Proceedings of the IEEE
International Conference on Mechatronics & Automation
Niagara Falls, Canada • July 2005

Internet-based Tele-control System for Wheeled Mobile Robot

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Abstract— **This paper presents an Internet-based tele-control system for a wheeled mobile robot. A real-time embedded controller using Labview was designed to control the mobile robot remotely through Internet by a Web browse, for example, Internet Explorer or Netscape. A CCD camera is mounted on the mobile robot to acquire information, which is displayed inside the browser for the remote operator's operation. The IEEE802.11x(WiFi) Wireless LAN linking the robot to Internet and long run batteries are used so that the mobile robot can move without any cable connected to power supply or Internet. The designed mobile robot can be remotely operated from anywhere around the world as long as there is a set of computer with keyboard, mouse, display and connection to Internet.**

Index Terms— **Internet, Tele-operation, Wheeled Mobile Robot, Labview, Wireless.**

I. INTRODUCTION

Remote controlled robots including tele-manipulators and tele-operated mobile robots via Internet have been studied for more than one decade [1], [2], [4], [5], [6], [3]. In 1995, the first remote controller robot was proposed[1]. With the rapid spread of the use of Internet and with the increase of the data transmission speed of Internet, many research results for the control education[13], for the laboratory experiments [6], [8], [3], for the practical applications [12], [27], and for the human daily life [20] can be found in literatures.

Some of them are concentrated on the control problems, like as the supervisory control[5], [11], neural Network control[26], and the intelligent control[12] to due with the uncertain and unpredictable time-delay of the communication through Internet. Some others proposed some kind of configurations of remote robot controller to enhance the communication between the operator and the robot[8], [18], [25], [27] and to improve the image streaming for the information acquirement[22]. Cooperation control of multiple telerobots is also researched[10].

To realize a totally wireless remote controller, some kind communication methods to connect the robot or the robot controller to Internet are needed. Radio transmission was often used in the earlier researches but recently, it has been proposed to use a cell phone[18], [27] and the wireless LAN[25] together with Internet. In Tokyo Denki University, it has been realized to control a wheeled mobile robot (WMR) remotely by using the cellular network[27] from a Web browser of PC or a PDA.

In this paper, an Internet-based tele-control system for a WMR will be presented by using the IEEE802.11x(WiFi) wireless LAN, the Labview PXI real-time (RT) controller, and the Labview Professional Development system. A CCD camera is mounted on the mobile robot, which is displayed inside the WEB browser so that the operator can get the image information around the robot. The IEEE802.11x(WiFi) wireless LAN linking the robot to Internet and long run batteries are used so that the mobile robot can move without any cable connected to power supply or Internet. Using a WEB browser of Internet Explorer or Netscape, the WMR can be remotely operated by anyone around the world. What is needed for the remote operation is a computer connected to Internet.

The arrangement of the paper is as follows: Section 2 presents the configuration of the WMR designed in Tokyo Denki University; Section 3 and Section 4 describe the hardware and software of the remote controller, respectively; Section 5 gives the experimental results; and Section 6 concludes the paper.

II. WHEELED MOBILE ROBOT

The experimental wheeled mobile robot (WMR) designed in Tokyo Denki University is shown in Figure 1. Two motorized rear wheels are driven in both directions by the pulse-width-modulated current control while the front wheel is passive as shown in Figure 2.

The movement of WMR can be explained by Figure 3. The dynamic model of the WMR is described as follows:

$$v_r = r\dot{\theta}_r, \quad v_l = r\dot{\theta}_l \tag{1}$$

$$\frac{v_r - v_l}{2l} = \dot{\phi}, \quad \frac{v_r + v_l}{2} = v \tag{2}$$

$$v_r = v + l\dot{\phi}, \quad v_l = v - l\dot{\phi} \tag{3}$$

$$\begin{bmatrix} \dot{\theta}_r \\ \dot{\theta}_l \end{bmatrix} = \begin{bmatrix} \frac{1}{r} & \frac{l}{r} \\ \frac{1}{r} & \frac{-l}{r} \end{bmatrix} \begin{bmatrix} v \\ \dot{\phi} \end{bmatrix} \tag{4}$$

where r is the radius of wheels, l is half of the distance between two wheels, and the state variables v_l, v_r, ϕ, v, θ_r

