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Service Robot Operated by CDMA Networks for Security Guard at Home

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1. Introduction

Mobile robotic technology and its application in various field is currently an area of high interest. Especially, the progression of a mobile robot and communication techniques enables intelligent robots to be developed with more versatile applications. Telerobotic techniques combine robotic systems with remote control technology to enable the performance of task which is impossible or hazardous for human to perform directly. Through these ubiquitous robot controls, the paradigm of robot which performs specific tasks remotely has changed into intelligent robots to perform public and individual tasks.

The purpose of the SG-Robot(*Security Guard Robot*) project is in-line with on-going activities towards the development of autonomous robots for security guard design at home. In security industry, ubiquitous robots have provided a variety of information to the user and achieve its duty through the Web. The mentioned project aims at the development of interactive security guard robots, which are able to be operated with a mobile phone.

Last year, the interface for telepresence robot has developed over the Web or RF between robots, but these systems have the demerits of limited distance or geographical limit to be established to an internet link. In this paper, we propose the SG-Robot that can be operated and conduct surveillance of the environment around itself anytime/anywhere using wireless communication networks such as CDMA (Code Division Multiple Access) Networks.

This robot has the functionalities of detecting and avoiding obstacles, recognizing face, navigating using a map, capturing and compressing image at high speed, transferring image at real time to CDMA phone, and operating remotely by a mobile phone. The goal of these functionalities is to tele-operate robot using a mobile phone anytime/anywhere and to construct the systems that has the home network function, ubiquitous computing, and home security.

2. Related works

A variety of service robots were developed that are designed to remotely operate in the various environments over the last decade. Moreover, Web-based tele-operation interfaces for robots have been developed and have gained serious interest over the last few years.

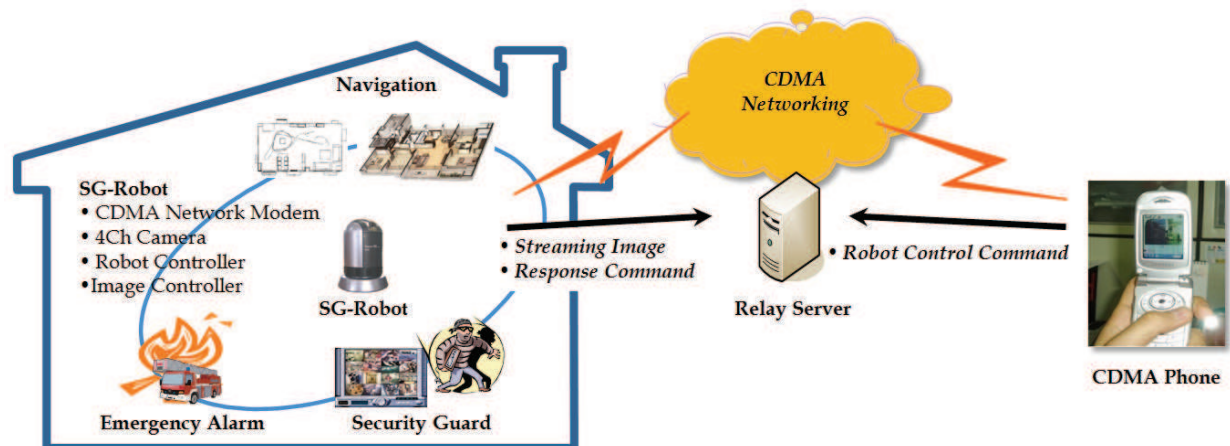


Fig. 1. Configuration of the SG-Robot using CDMA networks.

The Web interfaces for robots allow users to issue single commands which are executed immediately. Three of the earlier systems are the Mercury Project installed in 1994 (Goldberg et al., 2002), Austria's Tele-robot on the Web (Taylor & Trevelyan, 1995), which came on-line nearly at the same time, and the Tele-Garden (Goldberg et al., 1995), which replaced the Mercury robot in 1995. While the Mercury robot and the Tele-Garden allow Web user to perform different types of digging tasks, such as excavation of artifacts as well as watering and seeding flowers, the tele-robot on the Web gives Web users the opportunity to build complex structures from toy blocks. These systems also suffice to provide still images from a camera mounted on the robot arm after a requested movement task has been completed.

