes, such as RMGC (Rail Mounted Gantry Crane), RTGC (Rubber Tired Gantry Crane), OHBC (Over Head Bridge Crane), and so on. First, this paper designs a wireless web-based video and audio transmission system which is composed of 3 web cameras and a microphone through the determination of the specifications and the setup of cameras and a microphone. Next, this paper proposes a TCP/IP-based remote crane control system on the basis of the delay performance simulations of TCP and UDP for real-time remote control.

This paper is organized as follows: Section II describes a configuration of a remote crane operation system, and Section III describes a wireless video and audio transmission system. Section IV describes a TCP/IP-based remote crane control system and its simulation results. Section V describes a graphic user interface design. Finally, some conclusions are drawn in Section VI.

II. A CONFIGURATION OF A REMOTE CRANE OPERATION SYSTEM

II.1. Object cranes

The cranes to be an object of this study are yard cranes such as RMGC, RTGC, OHBC in port container terminals. Figure 1 shows a configuration of RMGC (Rail Mounted Gantry Crane). An operator operates a crane manually in an operating cabin hanging on the trolley, and carries out the container loading on the craneyard or on AGV (Automated Guided Vehicle), and container unloading from them.

The motion of a yard crane is categorized into traveling, traversing, hoisting up/down, and twist lock/unlock, as shown in Fig. 1: traveling is the motion when the whole body of a crane moves along the railroad; traversing is the motion when the trolley moves along the trolley railroad to load or unload a container with the spreader in the direction of the right or left of Fig. 1; hoisting up/down is the up or down motion of

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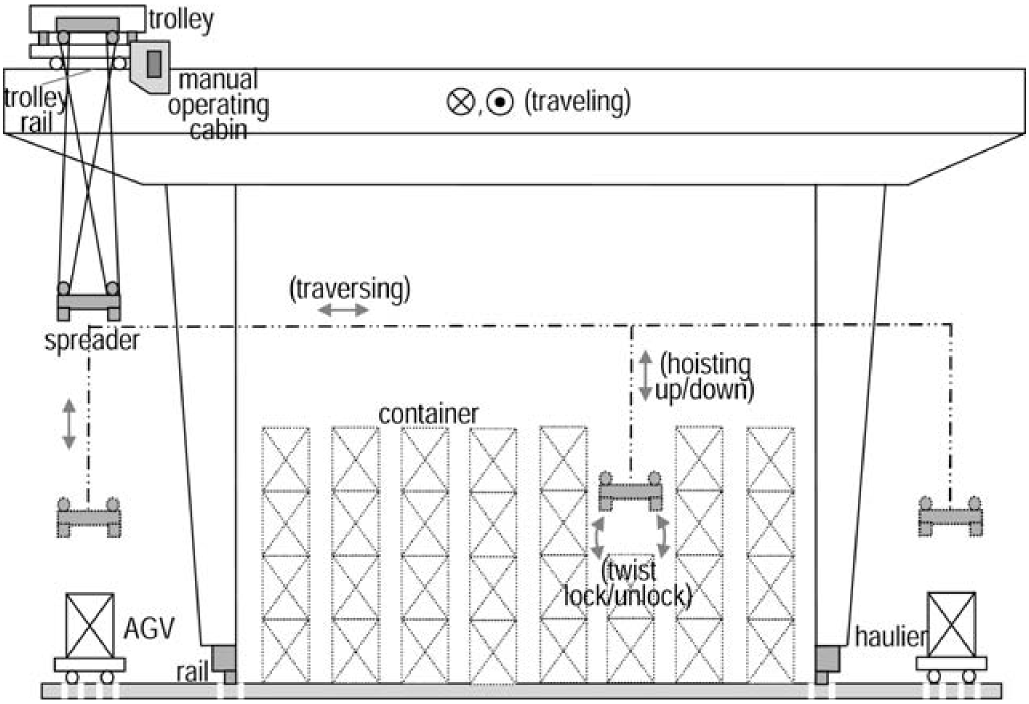

Fig. 1. A schematic diagram of a RMGC.

the spreader; twist lock/unlock is the lock or unlock motion of the spreader to grasp or release a container.

II.2. A system configuration

For smooth and successful remote operation, it is desirable to make a remote operator in a remote operating room feel as if he operates the crane directly in the manual operating cabin hanging on the trolley. In other words, it is necessary that a remote crane operation system transmits the on-site situation of a craneyard including the images and the sounds in real-time. In order to do so, this study sets up some CCD cameras and a microphone in the proper positions of the crane.

