Chapter 9

Demonstration Experiments on Rescue Search Robots and On-Scenario Training in Practical Field with First Responders

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Abstract This chapter presents a process of making connections between researchers who develop rescue search devices and first responders, and presents scenario training experiments utilizing the devices operated by the responders. The development of the rescue search devices is aimed at practical deployment in the future so that the development researchers must have taken a pragmatic approach. It was crucial that researchers took every opportunity to demonstrate them in the presence of first responders and that they had contacts with several volunteer incumbent firemen who offered practical comments on the developed devices. Such comments will be used in the next stage of the development of rescue search devices.

9.1 Introduction

The development of rescue robots involves a degree of pragmatism. In scientific fiction, a "rescue robot" is a super machine or a super humanoid to rescue injured persons in place of the first responders in a disaster area. However, we might as well call it a "rescue search robot" or a "rescue search device." The present authors at DDT project have endeavoured to develop such a series of devices rather than super robots appearing in science fictions, which can help first responders to search for surviving victims in the disaster area.

The DDT project (Special Project for Earthquake Disaster Mitigation in Urban Areas, III-4 Development of Advanced Robots and Information Systems for Disaster Response) aims at the development of search devices that can provide useful information for rescue activity in several types of locations suffering from a large-scale earthquake. The devices are required to be effectively utilized at actual disaster sites, which motivates us to integrate necessary element technologies, to assemble them into devices and demonstrate the effectiveness of these devices in providing necessary information in the target environment.

9.2 Who Is the User?

Who is the expected or proper user of such rescue search devices? It must be the first responders, for example, firemen or special rescue teams of disaster mitigation organizations.

An engineering device cannot be designed unless its necessary specifications are laid down. This implies that the correct approach to design a device must include the process of observation of its usage. We must observe where and how the device is used by the first responders and what types of functions these devices must be able to perform. If engineer designers could attend every disaster area and observe the rescue activity, it may be possible to draw the specifications considering the necessary functions. However, it is difficult for them to have permission every time to visit specific areas.

Therefore, as another approach, we may take interviews or questionnaire surveys of the first responders. Although this approach seems practical, the authors, as researchers at the DDT project, initially experienced difficulties in obtaining effective and meaningful information from such surveys. The difficulties arose from the following facts:

1. The researchers had few connections with the first responders having practical experience.
2. Even when some of the researchers of DDT questioned some responders as to what type of a device will be useful, the responders offered notional answers or were at a loss to answer the question.

The second fact can be understood because of a lack of communication between researchers and responders. They them had no shared common understanding on the topic of introducing robotic technologies into rescue search devices. The responders did not have sufficient information on what could be possible by introducing new technologies; as a result, they could not give proper answers to the researchers. To say in a figurative dialogue, "Please teach me your idea. We develop useful staffs," "What could I teach you? I do not know what kind stuffs you can develop!" Time, interest, and effort are required to enable the two parties to reach a common understanding.

9.3 Progress of the Development of the Rescue Search Devices and IRS-U

Intensive academic activities just after the Great Hanshin-Awaji Earthquake in January 1995 triggered the development of rescue robots or rescue search devices. The development was encouraged and accelerated by the grant under the MEXT's Special Project For Earthquake Disaster Mitigation in Urban Areas, called the DDT project, from 2002 to 2006 for 5 years, where the subproject of DDT, "Development of Advanced Robots and Information Systems for Disaster Response" was assigned. The NPO, International Rescue System Institute (IRS), was established and enrolled as a central organization for the management of the development. Under the leadership and supervision of the IRS, researchers in Japanese universities and research institutes gathered to accelerate the development.

Figure 9.1 illustrates the road map of the project, where

1. the researchers develop prototypes of rescue robots or rescue search devices based on robotic technological elements, which can be used after integration and sophistication of the elements;
2. however, the development must consider possible and realistic scenarios for the use of devices; and finally,
3. the developed prototype must be evaluated in practical environments, which realize actual disaster sites as far as possible.

The primary mission of the DDT project is to show possibilities to realize practically usable high-performance search devices. Thereafter, we can proceed to develop robust devices suitable for repeated use and the deployment of these devices to the first responder organizations.