This work was supported by the 21st COE Program of METX of Japan: "Human Adaptive Mechatronics" in Tokyo Denki University

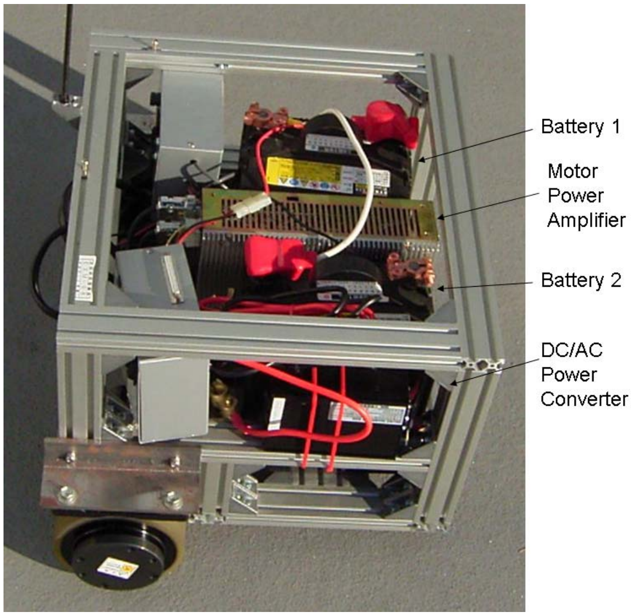

Fig. 1. Wheeled Mobile Robot

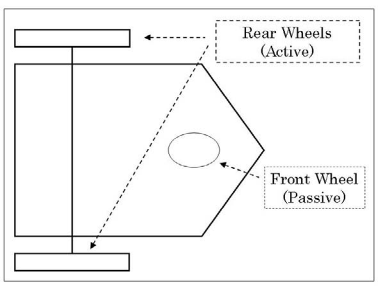

Fig. 2. WMR Wheel Configuration

and θ_l of the vehicle are defined as follows.

- v_l and v_r – Velocities of left and right wheels,
- v – Velocity of the center of gravity of the vehicle,
- θ_r and θ_l – Rotation angles of left and right wheels,

Parameters of the WMR are given in Table 1 where the weight of the Labview RT controller, the CCD camera, the wireless converter, and the battery used for the RT controller is not included.

The commands from the operator are the desired rotation speed $\dot{\phi}$ and velocity v of the WMR. From Equations (2) and (3) and a known ϕ_0, the desired velocities v_l^d and v_r^d of wheels can be calculated. There is a feedback control law implemented to let the velocities v_l, v_r of wheels track the desired velocities v_l^d and v_r^d. The block diagram of the control loop is shown in Figure 4. The block H transforms the reference signals $\dot{\phi}$ and velocity v to the desired rotation velocities v_l^d and v_r^d of wheels. i_l and i_r are currents of left and right motors, which are proportional to driving torques.

The motors and the motor power amplifier used in the WMR are the products of Waco Giken Co. Ltd.. Two rear wheels are respectively driven by two AWR010B-B408 AC servo motors with up to 0.47 $(N \cdot m)$ torque output, which are controller by a ABH2 Series Speed control style digital AC servo amplifier with 24 volt battery power supply. Two 12 volt long run batteries are used for the power supply of the motors and the amplifier. The amplifier also provides two internal wheel pulse counters for rotation position measurements, which give a resolution of 0.02 degree. The amplifier generates pulse width modulators to drive the motors and offers 10bit resolution for torque control. That is, the amplifier collects movement information from wheels (counter input) and generates PWM signals for both motors. The Motor servo control system includes a PID speed feedback controller with adjustable parameters. The motor speed responds with different parameters are shown in Figure 5.