Mobile robots which can be controlled over the Web provide exclusive remote control to a single person or provide queues to schedules user requests. KhepOnTheWeb (Saucy & Mondada, 1998) is a typical representative of mobile robots with a Web interface. Users can give elementary movement actions to the robots and observe them using several Web-cameras. Xavier (Simmons et al., 1997) was probably the first mobile robot which operates in a populated office building controlled through the Web. Xavier can be advised by Web users to move to an office and to tell a knock-knock joke after arrival. The mobile robotic platforms Rhino (Buhmann et al., 1995 ; Burgard et al., 1998) and Minerva (Thrun et al., 1999 ; Thrun et al., 2000) could also be operated over the Web for museum tour guide. Their interfaces relied on client-pull and server-push techniques to provide visual feedback of the robot's movements. Cyberguard (Massios & Voorbraak, 1999) is a mobile security robot marketed by Cybermotion. The aim of Cyberguard is to patrol indoor building areas for intruders, fires and chemical threats. The robot would collect the images with inexpensive camera that could be sent over very low speed radio links. The CAPM (Suthakorn et al., 2001) project of the Johns Hopkins University have built a robot working for a library. The robot system is designed and implemented in a friendly library environment. But, it needs another robot system for browsing the selected book.

The SG-Robot system uses video streams to convey observed information to the user. Additionally, Multi SG-Robots can provide their information to single user or multiple users. Therefore, the users can control, with selecting the SG-Robots in ubiquitous computing environment. The SG-Robot was able to conduct the surveillance task and communicate between the SG-Robot and users over the CDMA2000-1x communication network efficiently.

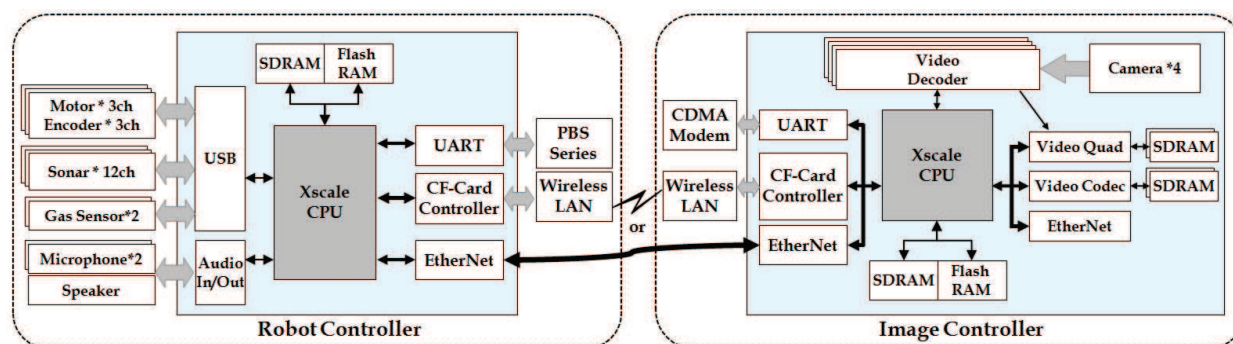


Fig. 2. Architecture of SG-Robot.

3. System configuration

The SG-Robot project, a research and development activity entitled “Tele-operated robot using CDMA networks”, introduces a new communication interface approach to telepresence and security surveillance of robot at home or at outdoor. The user is offered the capability to remotely issue commands to navigate specific place. In order to execute such commands, the SG-Robot moves autonomously or manually in the home site, reaching thus the desired navigation targets. At the same time, imaged scenes by cameras are transmitted to the user as a video stream, enabling tele-observation of the real home site and the public institution. Fig. 1 represents the concept of communication link of the developed SG-Robot. The SG-Robot entirely consists of the image controller and the robot controller. This structure is easy to establish the image controller for other robot systems. Any robot controller is able to simply communicate with this image controller by specific data protocol.