Communication through wire for remote crane operation can cause some troubles such as cable tangling due to the movement of the crane and the trolley. And so, this paper describes a remote crane operation system by wireless communication. Figure 2 shows a configuration of the presented remote crane operation system.

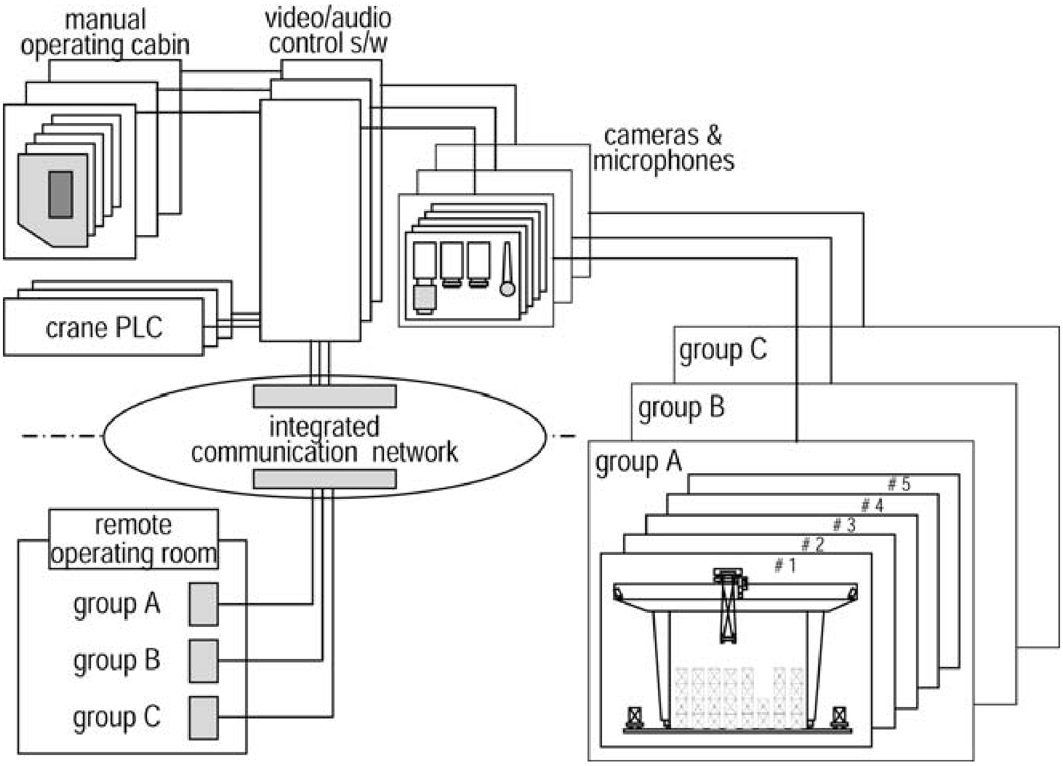

Fig. 2. A configuration of a remote crane operation system.

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III. DESIGN OF A VIDEO AND AUDIO TRANSMISSION SYSTEM

III.1. Camera location and specifications

There is a need to determine the proper number of cameras and their installation locations when taking the detailed crane work and the craneyard size for container loading/unloading into consideration. When an operator operates a crane manually in an operating cabin, he carries out the container loading/unloading work looking down at the spreader and the container.

Therefore, this study first sets up one camera at the bottom of a manual operating cabin, which has a bird's-eye view of a container loading/unloading work as a manual operator, traversing the trolley along the trolley railroad. The camera plays the role of an operator's eye as the main camera in a remote crane operation system. By providing the functions of pan, tilt, and zoom to the main camera which plays one of the most important roles in a remote operation system, it is necessary to help the camera to have a view of only a necessary direction or a magnified view by zooming in. These functions will be helpful for a more elaborate and safe operation by acquiring more decipherable and clearer images.

Next, this study sets up two auxiliary cameras additionally, one each on both sides of a crane, which play an auxiliary role for the main camera. Although the auxiliary cameras don't have pan/tilt/zoom functions, they are indispensable for a remote crane operation system. They monitor a part of a craneyard, for example, the area where the main camera is not monitoring or is not able to monitor. Figure 3 shows the setup locations and the fields of view of the main camera and the auxiliary cameras.

