Development of a Networked Robotic System for Disaster Mitigation

-System Description of Multi-robot System and Report of Performance Tests-

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Summary. In this paper, our research project named "networked robotic system for disaster mitigation" is introduced. It is aimed that multiple robots are teleoperated through a wireless communication network which includes a satellite communication link, for surveillance tasks at a disaster site. The robotic system consists of a large-scale outdoor robot and a group of smaller indoor robots. The large-scale robot will serve as a carrier for the smaller robots which will be deployed inside a partly-collapsed building. A three-dimensional range sensor and an omnidirectional camera are used as tools to ease the teleoperation for the human operator. This paper presents the scenario of our mission and the development status of our networked multi-robotic system. The results of the performance test using our system is also reported.

Key words: Disaster mitigation, Surveillance robots, Ad-hoc network, Teleoperation, Omnidirectional camera, Laser range sensor, Mixed reality

1 Introduction

Development of robotic systems for search and rescue operations receives increasing attention and national priority after the Hanshin-Awaji earthquake in 1995 (Japan) and the World Trade Center bombing in 2001 (U.S.A.). In case of such disasters, it is necessary to grasp a whole picture of damages and victims' locations as quick as possible. To reduce the risk of rescue crews and to help rescue operation, the development of remotely operated robots for immediate surveillance is strongly expected to the robotics community[1].

Since 2003, we have been working on a newly initiated project based on a networked robotic system to help mitigate disasters affected areas [2], under the support of the Japanese Ministry of Internal Affairs and Communications (MIC). The project is organized by Tohoku University, Osaka University, IHI Aerospace, Eizoh Co., Ltd and NICT (National Institute of Information and Communications Technology). The project aims at the development of a robotic system for surveillance of a remote disaster site.

The target environment is assumed to be a large-scale earthquake disaster inside a urban area. Concrete buildings are half collapse or completely destroyed. Road networks are damaged so that firefighters have a difficult access to the disaster area. Conventional communication networks may be also damaged. In such conditions, the first priority in any rescue procedure is to gather information of the damaged site conditions and to locate victims inside the site. To be able to tackle such tasks with a robotic technology, we have developed a robotic system which consists of a large-scale outdoor robot (hereafter termed as a "parent robot") and small-scale indoor robots (hereafter termed as "child robots"). There have been several robotic research projects related to marsupial type robots to deal with uneven and hazardous environments (e.g.[3]). One of the features in our robotic system is that each child robot has a relatively large locomotion capability (without cables). More specifically, this system will proceed as follows:

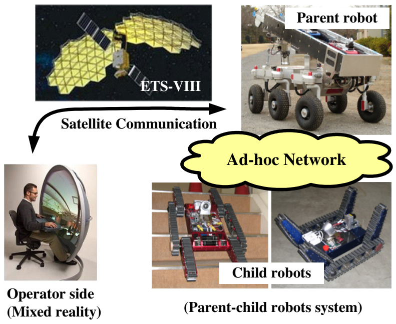

Fig. 1. Project overview

1. Whole "parent-child robotic system" is deployed by large helicopter in a disaster environment. (This part is out of our scope.)
2. The parent robot navigates the outdoor and acquires 3-dimensional range data of the environment to construct a map of the disaster site.
3. It then approaches to a half collapse building in which some victims may exist, and deploys child robots into higher floor using its extendable ramp.
4. The child robots explore inside to find victims and to map the environment.
5. Both control commands and obtained information are communicated with operators in remote site via wireless network.

Three key issues to realize the above scenario are summarized, (1) **development of a robotic system** that can be deployed in the disaster site and can do surveillance tasks remotely, (2) **development of a Mixed Reality technology** to display 3-dimensional geometry of the disaster site and, (3) **development of a satellite-based ad-hoc networking system** to secure the emergency communication by use of satellite-based IP communication link and wireless ad-hoc networks. Each research institute in this project is assigned to one of the above issues as sub-goals. Finally, the project will perform a demonstration of the integrated technology using a satellite-based