3.1 Architecture of SG-Robot

SG-Robot is characterized by differential drive, turret drive for turning body without driving the wheels, communication interface and various sensors. The sensory equipment includes auditory, vision, ultrasonic, and IR scanner sensors, which allow the robot to behave autonomously and to observe environments around it.

Fig. 2 represents the architecture of the developed SG-Robot. The controller of SG-Robot entirely consists of the image controller and the robot controller. Main CPU of each controller is PXA255, ARM architecture, which has the characteristics suitable for the embedded robot system, such as low power and high performance. Each controller exchanges command data through the wireless adhoc LAN. The reason of that is to easily establish the image controller for other robot systems.

The robot controller is divided into three branches by function: communication, sensory, and drive function. And the image controller is divided into two parts by function: internal/external communication and image processing function. The image controller directly communicates with mobile phone through CDMA modem placed in robot system. Received/transmitted packets are streaming images and robot control commands. Input images through a camera placed in front of the SG-Robot are compressed with the QCIF size and transmitted to mobile phone by CDMA modem using CDMA2000-1x network. Image controller allows data to be sent to mobile phone, after CDMA modem connects to the relay server.

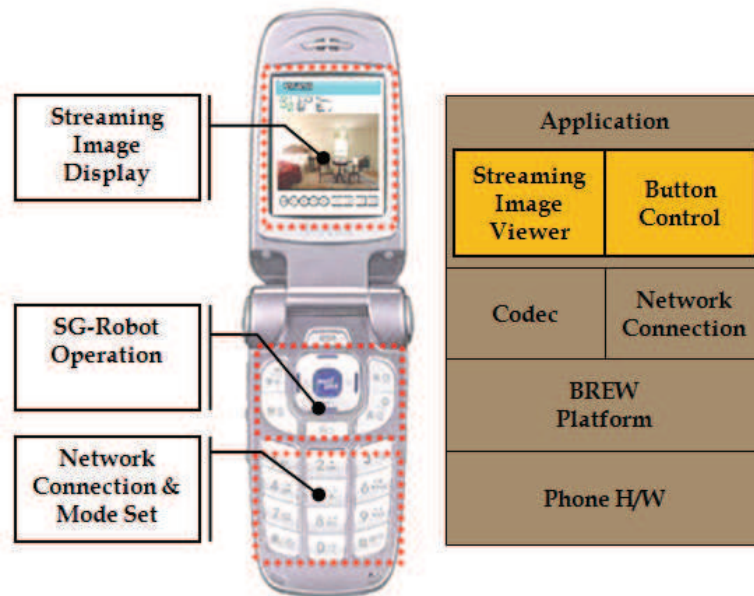


Fig. 3. Mobile phone for controlling SG-Robot.

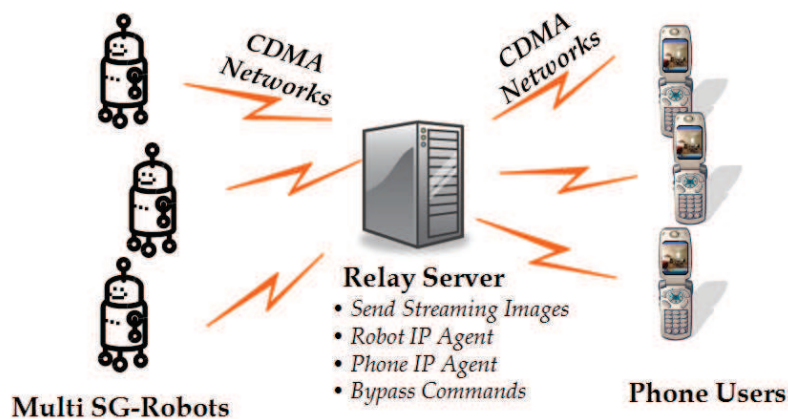


Fig. 4. Relay server for connection management.

3.2 CDMA mobile phone for robot control

For decades the telephone has always been within easy reach to provide us with real-time voice communication (Fischer, 1992). More recently, CDMA communication has proved itself as a remarkable communication network, allowing us to exchange message and images with others and to download VOD from multimedia server. Therefore, a user can be offered various services and contents anytime/anywhere.