Let us assume that an object is projected fully to an image plane when an object size is a, an image plane size is b, and an object distance is d. And then, from the thin-lens formula,[9] the focal length f of a camera lens can be obtained as

$$f = \frac{b \cdot d}{a + b}. \tag{1}$$

On the other hand, all kinds of international standard containers,[10] established by ISO (International Standard Organization) are taken into consideration as target containers for a remote operation system of this paper. The maximum length out of the target containers is 12.192 m, and the minimum length out of them is 2.991 m. Their heights are either 2.438 m or 2.591 m. And, the widths of the target containers are the same as 2.438 m. In addition to ISO standards, there are some kinds of containers with other dimensions, but they are nearly similar to ISO standards. Therefore, the specifications of the cameras and their respective corresponding lenses for a remote crane operation system considering only ISO standards are almost available for other containers.

Considering the height of the large-sized cranes reaching about 25 m, let us assume that containers are loaded up to 4 floors, and the cameras are set up at a height of 25 m. And then, the total height of containers loaded up to the 4th floor gets to be 10.364 m in case that the containers have a height of 2.591 m. In order to select the cameras and their corresponding lenses, the followings are considered: the dimensions of the target crane and the target containers, and camera setup space. This paper selected a 1/4″ CCD camera as the main camera, and a proper lens corresponding to the selected camera on the basis of the focal length calculated by Eq. (1).

Let us take two extreme cases into consideration in order to find out the range of the required focal length: The required minimum focal length f_n is 4.32 mm in case that the longest

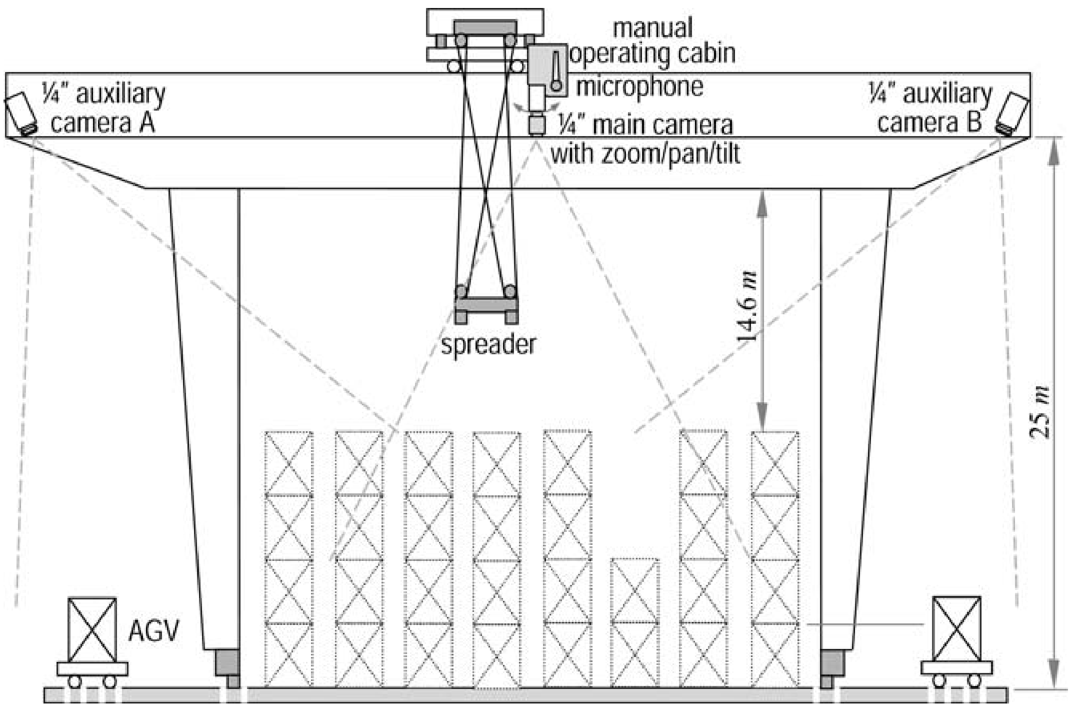

Fig. 3. Locating three cameras and a microphone.

