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Rescue robot systems -From snake-like robots to human interface-

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Abstract: Intelligent rescue systems with high information and robot technology have been expected to mitigate disaster damages, especially in Japan after the 1995 Hanshin Awaji Earthquake and in USA after the September 11, 2001 terrorist attack on New York City. Public safety and security problems are not limited to Japan and the United States, since every country has experienced man-made and natural disasters in the past. This paper introduces a developed grouped rescue robot systems with high-functionality multiple mobile robots and robust/scalable information infrastructure for searching tasks in disaster scenario.

Keywords: search and rescue, safety and security, RT and ICT,

I. Introduction

Intelligent rescue systems with information and communications technologies (ICT) and robotics technology (RT) have been proposed to mitigate disaster damages, especially in Japan after the 1995 Hanshin-Awaji Earthquake. In particular, it has been stressed the importance of developing robots for search and rescue tasks, which can actually work in a real disaster site. In USA the September 11, 2001 terrorist attack on New York City and Washington, DC, the hijacked plane crash in Pennsylvania, and the Anthrax attack that immediately followed instantly changed people attitude about safety and security in their personal lives. Public safety and security problems are not limited to Japan and the United States, since every country has experienced man-made and natural disasters in the past. Solutions will depend upon new, unconventional approaches to search and rescue. Robotics, information and communications technologies, devices and system integration can play an important role in providing technology that can contribute to Safety, Security and Rescue activities.

II. DDT project of rescue robot systems

Japan, which suffered Hanshin Awaji Earthquake, has drawn on the lessons of that experience to alleviate the damage caused by disasters in major urban areas. It is well known that rescue in 3 hours is desirable, and that the survival rate becomes drastically low after 72 hours. We should search and rescue victims from debris within this 'golden 72 hours' [1].

A lot of rescue robots have been developed in Japan. From 2002 to 2007 "Special Project for Earthquake Disaster Mitigation in Urban Areas" (DDT Project) launched by Ministry of Education, Culture, Sports, Science and Technology, Japan [2]. In DDT project we have 4 mission units (MU) to accomplish our objective as follows with considering disaster scenario (Fig. 1).

Fig. 1 Overall concept in disaster scenario

1. Information Infrastructure System Mission Unit

Main systems in this MU are RF ID tags and Micro servers. Tasks of this group is global information collection (> 10 km) using ad hoc networks, micro servers, RF ID tags, home facilities, etc. and development of communication protocols, data structures, etc. for data integration.

2. Aerial Robot System Mission Unit

Main systems in this MU are helicopters, airships, balloons. Tasks of this group are global surveillance (< some km) for information collection at the initial state of incidents and local surveillance from sky (< 200 m) for victim search and support of ground vehicles as the second deployment. Fig. 2 and 3 show an autonomous helicopter (Prof. H. Nakanishi, Kyoto Univ.) and a balloon for information gathering (Prof. M. Onosato, Hokkaido Univ.), respectively.

Fig. 2 Autonomous helicopter (Prof. H. Nakanishi)

Fig. 3 Info-balloon (Prof. M. Onosato)

3. In-Rubble Robot System Mission Unit

Main systems in this MU are serpentine robots, crawler-type robots, and sensor balls. Tasks of this group are local information collection in the rubble pile (< 30 m) for victim search and environmental check.
Serpentine snake-like robots KOHGA (Prof. F. Matsuno, Kyoto Univ.) and SORYU (Prof. S. Hirose, Tokyo Institute of Technology) are shown in Fig. 4 and Fig. 5, respectively.

Fig. 4 KOHGA (Prof. F. Matsuno)

Fig. 5 SORYU (Prof. S. Hirose)

4. On-Rubble Robot System Mission Unit

Main robots in this MU are crawler type, wheeled, and jumping robots. Tasks of this group are local surveillance on the rubble pile (< 50 m) for victim search and environmental check. Fig. 6, 7 and 8 show a wheel type robot FUMA (Prof. F. Matsuno, Kyoto Univ.), a two-tracks robot with an arm HELIOS (Prof. S. Hirose, Tokyo Institute of Technology) and a four-tracks robot with an arm KOHGA3 (Prof. F. Matsuno, Kyoto Univ.), respectively.

Fig. 6 FUMA (Prof. F. Matsuno)

Fig. 7 HELIOS (Prof. S. Hirose)

Fig. 8 KOHGA 3 (Prof. F. Matsuno)

These rescue robot systems have some sensor, for example a camera and a laser range finder (LRF). An operator controls a robot using a user interface based on the transmitted information from the remote site. Their abilities are restricted by communication performance in a practical environment.