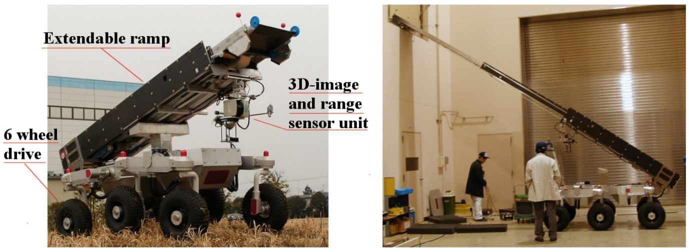

Fig. 2. An overview of the parent robot "Muros-Grande" and its ramp

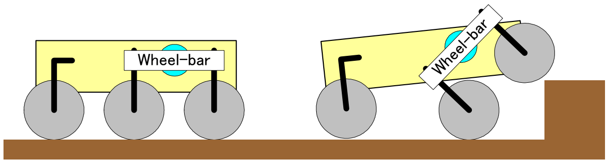

Fig. 3. Description of the wheel-bar of the parent robot

IP communication link. Such communication has the disadvantage of a lower transmission bandwidth, however it has a greater advantage given by the fact that the satellites are not damaged by the disasters on the ground. A concept figure is shown in Fig.1.

In this paper, progress reports about the issues are shown from Section 2 to Section 4. A performance test of our robot system is reported in Section 5.

2 Parent-child Robotic System (Sub-goal #1)

2.1 System Description of the Parent Robot

A parent robot is required to overcome uneven surfaces, and to be controlled precisely so that the robot can deploy the child robots into higher floors. Therefore, a six-wheels locomotion and an extendable ramp system are adopted to the parent robot (which was developed in IHI aerospace Co., Ltd.). An overview of the robot is shown in Fig.2.

The locomotion mechanism is based on a 6-wheel-drive and a 6-wheel-steering. Maximum speed is about 4.0[km/hr] and its dimensions are 2.3[m] in length, 1.3[m] in width, and 0.8[m] in height. It mounts the three-segmented extendable ramp which can deploy two child-robots to a 2nd floor of buildings. The maximum length of the ramp is about 7 [m]. The total weight of the robot without the ramp is about 300[kg] .

One of the features in the locomotion mechanism of the robot is that two wheel-bars located at both sides of the robot (each bar has two struts at both ends for supporting wheels) can be actuated independently. Therefore, conventional rocker-link motion can be realized by force feedback control using load-cell sensors in the struts reactively. Furthermore, about 50cm steps can be overcome by controlling of the wheel-bars in the same rotational direction

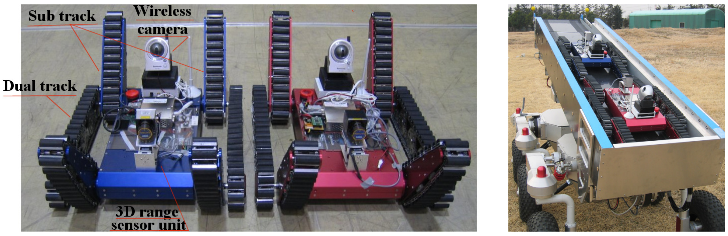

Fig. 4. The child robots “Muros-Piccolo” (left) and mounted on parent robot (right)

actively (see Fig.3). For steering, the six-wheel-steering enables not only a conventional maneuver but direct-side motion.

In the features of its sensor system, the main external sensor is 3-dimensional image and range sensor unit (shown in Section 3.4). In near future, RTK-GPS and inclination sensor are going to be mounted.

2.2 System Description of the Child Robots

A child robot is required to have a capability of climbing up/down stairs and overcoming small obstacles to search victims inside of buildings or houses. Therefore, our research group has adopted as our chassis a tracked-mobile robot (designed by Technocraft), and developed two child-robots in Tohoku university. An overview of them before and while being carried by the parent robot is shown in Fig.4.

The locomotion mechanism of the robot is accomplished by dual-track (with four actuated sub-tracks) and skid-steering. Maximum speed is about 1.8[km/hr] and its dimensions are 1.0[m] in length, 0.5[m] in width, and 0.5[m] in height.

One of the features in the locomotion mechanism of the robot is that two pairs of sub-tracks are located at the front and at the back. By changing both of the sub-tracks configuration, it enables to overcome high obstacles. An example of such motion is shown in Fig.5.

Fig. 5. The child robot overcoming an obstacle

In the features of its sensor system, the robot has 3-dimensional range sensor units, a conventional pan-tilt web-camera, and an inclination sensor. Particularly, the 3-dimensional range sensor is supposed to be used in teleoperation system, shown in Section 2.3.