Fig. 3 shows the mobile phone for controlling SG-Robot. CDMA mobile phone has two functions for controlling SG-Robot. First, it can display streaming images. When a camera is used for SG-Robot, motion picture data need to be transferred to mobile phone through the CDMA networks. CDMA2000-1x network has very low bit rate of the bandwidth.

Due to the mismatch between the data rates of the CDMA networks and the motion picture, data compression should be performed before the transmission from the mobile phone. Image controller of the SG-Robot provides MPEG-4 and JPEG compression of the motion

picture. While MPEG-4 algorithms require large intermediate memory space, the JPEG algorithm does not need to store an entire frame for the compression. As mobile phone has low capacity memory, the baseline JPEG compressing methods are used in image coding over the CDMA networks. Next, mobile phone allows user to control SG-Robot. SG-Robot is operated by pushing the buttons. Therefore, a user can monitor the environment around SG-Robot and control to navigate it through the LCD screen of mobile phone.

3.3 Relay server for connection management

The CDMA modem in SG-Robot uses PPP Protocol based on Mobile IP for wireless network access. For continuing connection between SG-Robot and mobile phone, relay server need to be established. Multi SG-Robots and users can be also constructed in this configuration. The relay server allows multiple users to connect with SG-Robot in accordance with their permission degree. In the whole SG-Robot configuration, a relay strategy is designed to increase the system efficiency and to satisfy the isochronous requirements of showing motion pictures and providing command control of SG-Robot to multiple users. Fig. 4 shows the relay server for connection management. Table 1- 4 also represent protocols between the SG-Robot and relay server and between the relay server and mobile phone.

| Byte1 | Byte 2 | Byte 3 |
|-------|--------------|--------------|
| 0x33 | COMMAND_TYPE | COMMAND_DATA |

Table 1. Packet for data transmission to robot (to relay server)

| COMMAND_TYPE | COMMAND_DATA | Description |
|--------------|--------------|-------------------------------------|
| 0x00 | 0x01 | ACK for phone connection |
| | 0x03 | Close the connection |
| 0x10 | 0x08 | Forward go |
| | 0x02 | Backward go |
| | 0x04 | Turn left |
| | 0x06 | Turn right |
| | 0x05 | Stop |
| 0x20 | 0x01 | Initial mode |
| | 0x02 | Manual mode |
| | 0x03 | Free navigation mode |
| 0x30 | 0x32 | Request to start image transmission |
| | 0x33 | Request to stop image transmission |
| 0x40 | 0x01 | Forced termination |

Table 2. Command from mobile phone to robot (or relay server)

| Byte1 | Byte 2 | Byte 3 | Byte 4 |
|-------|---------|--------|--------|
| 0x44 | COMMAND | DATA 1 | DATA 2 |

Table 3. Packet for data transmission to mobile phone (or delay server)

| COMMAND | DATA 1 | DATA 2 | Description |
|---------|--------------------|--------------------|--|
| 0x50 | High byte of image | High byte of image | If COMMAND equals 0x50, transmit key frame (I-picture) |
| 0x51 | High byte of Image | High byte of image | If COMMAND equals 0x51, transmit P-picture |
| 0x00 | 0x01 | 0x01 | ACK for robot connection |
| | 0x03 | 0x03 | Close the connection |
| 0x40 | 0x01 | 0x01 | State that SG-Robot is performing the command after receiving it |
| | | 0x02 | State that SG-Robot can't perform the command |
| | 0x02 | 0x01 | State that SG-Robot don't connect to the Relay server |

Table 4. Response from robot to mobile phone (or relay server)

4. Implementation of SG-robot

The objectives of SG-Robot are to guard home or public places, to inform user of the state of emergency, and to be controlled for specific mission. To accomplish these objectives, robot controller uses the RTAI (Real Time Application Interface) to provide real-time performance with embedded Linux. It provides a high-performance real-time kernel which supports both deadline and highest-priority-first scheduling.