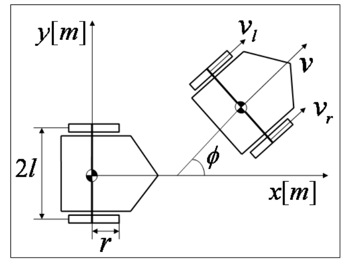

Fig. 3. Scheme of the WMR

TABLE I
PARAMETERS OF WMR (WITHOUT CONTROLLER)

r, Radius of Wheels	0.065 (m)
2l, Distance between Wheels	0.240 (m)
Height of WMR	0.140 (m)
Width of WMR	0.385 (m)
Length of WMR	0.212 (m)
Wight of WMR	47.5 (kg)

III. RT CONTROLLER WITH WIRELESS

To design an embedded RT controller for the WMR, requirements to embedded controller hardware are: enough computing capabilities to handle simultaneous image acquiring and image compress calculating and control law execution; real-time operation system with embedded web

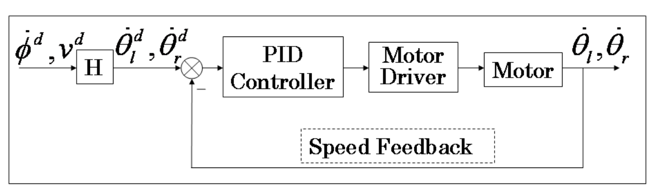

Fig. 4. Block Diagram of Tracking Control System for WMR

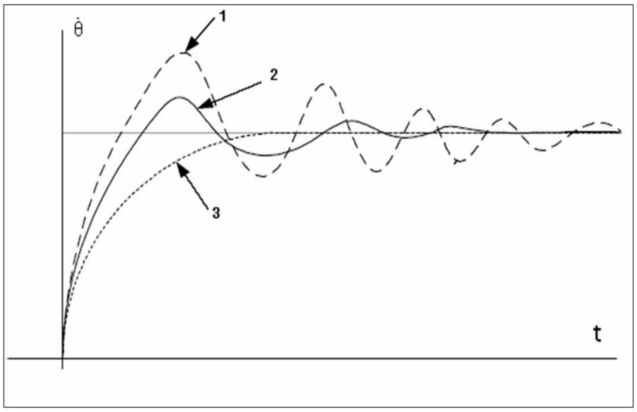

Fig. 5. Time Response of AC Motor with Power Amplifier

TABLE II
LIST OF LABVIEW HARDWARE USED FOR WMR REMOTE RT CONTROL

PXI-8186RT	High-Performance RT Series PXI Embedded Controller
PXI-1031	4-slot 3U PXI Chassis with Universal AC
PXI-1407	Single-Channel, Analog, Monochrome image acquisition board
PXI-6722	Static and Waveform Analog Output – 13-Bit, 8 Channels
PXI-6025E	200 kS/s, 12-Bit, 16-Analog-Input Multifunction DAQ

server, A/D, D/A and digit I/O interface for WMR control. The National Instruments real-time embedded PXI controller is one of the solutions as National Instruments is the leader in providing powerful and innovative controller options for PXI system, and offers remote PC control with network control over Ethernet, embedded controllers with Microsoft operating systems, and real-time embedded controllers using the National Instruments Labview Real-Time Embedded Software (called the RT Engine). Table 2 shows the hardware from Labview used in the remote control of the WMR.

The WMR with the Labview RT controller, a CCD camera, and a wireless LAN converter is shown in Figure 6.

The National Instruments PXI-8186 RT controller was chosen as the RT controller for WMR. It can make up to 42 kHz single-channel PID loop, with a mobile 2.2 GHz Intel Pentium 4 processor, 30 GB hard drive, 256 MB DDR RAM Standard/1 GB Maximum (Extended to 512 MB), 10/100BaseTX Ethernet, 2 RS-232 serial ports, and 1 GPIB port. It offers a high-performance real-time platform and is ideal for real-time test and control applications. To configure a complete RT control system based on the PXI RT Controllers, three interface boards, PXI-1407, PXI-6025E, and PXI-6722 for image Acquirement, A/D converter, D/A converter and digit I/O interface are inserted in the PXI-1031 4-slot 3U PXI Chassis.