2.3 Teleoperation using 3-dimensional Information

“The time delay and narrow bandwidth via satellite communication” is one important issue when using vision based teleoperation, because vision system requires heavy network traffic. As a solution to this issue, we adopt “3D-information-based teleoperation” method for the child robots using 3-dimensional range sensor.

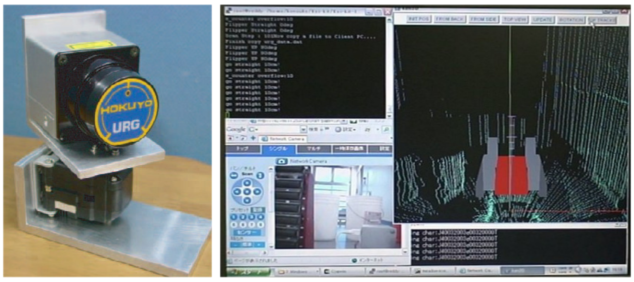

Fig. 6. The 3-dimensional range sensor (left) and the operator's GUI (right)

The sensor is comprised of a conventional small laser range finder (URG-04LX, Hokuyo Co. Ltd.) and a Smart Motor (DX-117, Dynamixel) that rotates the laser range finder about the vertical axis in 180 [deg]. The sensor is shown in the left side of the figure 6. It can obtain range data in every 0.35 [deg] in both vertical and horizontal directions, and the maximum measuring range is about 400 [cm]. The actual scanning speed is about 1[min / 180 deg], but the speed can be increased by changing the rotational speed of the Smart Motor faster, although the horizontal resolution will be decreased.

Using the sensor, the teleoperation procedure of the robot is as follows:

- S1: [robot] Obtaining local 3-dimensional environment information (hereafter called "3D-info") and sending the 3D-info to the operator.
- S2: [robot] Obtaining position and orientation of the robot using odometry and sending them to the operator.
- S3: [operator] Displaying 3D-info and super-imposing the robot model on it.
- S4: [operator] Operating a virtual robot using input device such as joystick based on displayed 3D-info and sending the commands to the robots side.
- S5: [robot] Controlling the robot based on the commands from the operator.
- S6: Repeating from S2 to S5 until the robot runs a certain distance.
- S7: Going to S1 for obtaining a new 3D-info.

The right side of the figure 6 shows the operator's GUI for the teleoperation of the child robot. Based on the above procedure, the operator controls the real robot, but he thinks as if he controls the virtual robot in the virtual environment.

Advantages of this method are, (1) the operator can choose any view direction and any zoom-size of the virtual environment, and (2) communication load is relatively small. After sending a large amount of 3-dimensional information from the robot to the operator, only both the control commands and the status information of the robot are communicated through the network in the procedure of S4 and S5, until a new scan is required.

A disadvantage of this method is the position estimation. In our implementation, odometry is used for the acquisition of the robot's position. However the skid-steering of our tracked robot usually generates large odometry errors. When the 3-dimensional environment information is updated by sensing, the error is always cancelled because the sensor's position is set to the origin of the environment. However if the odometry's performance is not reliable, the operator should re-scan to cancel the error by frequent sensing. The problem of track's slippage is well described in [4], and we are researching on how to improve the odometry for tracked robots. Details are in [5].

3 Omnivision and 3-dimensional Range Sensor Unit for Effective Telepresence (Sub-goal #2)

3.1 Development of hanging mechanism

Fig. 7. Hanging mechanism

When a robot runs on bumpy terrains, the acquired data is also tilted if the sensor is fixed to the robot's body. The use of an inclination sensor to cancel the body's inclination is one option, but the missing information caused by changing view area may become a problem. To solve such a problem, a "hanging mechanism" was developed for our sensor unit. It is a passive gimbal mechanism (shown in Fig. 7) which consists of two rotary-disk-dampers (FDT-47A, Fuji-Latex Co., Ltd). By hanging the sensor unit from the mechanism, it enables to keep the sensor's pose passively by its own weight.

3.2 Non-isotropic Omnidirectional Imaging System

Considering both surveillance and robot navigation, high-resolution image and wide-angle-vision are effective, but both are in a trade-off relation with each other. To obtain both the features, non-isotropic omnidirectional imaging system has been developed in Osaka university[6]. The sensor has the Horizontal fixed viewpoints Biconical Paraboloidal (HBP) mirror which generates an inhomogeneous angular resolution. It enables the operator obtain not only an omni-directional scene but high-resolution views in a particular direction (in our case, front side). Figure 8 shows an overview of the sensor and an obtained view. We can see that the resolution at the front view is larger than at the side view (by comparison between the characters "HBP").