III. Development and Integration of New Grouped Rescue Robots System

When size of a disaster area is very large and fast information gathering is required, robotic system has to use multiple robots to acquire information. Another requirement is online data processing to use collected information to subsequent rescuer operation. To address these issues, the project [3] in our group founded by NEDO from 2006 to 2008 focuses on the following:

I. A high-functionality multiple mobile robot system.

II. A robust and scalable information infrastructure, which includes network and GIS data system.

III. An efficient user interface and control system to operate robots and to manage lots of information.

To design above systems, we also focused following issues:

ADAPTABILITY: There are no "same-situation and same-environments" in a disaster target area, and a situation will change fast in the disaster. The system has to have adaptability by a configuration and capabilities to adapt to changing environments.

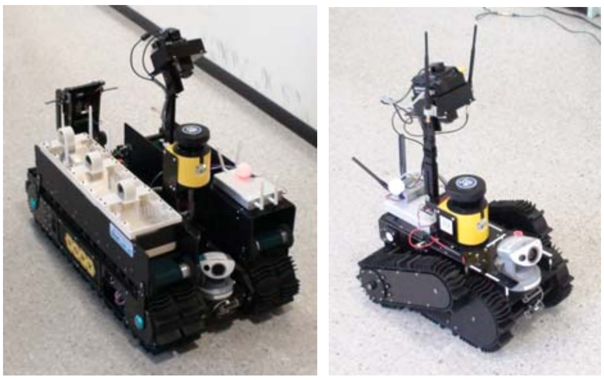
SCALABILITY: To deploy robots, the communication infrastructure is also extensible physically. Note: only robots can address to the disaster area, robots have to have network building function by itself.

USABILITY: The human resource is one of the highest cost components of the system. The system has to have efficient/usable interface to operate. For example, simultaneous multiple robots operation support, semi-auto operation support and information presentation interface that only shows necessary information to operators, for each situation.

According to the above mentioned sub-themes and issues, we newly developed four elements: mobile robot platforms, ad-hoc wireless network called Robohoc network, user interface to control multiple robots and GIS data server

1. Mobile robot platforms

We have developed two types of mobile robot platforms which achieve 1.0[m/sec] driving on a flat plane, and have high mobility and high ability. One is a pioneer type robot as shown in Fig. 9 (a), and the other is a surveyor type robot as shown in Fig. 9 (b). The function and role of each type are below.



(a) Pioneer robot (b) Surveyor robot

Fig. 9 Developed Robot system (Prof. F. Matsuno)

At first of a given mission, pioneer type robots expand the wireless network area by deploying wireless network ad-hoc nodes. The robot can eliminate lightweight obstacles and open doors by using a mounted manipulator. To construct a wireless infrastructure, the pioneer type robot is mainly teleoperated from a remote safe place by an operator.

Next of the mission, a number of surveyor type robots semi-autonomously search a target building under the information infrastructure that was already constructed by the pioneer type robots, and gather information of damaged building and victims.

Each robot has a network camera, a fish-eye camera, a LRF, an attitude sensor, IR sensors, rotary encoders for motors which drive tracks, and potentiometer to measure angles of multifunctional and flipper arms. To control developed mobile robot platforms, following methods are implemented.

M1. Full manual control method with virtual bumper: A robot is controlled by sending commands related to translational velocity and rotational velocity directly with joystick device. Function of the virtual bumper stops the movement of the controlled robot when an obstacle is detected within the pre-defined area around the robot by LRF and IR sensors.

M2. Line trajectory trace method: An operator points a sub-goal location of the robot on an environment map generated by a LRF, then the robot is controlled to follow the line created by connecting the current and sub-goal points with a certain velocity until the robot reaches the goal point.

M3. Right/Left hand wall following full-autonomous control method: In this mode, a robot autonomously cruises in the building along right/left wall with keeping a certain distance from the wall without operator's commands.

M4 Direction oriented semi-autonomous control method: In this mode, an operator commands desired moving direction of a robot. The robot runs to the direction according to compass data with avoiding obstacles.

2. GUI for controlling multiple robots

Developed user interface is shown in Fig. 10. GUI enables to control multiple robots by one operator. For selecting a control method of a robot, the operator clicks a control button at the upper side of GUI (1 in Fig. 10). To select destination of command for a robot, an operator selects a target robot in a panel located at the bottom of the GUI. Outside of the selected robot panel is colored. For each robot, the selected control method is indicated in the robot panel (2 in Fig. 10). The robot panel displays 3D CG model of each robot and shows arm position, velocity and attitude of each robot, laser range finder data around robot and on/off status of the virtual bumper (3 in Fig. 10). The robot panel also displays the state of network communication for the robot (4 in Fig. 10). The robots have two or three cameras, and images from them are displayed at the upper left side of GUI. To select which camera image to be displayed, a camera selecting button is located at the right side of the camera image (5 in Fig. 10). Note that an operator can select only one camera, in order not to affect a heavy load to Robohoc network. Quality of camera image (frame rate and compressing rate) also can be selected by a slider bar (6 in Fig. 10). Moreover, the operator can choose a sending method of image data. In first method a raw jpeg image is send directly. In the other method a jpeg image is divided into small reconfigurable images and divided images are sent.