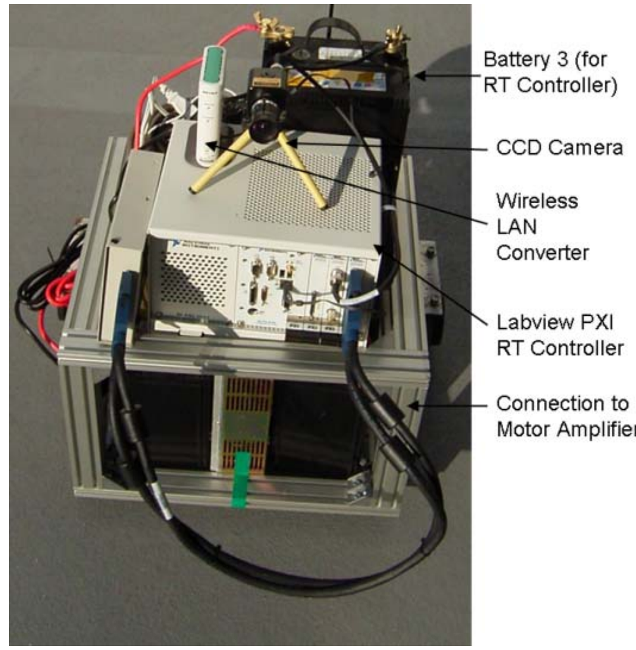

Fig. 6. WMR with Camera, RT Controller, and Wireless LAN Converter

1) The NI PXI-1407 is chosen for WMR vision. The PXI-1407 has a single high-accuracy monochrome video input, external triggering capabilities, and easy-to-use image acquisition driver software.
2) The National instruments PXI-6025E is used as the controller interface, which is lowest cost PXI data acquisition module to deliver high performance and reliable data acquisition capabilities in a wide range of applications. It has Two 12-bit analog outputs, 32 digital I/O lines, two 24-bit counters and getting up to 200 kS/s sampling and 12-bit resolution on 16 single-ended analog inputs.
3) The National Instruments PXI-6722 delivers low-cost analog outputs to meet a wide range of application requirements. It provides eight analog output channels with speeds of 182 kS/s per channel, 13-bit resolution, and digital triggering. This module also features eight digital I/O and two 24-bit counter timers.

As the Labview RT controller does not provide the wireless communication function, a wireless LAN converter (Buffalo WLI2-TX1-AG54 Air Station Ethernet Converter) is used to convert the Ethernet 10/100BaseTX of the Labview RT controller to the IEEE802.11a/b/g(WiFi) Wireless LAN as shown in Figure 7. The wireless LAN converter communicates with a wireless Route (Buffalo WHR3-AG54 Air Station BroadBand Route) in the IEEE802.11a/b/g(WiFi) format, which connects to Internet.

To completely realize a wireless RT controller, a DC/AC power converter is used to let the Labview RT controller can work with battery power supply. To avoid noise from the

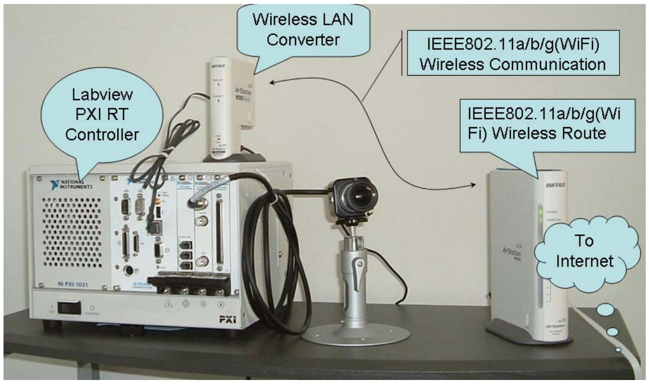

Fig. 7. Scene of Internet-based Wireless Control Experiment in Campus

motor power amplifier, a battery is dedicated for the power supply of the Labview RT controller as shown in Figure 6.