3.3 The 3-dimensional range sensor for outdoor

To obtain a 3-dimensional range information, 3-dimensional range sensor has been developed in Tohoku university. A scanning system is almost the same as indoor-type shown in Section 2.3, but SICK LMS291 is used as the laser range finder. The scanning speed is about 1 [min / 180 deg]. In this case, the sensor acquires range data in every 0.5 [deg] in both vertical and horizontal direction, and the maximum range is about 30[m].

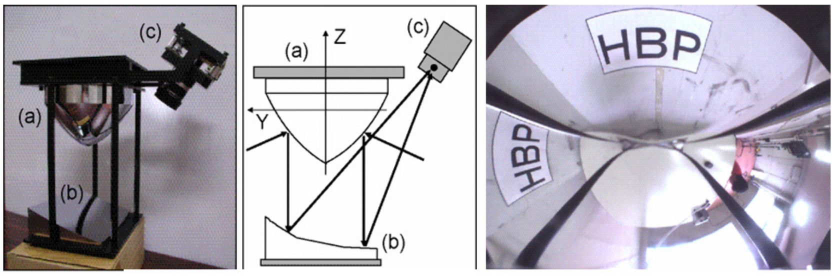

Fig. 8. Non-isotropic omnidirectional imaging system and obtained image

Fig. 9. Proposed sensor unit and obtained 3-dimensional information

3.4 Integration of Sensor Unit

Integrating the above sub-components, "Omni-Vision and 3-dimensional Range Sensor Unit" is completed[7]. The sensor unit mounted on the parent robot is shown on the left side of the figure 9, and an obtained textured 3-dimensional range information is shown in the right side of the figure 9.

4 Satellite-based Ad-hoc Network System (Sub-goal #3)

4.1 Engineering Test Satellite VIII

The Japanese Engineering Test Satellite VIII (ETS-VIII), designed by Japan Aerospace Exploration Agency (JAXA), is assumed to be used between operators and the network router of robots located in a disaster site. The satellite was launched in December 18th, 2006, and it was injected into the target geostationary orbit at an east longitude of 146 [deg]. The satellite has two communication antennas, and each antenna covers an area from 300 to 400 [km] in diameter.

The satellite works as a repeater station between two portable terminals. One is located at the operators' side, and the other is located in disaster site. The satellite has the capability to provide IP communication link up to 1.5 [Mbps], but the fastest communication requires big parabola antennas (1.2 [m] in diameter) and more than 800[km] distance between both portable terminals not to interfere beams coming from two-satellite antennas. In our case, it is

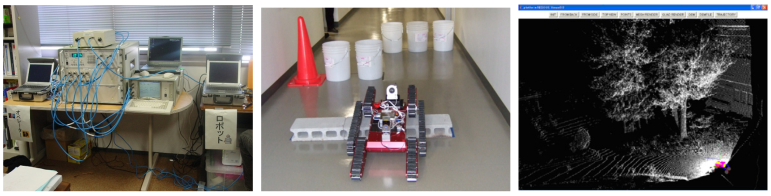

Fig. 10. The satellite simulator and the teleoperation performance tests

supposed that one-satellite antenna on the satellite and two parabola antennas (75 [cm] in diameter) on the ground are used. In this setup, the communication of the throughout can be 64 [Kbps] for sending and 768 [Kbps] for receiving.

4.2 Wireless ad-hoc network

It is supposed that some mobile robots are controlled remotely, and the local network for them at the disaster environments should be robust enough so that it won't be disconnected. To enable such requirement, a wireless ad-hoc network is useful. In this research, an ad-hoc network software (produced by Decentra) was installed on the child robots and on a router have realized multi-hop communication in inter-robots-communication.

4.3 Performance Test of Teleoperation using satellite simulator

To confirm the connection of user-devices to portable terminals for ETS-VIII, JAXA developed a satellite communication simulator. An overview of the simulator is shown in the left side of the figure 10. The box located at the center (where many cables are connected to) is the main body of the simulator. There is also a portable terminal at each side of the box. With this simulator, a realistic teleoperation test including actual portable terminals can be performed.