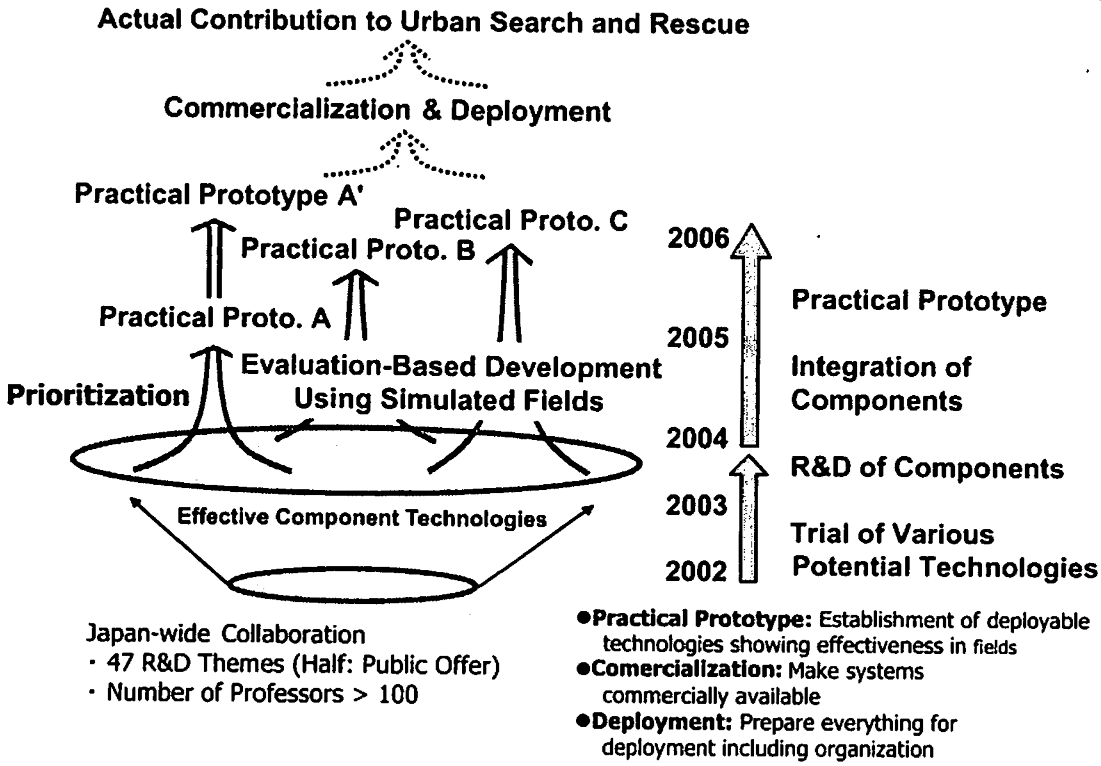


Fig. 9.1 Development mission for high performance devices for search at disaster sites

In mid-2004, i.e., around 3 years after the launch of the DDT project, rescue robots or rescue search devices were developed. For example, "IRS Souryu" (Fig. 9.2) was one of the leading devices. It was equipped with a video camera and aural communication facilities (intercom) on the base mechanism of the original "Souryu," which was developed in the laboratory of Professor Hirose at Tokyo Institute of Technology. For publicity, the IRS or related researchers made efforts to take every opportunity to demonstrate IRS Souryu or other devices available at that time to the staff of fire stations, first responders, and local citizens.

The IRS staff greatly contributed toward receiving publicity, which was a great merit of the project framework that the IRS was enrolled as the central organization for the management. The IRS staff not only received the offers of demonstration opportunities at local events, but also developed opportunities to communicate with the first responders. This opportunity development activity gave strong effect to establish desirable contacts with responders. The usual way of receiving a grant and pursuing research involves a contract directly between the grant support organization and the university or research institute. However, the staffs of the university or the institute could hardly make efforts to negotiate with responders. It is admirable that the IRS has expert staff.

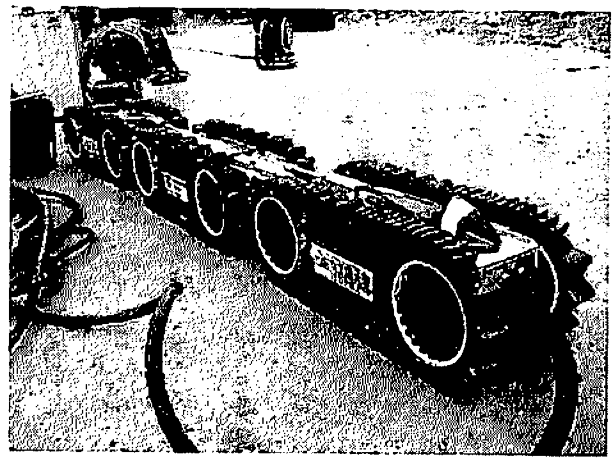


Fig. 9.2 IRS Souryu

In the later half of the year 2005, the efforts of publicity to responder-related organizations showed results. As one of the results, we encountered a fireman in a local prefectural fire station who was very interested in introducing robotic technology into the rescue and search devices. He was interested in using robotic technology for the safe and efficient conduct of rescue activities and the prevention of secondary disasters at a disaster site. Taking the opportunity to make contact with the IRS, he and his colleagues observed and operated the devices developed on off-duty days. They offered practical information on the use-case environment for the functions of a developed device or necessary functions for the device at a practical site. They offered volunteers to prepare an operation manual for IRS Souryu.