4.1 Framework of SG-robot

Sensor-based robotic systems contain both general and special purpose hardware, and thus the development of applications tends to be a very tedious and time consuming task. In the SG-Robot system, obstacle avoiding behavior, various robot motion, efficient user interface, communication interface, and system fail check are easily implemented by using multitasking function, intertask communication mechanism, and real-time runtime libraries of RTAI. Fig. 5 and Fig. 6 represent the implemented framework in this system.

The framework for the SG-Robot controller consists of 5 layers, such as hardware layer, firmware layer, task layer, thread layer, and GUI layer. Especially, in the thread layer and task layer, data share uses the shared memory and data transfer uses the FIFO. Each thread communicates with each other using the message event. Data interface of this robot framework was designed with similarly a nervous system and memory system of human. As SG-Robot simultaneously processes the command of user and the navigation procedure, it can guarantee a high efficiency and stability the designed system. PBS series and sonar array is updated each 200ms, and odometry is only updated each 100ms. After gained information is stored in shared memory, free navigation thread and find obstacle thread reprocess the information to avoid obstacle and to navigate to specific goal.

Multi threads in framework for image controller also have the soft real-time performance. Captured image information is updated each 0.1ms and stored in Queue. At the same time, face recognition thread conducts the process to find who was known through comparing with sample face in DB, and CDMA communication thread send the captured images in queue to mobile phone.

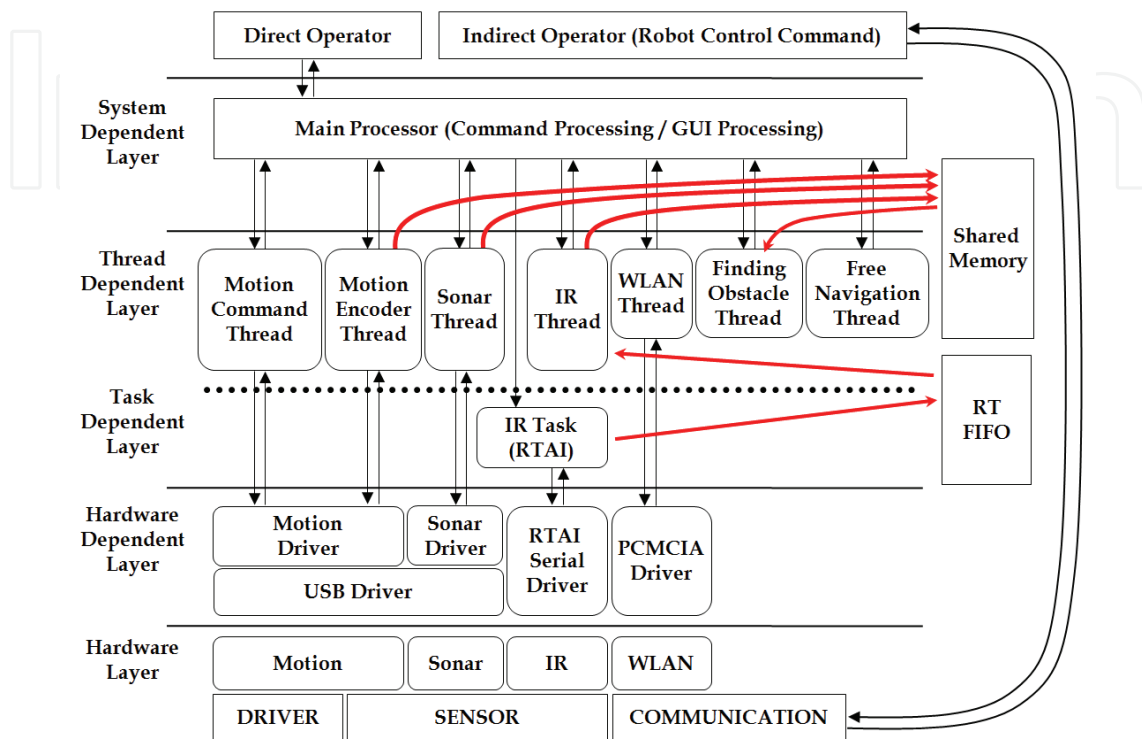


Fig. 5. Framework for robot controller.