Using the simulator, three simple performance tests were carried out on December, 2006. One consisted on the use of small programs which enables only simple communication and measurements of the time-delay between peers. These programs are installed at both the operator computer and the robot's computer. Using these programs, a packet-collision problem was observed in the case of a communication rate of 768 [Kbps] or lower (the sending interval of 2 [MB] data is 5.0 [sec]).

On the second performance test was to use the actual robot to simulate the teleoperation. The environment and the test scene is shown in the center of the figure 10. To control the robot, the 3D-information-oriented teleoperation (shown in Section 2.3) is adopted. 10 people (that includes three skilled operators) performed a short course teleoperation without visual observation.

During the performance test, we learned that a conventional speed control (the speed of the robot is determined by an angle of joystick-bar) is very hard even for an experienced operator in the case of unstable 1-2 [sec] delay. Therefore, in the performance test, we changed the control scheme from the speed control method to a "certain-amount-control" method. It means that one button push corresponds to a certain travelling distance (10[cm] in our case) or certain rotational angle (10 [deg] in our case). After that, total navigation time and safety were improved drastically. We did not perform a quantitative test yet, but obviously, the result has been suggested that a position-based-control has a big advantage under time-delay conditions.

The third performance test was carried out using a four-wheeled drive mobile robot outdoors (instead of the parent robot). This robot carries a 3-dimensional range sensor (shown in Section 3.3) and a pair of RTK-GPS for the localization of the robot. The right side of the figure 10 is one example of obtained 3-dimensional environment outside, and the position and pose of the robot is super-imposed based on the RTK-GPS. The teleoperation by skilled operator was succeeded in navigating the robot slowly. However, sometimes, a distortion effect on the signal coming from the GPS satellites to the antennas prevents accurate localization.

5 Performance Test of our parent-child robotic system

To confirm our developing parent-child robotic system for disaster mitigation, an open-demonstration was organized on March 10th, 2006. It was performed in a field and a building of IHI aerospace co., Ltd. in Kawagoe, Saitama, Japan. In this demonstration, the following scenario was assumed.

1. The parent robot is controlled through a visual feedback by an operator.
2. The parent robot performs acquisition of 3-dimensional range data and image to construct a texture mapped 3-dimensional virtual environment
3. The parent robot enters to the IHI's building, and puts the extendable ramp to the second floor's opening (located at the height of 4.2[m]).
4. Two child robots climbed the ramp to enter the 2nd floor.
5. Two child robots are controlled remotely to gather visual information and 3-dimensional range information.

In this performance test, it was assumed that a conventional wireless LAN can be used inside of the buildings.

The parent robot succeeded in deploying two child robots into the 2nd floor of the building. (The scene is shown in Fig.2). One of the two child robots climbed up to 3rd floor through stairs and found a dummy victim. The other child robot stepped down to the 1st floor. The parent robot went out after deploying the child robots into the building, and navigating in the presence of bumps and gaps.

The whole expected scenario was performed, and we concluded that installation of basic functions of our prototype robotic system is successfully completed except network part. From the point of view of the network communication, we have a lot to do in the near future:

1. A time-delay of communication was ignored in this performance test, but it should be considered practically.

2. In this performance test, wireless stations were located in the building beforehand, but practically an ad-hoc network should support a network.
3. Robust network is required. In our current implementation, once the communication was disconnected, the robot never reply back.

6 Conclusion

In this paper, our research project of "networked robotic system for disaster mitigation" was introduced. The project has three sub-goals, which are "development of parent-child robotic system", "development of omni-vision and 3-dimensional range sensor unit", and "development of a satellite-based adhoc networking system". This paper described the system architecture and state-of-the-art of the project. Finally, the open demonstration (on March 10th, 2006) was introduced as a performance test of our robot system.

In future work, firstly, the odometry for tracked robots to estimate precise robot's position is highlighted. As shown in Section 2.3, the accuracy of odometry for tracked robots was implemented but it works in a plainer case. The method should be extended to a slope or uneven surface. Secondly, to modify the odometry errors and to construct a global map, a SLAM techniques are introduced to achieve the robot positioning and global-map generation. Finally, proposed teleoperation method of mobile robots will be evaluated quantitatively in the presence of time-delay of communication.

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