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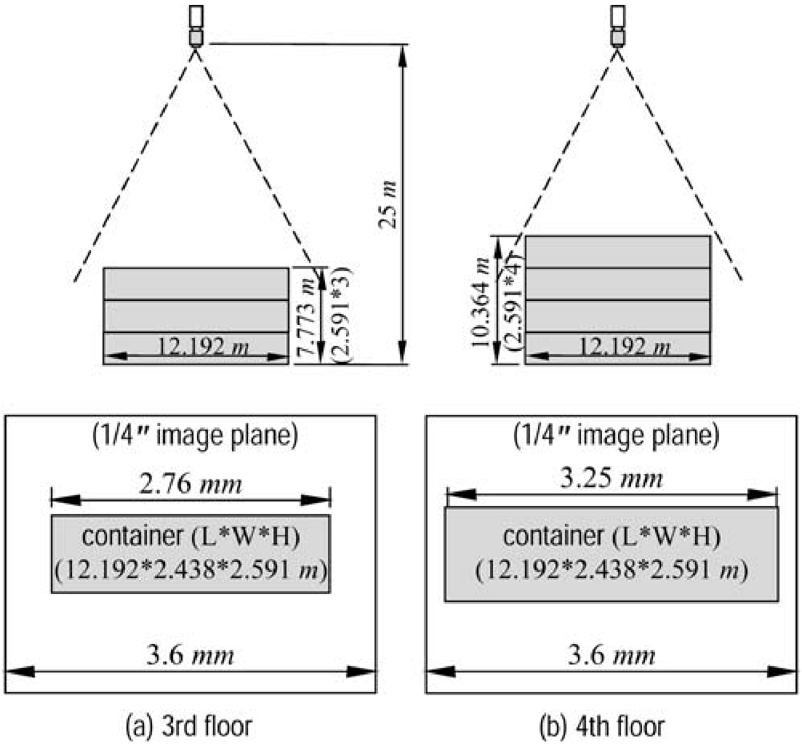

Fig. 4. Container images according to loaded height ($f = 3.9$ mm).

and the highest containers with a length of 12.192 m and a height of 2.591 m are loaded up to the 4th floor. The required maximum focal length f_x is 27.12 mm in case that only one of the shortest and the lowest container with a length of 2.991 m and a height of 2.438 m is on the first floor. The focal lengths required in other cases except the above-described two are between f_n and f_x. Consequently, the specification required in the focal length f of the lens for the main camera is to cover the range from 4.32 mm to 27.12 mm. Based on the specification, this paper selected a zoom lens with the focal length range of 3.9 mm ∼ 62.5 mm, which is a commercialized lens suitable for the main camera. By using the selected zoom lens, the main camera can show a full image of a container in its image plane in any case, or can show an enlarged view by zooming in.

Figure 4 shows the container images on the image plane when a container with a length of 12.192 m and a height of 2.591 m is laid on the 3rd floor and on the 4th floor in case of the minimum focal length of 3.9 mm without zooming in. In case of the 3rd floor, the container image is seen in a size of about 76.7% (= 2.76/3.6∗100) compared with the horizontal length of the image plane, as shown in Fig. 4(a). In case of the 4th floor, the image is seen in a size of about 90.3% (= 3.25/3.6∗100), as shown in Fig. 4(b). As the zoom lens is adjusted to a larger focal length by zooming in, the image is getting of a larger and larger size. Accordingly, the container on the 3rd floor or the 4th floor can be seen in a larger size than the images of Fig. 4 by zooming in. Consequently, by using the selected main camera and the zoom lens, the remote operation system is able to acquire a full image of a container in its image plane or an enlarged image of a container by zooming in wherever the container is, or whatever kind it is.

On the other hand, two auxiliary cameras just play an auxiliary role for the main camera. They provide a broad view of the area including an AGV that the main camera is not viewing. As an auxiliary camera, this paper selected two sets of a 1/4″ CCD camera and a camera lens with a fixed focal length of 3.9 mm. They will be useful, even though they cannot provide a detailed view due to no zoom function.

III.2. A video system configuration

There are three types in the video transmission systems: a VTR (Video Tape Recorder)-based system of an analog type, a DVR (Digital Video Recorder)-based system of a digital type, and a web-based system of a digital type. A VTR-based system has a complicated configuration, and the inferior functions/performances in the aspects of image storage, image search, and camera control as compared with the other systems. And it takes more costs and time in maintenance. A DVR-based system and a web-based system are more advantageous in various aspects such as image storage, image search, screen division, and extendability. However, in case of wireless transmission, a web-based system has the simplest configuration. This paper describes a web-based video transmission system in consideration of the present trend toward the Internet as well as economical efficiency, convenience, extendability, and easiness of maintenance.[8] Table I shows a comparison among three types of video transmission systems.

Figure 5 shows a configuration of a wireless web-based image and sound transmission system for remote operation of a crane. It supports a variety of protocols used on the Internet such as TCP/IP (Transmission Control Protocol/Internet Protocol), ARP (Address Resolution Protocol), FTP (File Transfer Protocol), HTTP (Hypertext Transfer Protocol). A

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Table I. Comparison among video transmission types.