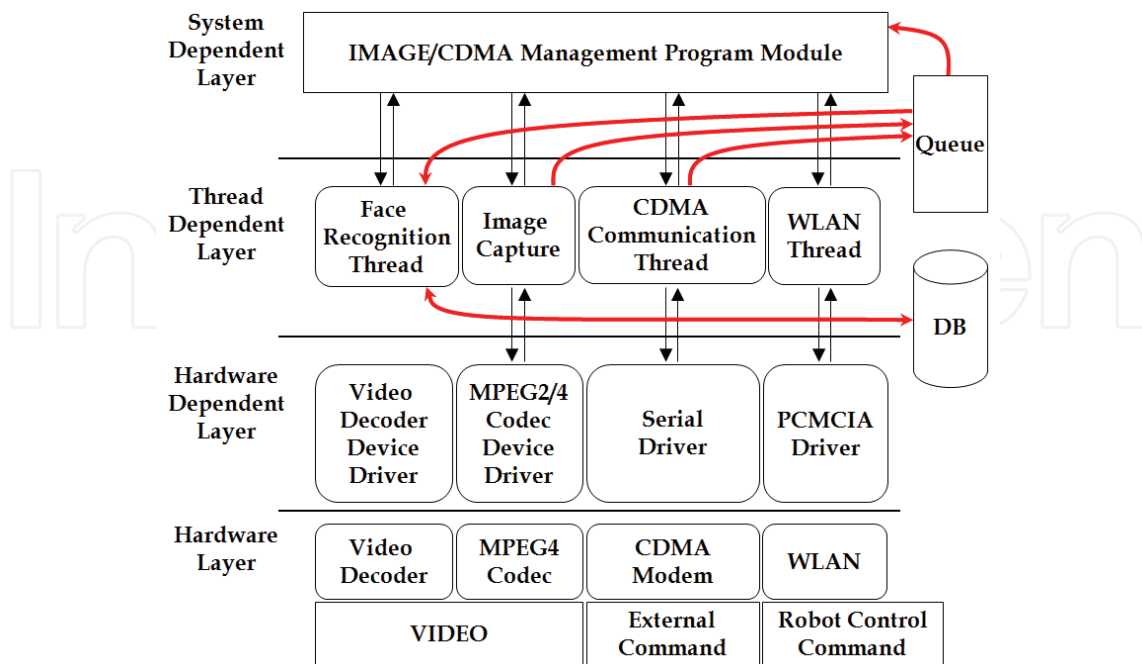


Fig. 6. Framework for image controller.

4.2 Locomotion of SG-robot

SG-Robot has the differential drive and the turret drive. As depicted in Fig. 7, differential drive is simple drive mechanism for a ground-contact mobile robot. Under differential drive, for each of the two drive wheels to exhibit rolling motion, the robot must rotate about a point that lines on the command axis of the two drive wheels. By varying the relative velocity of the two wheels, the point of this rotation can be varied, and different trajectories chosen.

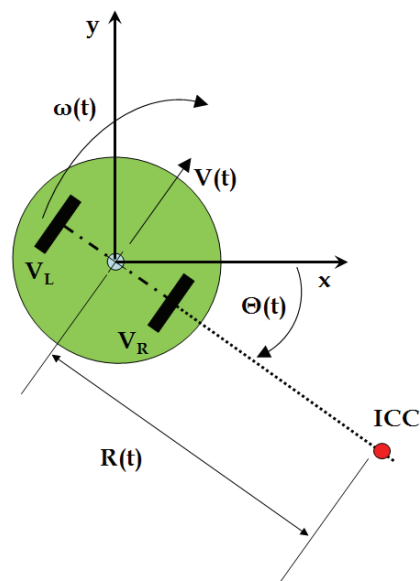


Fig. 7. Kinematics of SG-Robot using differential drives.