The CCD camera used for the image acquirement is WAT-231S 1/3" Interline Transfer CCD Image Sensor (GW-231S) with a 6mm F1.4(C) lens.

Figure 8 shows the configuration of the Labview remote RT controller.

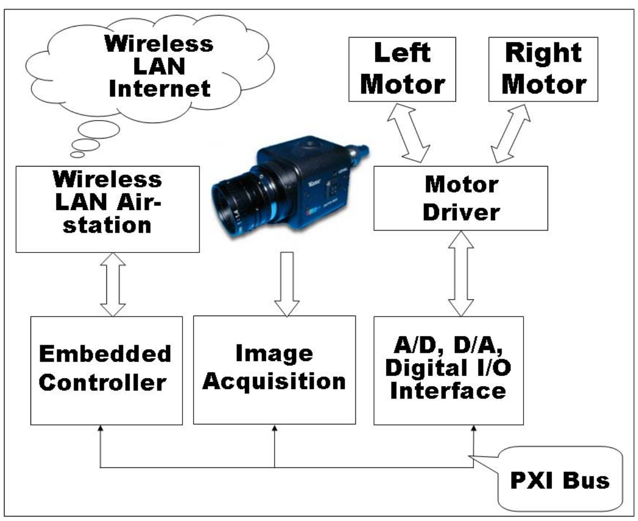

Fig. 8. Configuration of Wireless Remote Control System for WMR

IV. WMR Control Software

National Instruments provides a suite of software tools to develop, debug, and deploy real-time and embedded systems. National Instruments Labview and the NI Labview Real-Time Module provide a graphical development environment optimized for creating reliable, deterministic applications. In addition, the Labview Execution Trace Toolkit provides advanced debugging through low-level visibility into the execution timing of real-time systems. The National Instruments Labview application with the NI Labview Real-Time Module on Windows or Mac OS X, and then download the program to NI RT embedded controller via Ethernet. The embedded code executes on a real-time operating system. The most importance is that there is an embedded WEB server in the real-time module, the control front panel can being built in the format of homepage. The operator can use the web browser to control and monitor the WMR through Internet. Thus, the powerful flexible development tools of NI Labview are used to build an Internet-based remote RT controller for the WMR.

The control system is designed to support modes: Single Operator Single Robot (SOSR) and Multiple Operator Single Robot (MOSR). MOSR allows several operators to be connected to the robot (to the embedded WEB server) on the same time. Only one operator can take a task of controlling the WMR and environment monitoring, the other operators can only monitor at same time. The structure of WMR application software running on the controller computer is shown on Figure 9. The embedded WEB server provides user with the main WMR homepage.

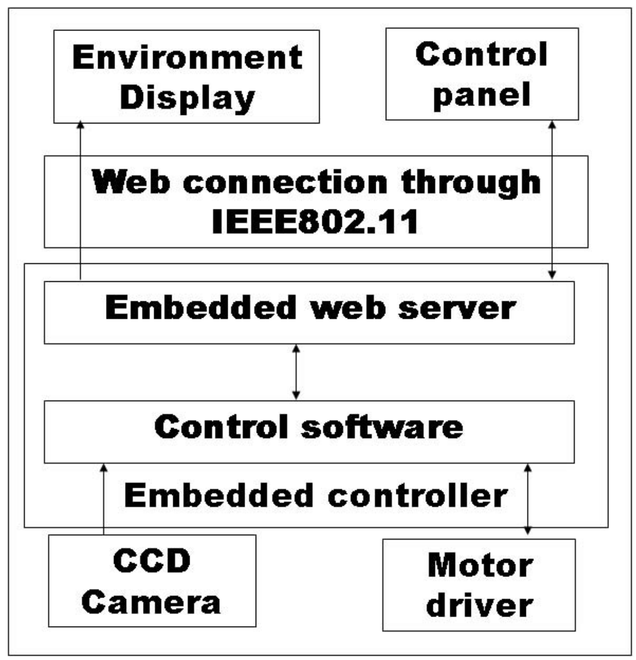

Fig. 9. Block Scheme of Wireless Remote Control System for WMR

V. Experimental Results

The WMR connects to Internet through the Ethernet 10/100BaseTX, the wireless LAN converter, and the wireless Route with 54MHz wireless transmission rate. The operator can not only use the Labview control panel directly to operate the WMR but also can use a WEB browser to control the WMR motion from any computer which connects to Internet. The problem of steering a WMR is that a mobile robot in the plane possesses three degrees of freedom but controlled by only two control inputs, i.e. with non-holonomic motion constraints. In the experimentation, the fuzzy logic control has been implemented for the position control of the WMR. Two types of commands are tested in the experiment:

1) Commands are the direction ϕ and the moving speed v of the WMR.
2) Commands are the target positions of the WMR.

All commands of both types can be modified on-line during the moving of the WMR. The acquired image (10fps) compressed by MPEG2 is transmitted to the control client panel continuously. The video compressed rate can be adjusted on the panel to keep the video transmitting smoothly. Figures 10 and 11 show the control panel of the WMR on the client by using the Labview software for the type 1 and type 2 commands, respectively.

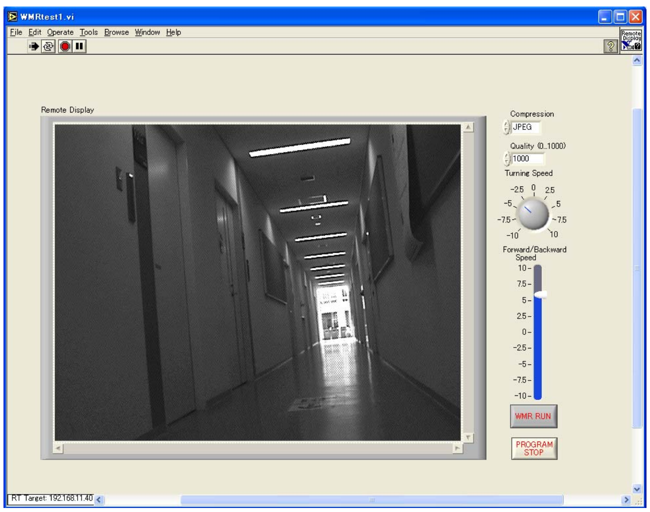

Fig. 10. Control Panel with Direction and Velocity Commands

The designed remote RT control WMR can be operated from any WEB browser, like as Internet Explorer and Netscape because a WEB server is set for the remote control in the Labview RT controller. Figures 12 and 13 show the control panel of the WMR on the client by using the Internet Explorer for the type 1 and type 2 commands, respectively.

Figure 14 is the scene of the Internet-based remote WMR control experiment in the campus of Tokyo Denki University.

VI. CONCLUSIONS

With the Labview RT controller, an Internet-based telecontrol system for a wheeled mobile robot was presented in the paper. The Labview RT controller and the Labview software development tools are used to develop the control software. The mobile robot can be remotely operated through Internet from a WEB browse. A CCD camera mounted on the WMR acquires the image information around the