Item	VTR-based	DVR-based	WEB-based
1. configuration	complicated	simple	simple
2. image store/search	store in tape time-consuming by sequential search	store in HDD fast by random search	store in HDD fast by random search
3. screen division	need additional equipments	no additional equipments	no additional equipments (internet-based)
4. extendability	need additional H/W	easy by S/W	easy by S/W
5. maintenance/installation	time-consuming, high cost	easy, need extra communication line	easy, use existing network
6. supervision	centralized	centralized	distributed (economically efficient)

web-based system can transmit information wherever the Internet is connected. However, in case of transmission by wire, a communications line can be entangled as a crane moves. That's why this study selected a wireless system. This study implemented an image transmission system by using a wireless LAN (Local Area Network) with a frequency band of 2.4 ∼ 2.4835GHz, and a transmission speed of 11 Mbps within a distance of 200 m and 2 Mbps within 350 m on the basis of IEEE 802.11 standards.

On the other hand, a port craneyard for container loading/unloading is usually in very inferior environment due to salt, wind, dust, and dampness. Therefore, each component of the system needs to be selected and designed in consideration of corrosion prevention, durability, robustness, easiness of maintenance, vibration and shock according to a crane motion, and so on.

III.3. An audio system configuration

A manual operator of a crane judges working situations, such as container locking/unlocking, and the occurrence of an accident from the sound as well as the vision of a craneyard during the operation. Therefore, a remote operation system needs an audio transmission system to transmit the sound of a craneyard. The audio transmission system assists a remote operator in operating a crane smoothly and safely, and in judging working situations correctly and quickly by transmitting the sound of a craneyard while a crane is lifting/lowering or locking/unlocking a container, and a crane or a trolley is in motion.

A manual operator hears a sound in a manual operating cabin during his operation. In order to make a remote operator feel like operating directly in a manual operating cabin hanging on a trolley, a microphone is set up in the operating cabin. The reason is that it is desirable to make a remote operator feel just like being on the scene of an actual operation. Durability and impact resistance as well as functions and performances need to be taken into consideration as the requirements of a microphone for a remote crane operation system. A configuration of a wireless audio transmission system is shown in Fig. 5. This study used a VoIP (Voice over Internet Protocol)-based interphone for an audio transmission system.

IV. DESIGN OF A REMOTE CONTROL SYSTEM

IV.1. Control network design

Internet-based machine control is feasible wherever the Internet is connected, but it is hard to control in real-time due to network congestion, etc. In case of a local network, there is little network congestion, and so real-time control is feasible. Because a craneyard is not usually so large, this study configured a remote crane control system on a local area network with a view to easy real-time control.[11,12] Figure 6 shows a conceptual schematic diagram of the proposed remote control system.

In order to control crane driving motors based on TCP/IP, the proposed system uses a protocol converter which converts TCP/IP messages to serial signals. This converter is connected to a PLC control panel, which controls crane motors directly, via RS-232C serial communication, and to a remote control computer via wireless LAN. In the system, a remote control computer is a manager, but a protocol

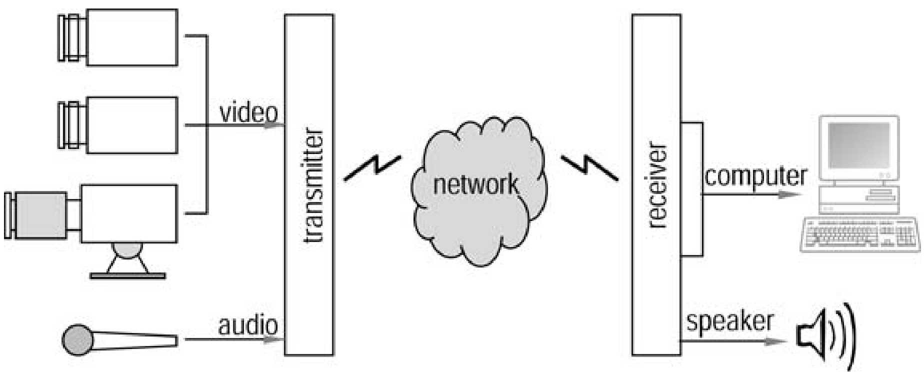

Fig. 5. A configuration of a wireless video/audio transmission system.