3. Communication system

To operate multiple robots simultaneously in the

Fig. 10 GUI (Prof. F. Matsuno)

disaster area, a sort of full-wireless network system is required. Moreover, it should be robust to withstand environment changes and dynamic extension by robots themselves. We proposed a network system which has the characteristics in our previous paper [4], and called it as "Robohoc network".

There are lots of previous studies about the networking for the robotic system and/or the sensor network system. However, the most important issue for the network for the disaster situation is the adaptability to the environment rather than the performance (throughput, number of nodes, etc.). This adaptability also relates to the network bandwidth management because both of the network throughput and latency are variable parameters. The system has to change the total usage of its network to follow such changes.

Followings are the requirements for the communication system from the system design's point of view

R1. Use wireless communication technology to communicate with multiple moving robots simultaneously and to collect information from lots of sensors which are deployed by robots in the target area.

R2. To communicate with moving robots and static sensors.

R3. To supply enough bandwidth to sent a video stream from a robot.

R4. To show the up-to-date status of the network itself to other system.

R5. To be physically extensible by robots alone without human help.

We developed not only the software and protocols for Robohoc network, but also the prototype of Robohoc nodes to construct the wireless ad-hoc network for our field trials (Fig. 11).

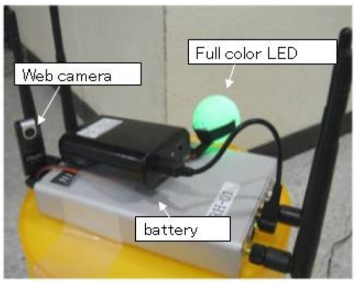


Fig. 11 Robohoc node (Dr. Y. Uo)

It is necessary to communicate information such as commands to robots and sensor data to an operator including video images stably with considering not to break down all network performance. Constructed Robohoc network is a kind of wireless ad-hoc network, so it has a limitation of throughput. To manage the bandwidth of Robohoc network, communication data is classified into four categories according to two attributes, data size and responsiveness, as shown in Fig. 12. This bandwidth management mechanism is based on time sharing of communication resource, namely not all

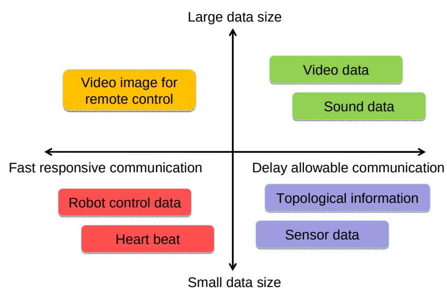


Fig. 12 Categories of communication data (Dr. Y. Uo)

data have to be sent in real time and there are delayable data.

4. GIS server

We categorized roles of GIS as two spheres, spatial temporal database management sphere and operation support sphere. In spatial temporal database management sphere GIS has to deal with following four types information;

I1. Base map information: In most of public building or underground space base map data exists. In this mission we assume that rescue team can get base map data before rescue activity. If different accuracy sets of data are provide, the highest accuracy data have to be selected.

I2. Information collected by grouped rescue robots: Trajectories of mobile robots to check their behavior, time series sensor information for robots themselves, environmental information to get from various sensors mounted on the mobile robots to check damage condition of the target space, and locations of access points for Robohoc network placed by the pioneer robots to manage Robohoc network condition must be stored.

I4. Robohoc network condition: Radio field intensity, correspondence of access points, and transmission path must be stored.

I5. Resources of mobile robots and access points for Robohoc network: Remaining amount of battery of each robot and access point, HDD of each robot, equipped access points of each pioneer type robot must be stored.

In operation support sphere we have two functions as follows;

F1. Function for making support information for robot operators: Calibration of initial point of robots, input of changed objects from base map information, and alert of no-operation areas caused by ground/communication condition are assumed.

F2. Function for operation support for information administrators: Access point location planning, removing location errors from environment map information generated by LRF data, input no-operation and search areas are assumed.

In order to realize the requirements for GIS it is effective to use a temporal GIS as a database management system. In this case we select our original temporal GIS "DiMSIS" which have been developed since immediately after Great Hanshin-Awaji Earthquake as a common spatial temporal database management system for disaster risk management [5]. Fig. 13 shows a screenshot of viewer of GIS.