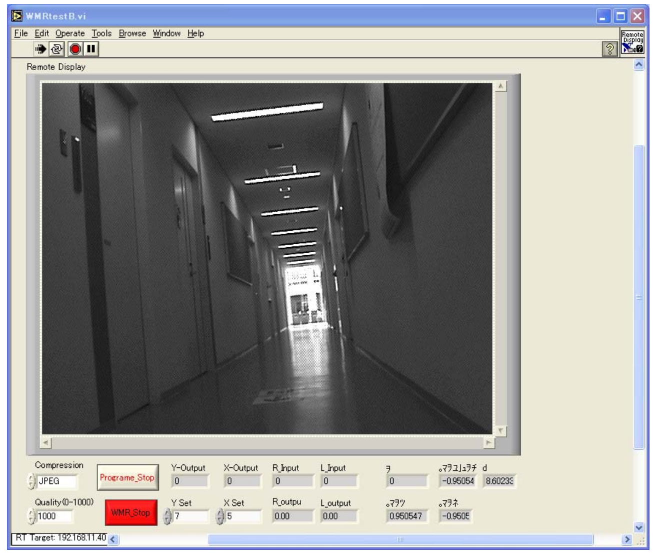

Fig. 11. Control Panel with Target Position Commands

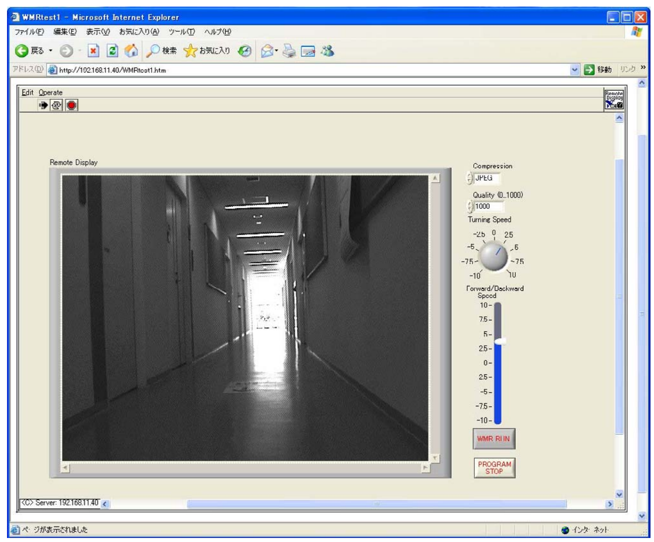

Fig. 12. Control Panel inside Internet Explorer with Direction and Velocity Commands

WMR, which is shown inside the WEB browser. The wireless converter is used to extend the Labview RT controller to the IEEE802.11x(WiFi) Wireless remote control system. Experiments were successfully done with the consideration of two types of command.

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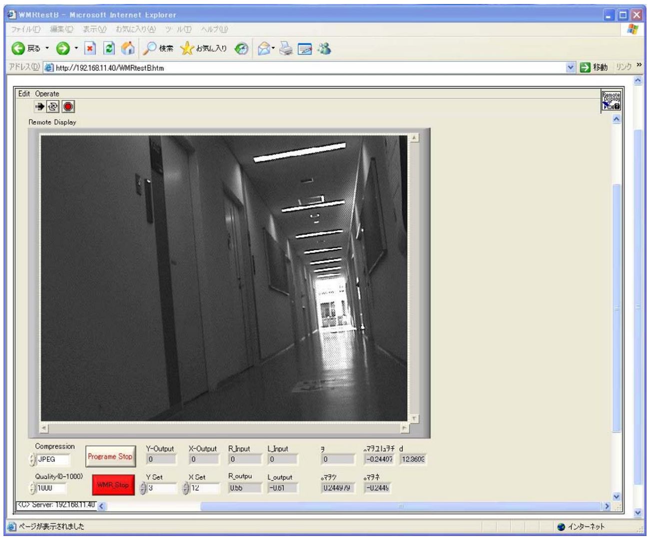
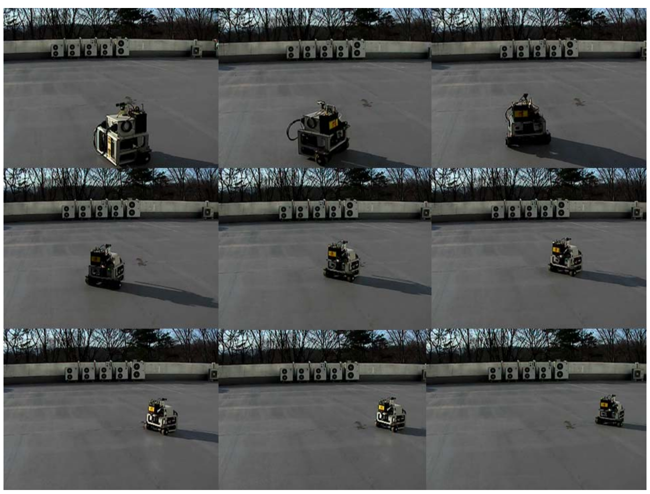


Fig. 13. Control Panel inside Internet Explorer with Target Position Commands



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