Differential drive has a nonholonomic constraint and is very difficult to solve in general. If it is assumed that $v_l(t) = v_l$, $v_r(t) = v_r$, and $v_r = v_l$, then equation (1) yields.

$$x(t) = \frac{l}{2} \frac{v_r + v_l}{v_r - v_l} \sin\left[\frac{t}{l}(v_r - v_l)\right]$$

$$y(t) = -\frac{l}{2} \frac{v_r + v_l}{v_r - v_l} \cos\left[\frac{t}{l}(v_r - v_l)\right] + \frac{l}{2} \frac{v_r + v_l}{v_r - v_l} \quad (1)$$

$$\theta(t) = \frac{t}{l}(v_r - v_l)$$

where l is the distance along the axle between the centers of the two wheels, the left wheel moves with velocity v_l along the ground and the right with velocity v_r , and $(x, y, \theta)_{t=0} = (0, 0, 0)$. Given a goal time t and goal position (x, y) . SG-Robot considers two special cases of the motion of the differential drive vehicle. If $v_l = v_r = v$, then the robot's motion simplifies as (2).

$$\begin{pmatrix} x' \\ y' \\ \theta' \end{pmatrix} = \begin{pmatrix} x + v \cos(\theta) \delta t \\ y + v \sin(\theta) \delta t \\ \theta \end{pmatrix} \quad (2)$$



Fig. 8. Operation of SG-Robot using mobile phone.

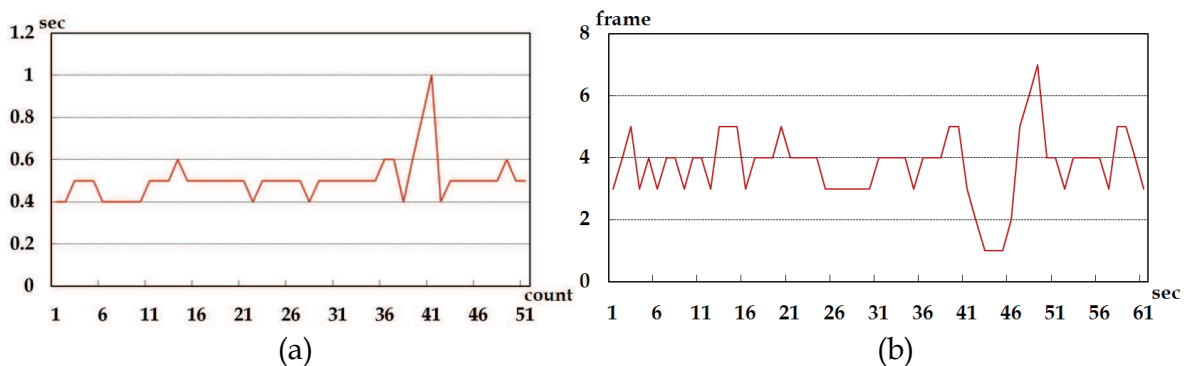


Fig. 9. Response time of robot control command and transmission rate of streaming image to the mobile phone.

And if SG-Robot choose $-v_l = v_r = v$, then equation (3) is simplified as follow.

$$\begin{pmatrix} x' \\ y' \\ \theta' \end{pmatrix} = \begin{pmatrix} x \\ y \\ \theta + \frac{2v\delta t}{l} \end{pmatrix} \quad (3)$$

To drive SG-Robot to some goal pose (x, y, θ) , the robot can be spun in place until it is aimed at (x, y) , then driven forward until it is at (x, y) , and then spun in place until the required goal orientation θ is met.

5. Experimental result

To evaluate the designed system, we measure the transmission rate of motion pictures and command data in the home environment. Fig. 8 shows the designed SR-Robot and CDMA mobile phone. Fig. 9 represents the response time of the robot after being issued the command by mobile phone and the transmission rate of streaming images from a camera in the robot to mobile phone.