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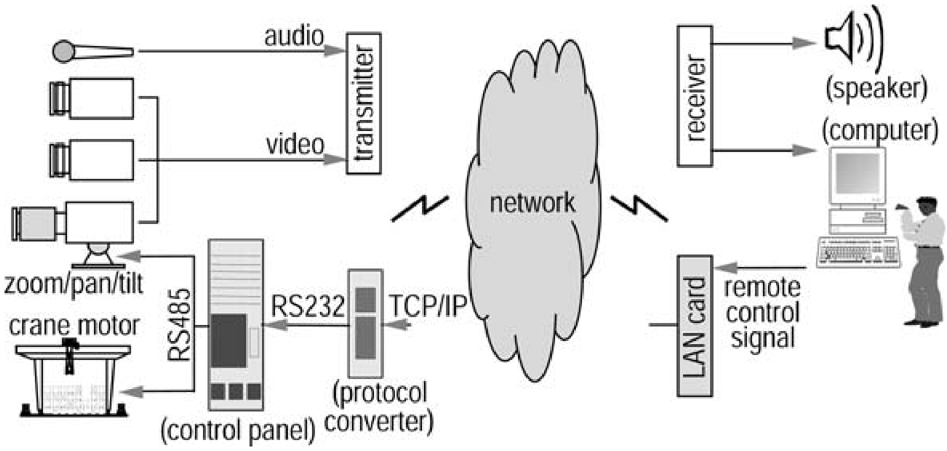

Fig. 6. A schematic diagram of a remote crane control system.

converter, a control panel, and crane motors belong to the managed systems. In this study, it is implemented that a manager can take or change information of the managed systems. And each crane motor is connected to a control panel via RS-232C or RS-485 serial communication.

In the design and operation of a remote control network, it is very important which protocol to select. This paper selects a protocol through the performance investigation of a TCP (transmission control protocol)-based system and a UDP (user datagram protocol)-based system.

A TCP-based system can reduce the possibility of packet loss or packet error because its transmitter transmits a proper amount of data to a receiver as much as it can through the exchange of the information about how much data can be transmitted. However, it cannot guarantee real-time transmission because of time consumption in opening or closing connection sets. A UDP-based control system has an advantage over a TCP-based system in real-time control, but some problems such as message loss, duplication, delay, non-sequential transmission, and connection loss can occur because there is no flow control or no window mechanism. In case of industrial machines or equipments such as a container crane, these problems can cause a fatal accident.[11,12]

This paper performed some simulations on delay performance by using the OPNET modeler.[13] Figure 7 shows the simulation results in cases that a TCP-based system and a UDP-based system each transmit the traffic of three web cameras and crane control from 15 cranes in a craneyard with a local network configuration. The simulation results show that the delay of TCP is about 2.5 ms larger than the delay of UDP, but the difference is small and insignificant. On the other hand, Fig. 8 shows a simulation result about the delay of TCP with light traffic from only a crane. The simulation results in local network configuration show that the difference of the delay according to the amount of traffic is small and insignificant, too.

The reason of little difference is that they were configured on a local network, and delay usually matters little in a local network due to the very small delay. A craneyard is not usually so large, and it can be configured on a local network. Therefore, real-time control of a crane is feasible in either case of TCP and UDP. In other words, a TCP-based remote control system has no problem in real-time control as well as load loss or load error. Thereupon, this study configured a remote crane control system by using TCP as a protocol.