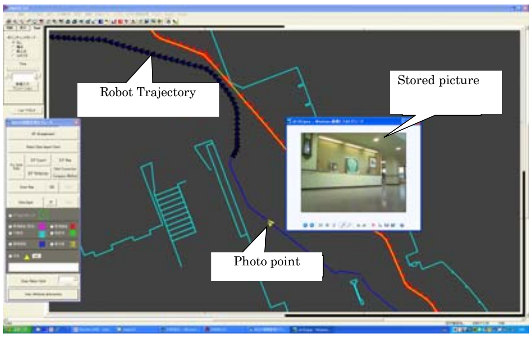


Fig. 13 Screenshot of viewer of GIS
(Prof. M. Hatayama)

5. System Integration

Constructed system structure is shown in Fig. 14. The system consists of an operator PC, a GIS server and a FE (Front End) server in the operator station, Robohoc network and robots. The GUI on the operator PC is an application for controlling grouped robots remotely, and displaying instantaneous data sending from robots. GIS server is a database server handling global position data such as position of robots, rescue teams and victims in the disaster site. FE server is an application to connect user interface, GIS server and robots. Robohoc network ensures communications between the operator station and robots. To use Robohoc network, the operator station system robots equip a special network controller. To connect with this special network controller, the operator station and robots are connecting each other without paying attention to the Robohoc network like normal wireless LAN network.

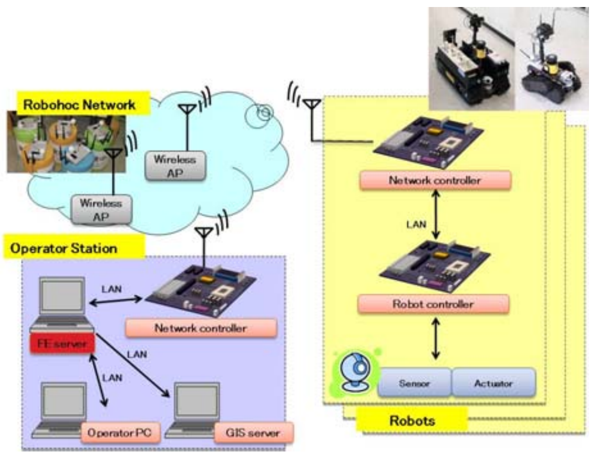


Fig. 14 Constructed system structure
(Dr. T. Kamegawa)

IV. DEMONSTRATIVE EXPERIMENTS AND TRAININGS

We carried out the demonstrative trainings to test developed robot system as shown in Fig. 15. This event was held as a special event for SICE International Conference on Instrumentation, Control and Information Technology 2008 (SICE Annual Conference 2008) in Tokyo on 21st August, 2008. In this training, two incumbent fire fighters controlled 4 robots manually, and Robohoc network was not utilized.

As a mission scenario, the pioneer type robot was controlled to put Rohoboc nodes on an environment, and then the surveyor type robots were controlled to investigate in a building. As a result, they could accomplish to find (dummy) victims through video images from the surveyor type robots.

Fig. 15 Demonstrative training by fire fighters

After a while, we carried out another demonstrative experiment for rescue activities using fully developed grouped robot systems as shown in Fig. 16.

Fig. 16 Demonstrative training by using Robohoc network

In the demonstrative experiments, the system was handled by three people, a commander for all system, a robot operator and an information operator, and 5 robots were controlled. In this demonstrative experiments, the size of target area is 57[m]x32 [m] that is larger than previous demonstrative trainings, and 8 Robohoc nodes were previously set in the building. It is assumed that a part of the map of the building were available for GIS data server. Fig. 17 shows an application of a network status monitoring viewer that indicates connection of wireless network to neighborhood nodes and which robot connects to which node.

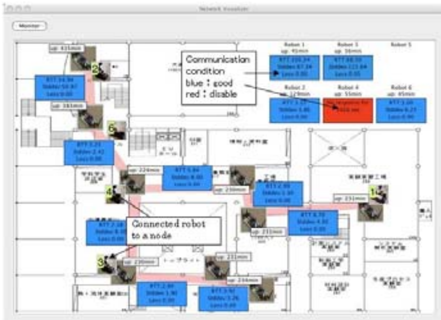


Fig. 17 Network status monitoring viewer (Dr. Y. Uo)

At first, the pioneer type robot was manually controlled to put Rohoboc nodes on an environment. Then the surveyor type robots were manually and automatically controlled to investigate in a building. When the robot operator found something to update to GIS data server, the information operator inputs the data to GIS. The information operator sometime fixes a robot trajectory drawn in a global map. When the robot entered new area, it means there is no previous map, the information operator creates a new map according to LRF information. Finally, operators could accomplish to find (dummy) all victims in the floor through video images from the surveyor type robots.

V. CONCLUSION

In this paper, the developed grouped rescue robots system for searching in damaged buildings is described. The system is consisted of four elements, mobile robot platforms, user interface, ad-hoc wireless network and GIS server. The system was integrated so as to complement the element's limitations each other.

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