In general, the average response time was 0.3~0.4ms. But, the response time takes about 1sec from time to time, due to the irregular wave interference or the spatial characteristics. The

image transmission rate is 4~5frame/sec. Sometimes, it was also delayed about 2~3frames by the same reason. Fig. 10 shows the scene which streaming images are transferred from camera in front of SG-Robot to mobile phone, when user operates the SG-Robot by mobile phone. Through the LCD screen displaying the images, user could recognize the scene and operate the robot to other place. When SG-Robot meet the obstacles while user issues the command of "Forward go", it don't go any more and send the message, "Can't accomplish the command because of obstacles", to the mobile phone.



Fig. 10. Images transmitted to mobile robot as SG-Robot moves.

Fig. 11 represents the navigated path when the user at outdoors operates the SG-Robot located in modeling house in an indoor environment. We obtained a rate of 95% of successive control during conducted experiments. The successive rate is calculated using an experimental time and the time that is subtracted by delay time due to irregular wave interference. In this experiment, the operator could control the SG-Robot to navigate to a specific place through the LCD screen of mobile phone.

6. Conclusion

We have created a surveillance robot that allows SG-Robot to be operated by mobile phone through the CDMA networks. The experiments have shown that CDMA networks communication link can be used for exploration, navigation and real-time tele-operation task.

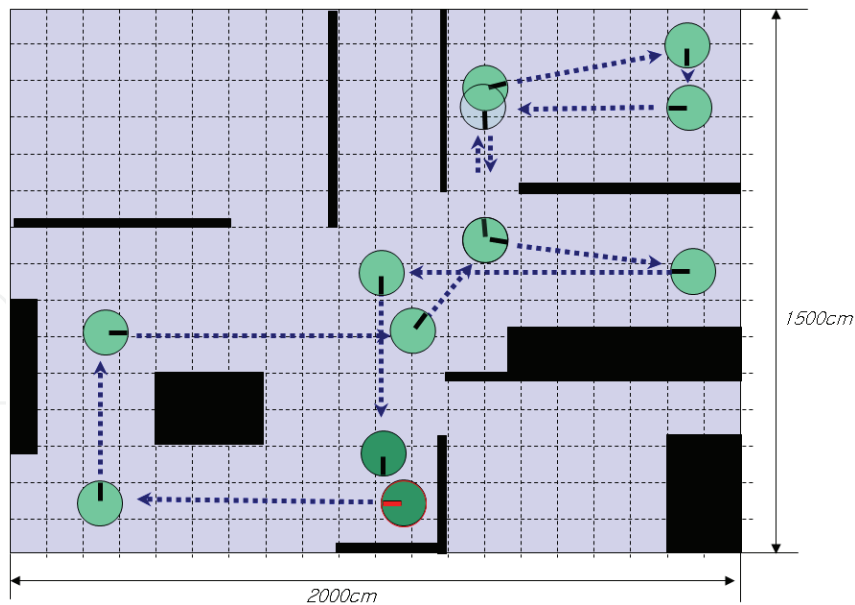


Fig. 11. SG-Robot navigation operated by the mobile phone of the user.

In most tele-robotic applications, communication line delays are limiting factor. Our experiments have shown that even in extreme delay situations streaming images over CDMA networks can successfully be used for robot control. That was possible because SG-Robot also has the decision to choose whether a “move and wait” strategy has to be adopted, or whether it is safe to move continuously in spite of line delays. Important another point addressed in this system lies in the fact that it can be used and monitored for multiple users and it is possible to operate multiple robots by one user. For these functions, relay server is constructed. The relay server authorizes multiple users to connect with SG-Robot in accordance with their permission degree, and enables multi SG-Robots to transmit the environment information to users in accordance with their registered level.

The outcomes of this study can be utilized for intelligent service robot and URC (Ubiquitous Robotic Companion) industries and will be considered to be a valuable technology to apply robot technology to mobile communication.

An ongoing and further area of investigation is to add the visual localization and map building to the SG-Robot. Using simultaneously localization and map building techniques with a single camera or camera set, the operator will be able to control the robot over visual map and robot will be able to possess powerful visual intelligence.

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The aim of this book is to provide new ideas, original results and practical experiences regarding service robotics. This book provides only a small example of this research activity, but it covers a great deal of what has been done in the field recently. Furthermore, it works as a valuable resource for researchers interested in this field.

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