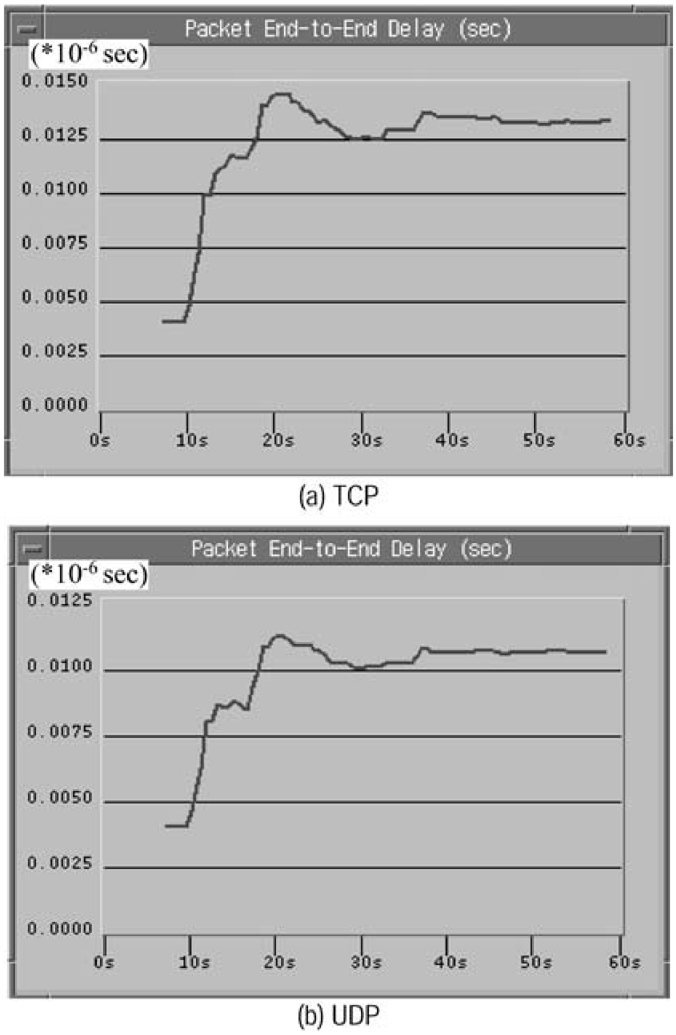

Fig. 7. Delay performance simulations of TCP and UDP with heavy traffic from 15 cranes.

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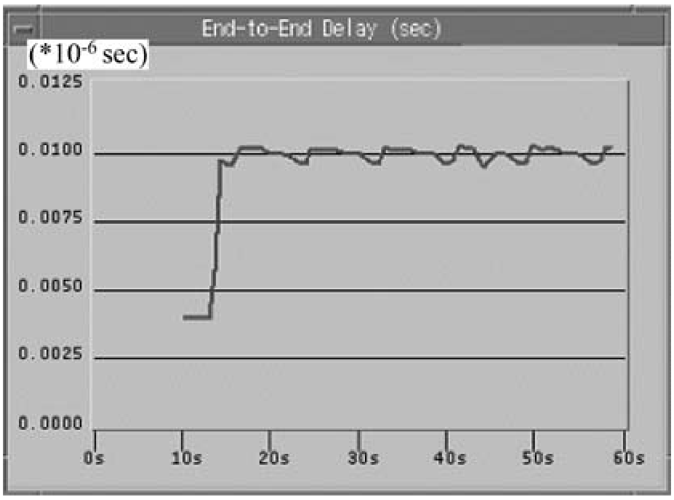

Fig. 8. Delay simulation of TCP with light traffic from a crane.

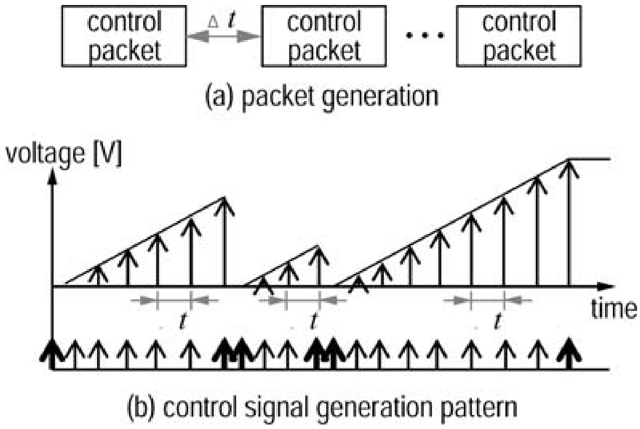

Fig. 9. Crane control packets (loads).

IV.2. Crane control signal

A control signal from a remote control computer, which is a manager, is transmitted to a protocol converter via the Iinternet in the form of a TCP message by a client socket. And then, it is transmitted to a PLC control panel of a crane after converting into an asynchronous RS-232C signal in the protocol converter. A microprocessor of the PLC control panel processes the RS-232C signal, and then controls each crane motor.

While a remote operator operates a crane remotely, a control computer is due to generate a control load at intervals of Δt, as shown in Fig. 9(a). If the interval between two control loads which arrived in a control panel via a network is nearly equal to Δt like when they were generated, then the control signals can be restored in a similar form to the signals of when an operator operates a crane manually. Every time a load (packet) arrives, the speed of a crane motor increases uniformly. In other words, the voltage increases uniformly, as shown in Fig. 9(b). After the last load has arrive, the voltage is forced to be 0 in order to perform the next command. If a new load doesn't come in within a pre-specified maximum delay time, one command is regarded as finished. As shown in Fig. 7(a) and Fig. 8, the difference of the delay according to the amount of traffic is small and insignificant. Accordingly,

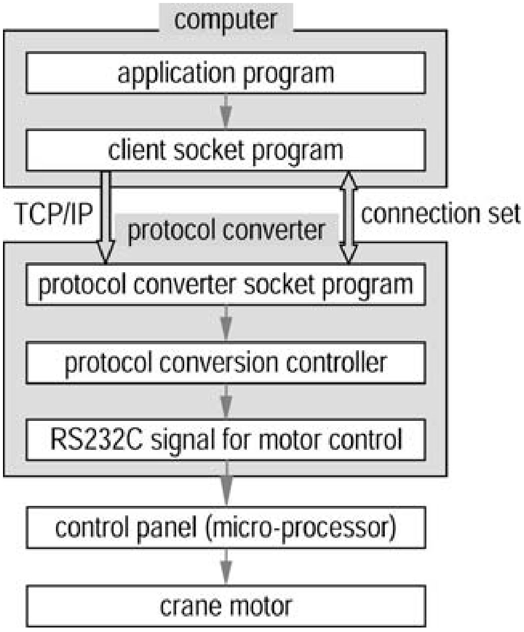

Fig. 10. A flowchart for control signal flow.

regardless of the amount of traffic, control signals can be restored in the form which the voltage increases uniformly like when an operator operates a crane manually, as shown in Fig. 9(b).

V. GRAPHIC USER INTERFACE DESIGN

This study implemented an application program to control crane motors by using *C/C++* programming, which is executed by the microprocessor of the PLC control panel. Figure 10 shows a flow which a control signal from the application program reaches a crane motor. A remote control computer for crane control becomes a client, and a protocol converter becomes a server. After a connection set between a client and a server, the client gets to send a control signal to the server.

A remote operator in a remote operating room gets a crane in operation through a graphic user interface including the functions for motor control and connection set, watching the images of a craneyard through a monitor screen and listening to the sounds of a craneyard through a speaker as if he operates a crane directly taking a bird's-eye view of the craneyard in a manual operating cabin hanging on the crane. Figure 11 shows an example of the implemented graphic user interface.

VI. CONCLUSIONS

The remote operation of 4∼5 cranes for container loading/unloading in a port container terminal by one operator will dramatically improve loading/unloading efficiency through productivity increase, cost reduction, and so on. This paper presented a remote crane control system for port container loading/unloading yard cranes.

First, this paper designed a wireless web-based video and audio transmission system to transmit the images and the sounds of a craneyard through the determination of the

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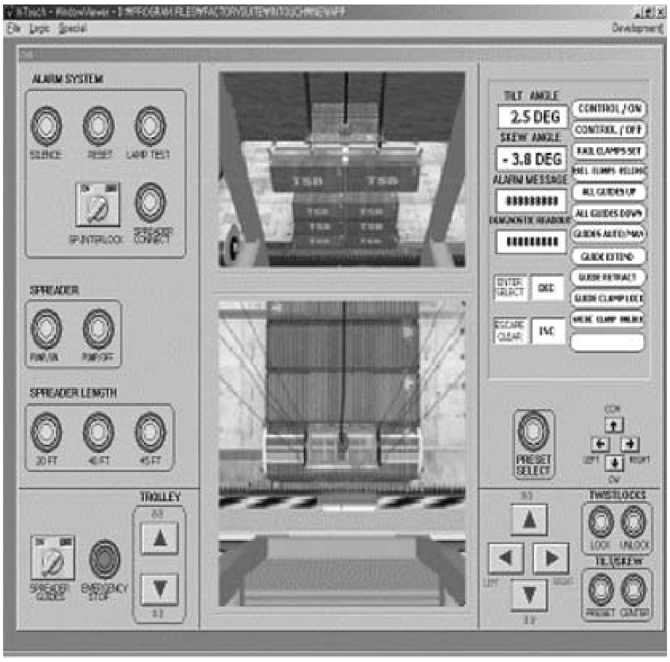

Fig. 11. A graphic user interface.

specifications and the setup of cameras and a microphone. It is composed of 3 web cameras and a microphone. The main camera among them has pan/tilt/zoom functions. Next, this paper proposed a TCP/IP-based remote crane control system on the basis of the delay performance simulations of a TCP-based system and a UDP-based system for real-time remote control. The simulation results show that there is little difference in the delay performances of a TCP-based system and a UDP-based system which are configured on a local network. In other words, real-time control is feasible in either case of the two systems. Based on the results, this paper designed a remote crane control system by using TCP/IP, because a TCP/IP-based system has the advantages of no load loss, as well as real-time control.

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