This connection served as the background to establish IRS-U and start its activities in March 2006. The IRS-U consists of voluntary members who are employed in fire departments including the one mentioned in the previous paragraph. The mission of IRS-U is:

1. to operate the devices developed by the DDT – and IRS – related research staffs under the assumed scenarios and environments;
2. to evaluate the performance of the devices;
3. to offer evaluation feedback to the development staff;
4. to identify and specify the scenes wherein each device is practically useful;
5. to provide the operation manuals for the developed devices; and
6. to offer publicity for the developed devices under the DDT project to the members of the national first-responder organizations.

The developed devices cannot be put to practical use in the real environment of search and rescue without testing them. They can be tested at the training facilities of fire stations, where firemen receive training everyday in a simulated practical environment. A member of IRS-U presented an idea to use such a training facility to conduct experimental training of the developed devices. In fact, experiments were conducted in training facilities in 2006, the final year of the project. Even after the DDT project was over, such experimental training was conducted several times.

9.4 Toward Practice Experiments and Training

9.4.1 Policies

As mentioned in the preceding section, we can recognize demonstration experiments or experimental training as an opportunity to present the effectiveness of the developed rescue robots or rescue search devices in a simulated disaster environment and to discover the drawbacks of these devices for their practical use in such an environment (Fig. 9.3). Furthermore, according to item 6 of IRS-U mission, for publicity, it is important to disclose the usage possibilities and abilities of the devices to which robotic technologies are applied to the concerned parties.

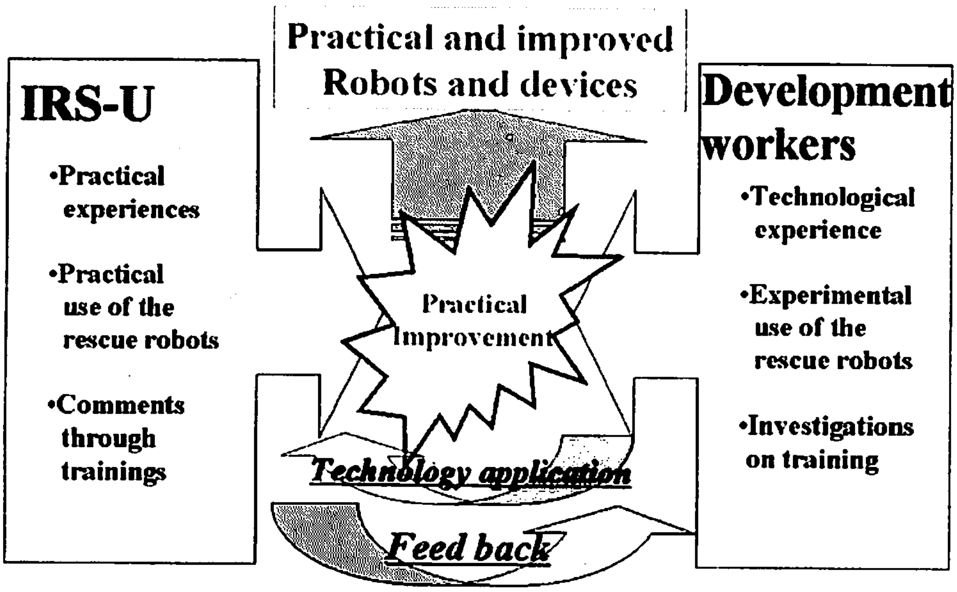


Fig. 9.3 Cooperations of the researchers and users

Usability assessment and establishment of a feedback cycle are important issues. The assessment must be performed under sufficient experience of practical operations in a practical field. For effective experiments, the authors adopted the following policies:

1. A scenario which assumes the use of devices in the experimental or training field as similar as possible to the real scene is composed by the members of first responders.
2. The devices are evaluated by the operation following the scenario.
3. The operation is performed by the first responders and not by the staff who developed the devices.

4. The performance is evaluated by the first responders to offer improvement feedback to the development staff.

The IRS conducted such scenario-based experiments several times in cooperation with IRS-U, the members of fire departments, and local governments.

In 2006, the final year of the DDT project, the IRS and IRS-U conducted scenario-based experiments and training five times in cooperation with Tokyo Fire Department, Kawasaki City Fire Department, Kobe City Fire Department, Kawasaki City, Kobe City, Japan Disaster Relief Team, and Hyogo Prefectural Emergency Management and Training Center. These experiments and training were mainly focused on items 1 to 3 in the IRS-U mission. However, each experiment and training exercise was made available not only to the organizations related to fire departments to accomplish the item 6 of the mission, but also to the press to gain general publicity on these activities.

9.4.2 *Commentaries*

The experiments and training conducted in 2006 were as follows:

1. Outdoor experiment and training on April 22 and 23, 2006

   Place: Tachikawa outdoor training field in 8th Fire District of Tokyo Fire Department.
   Scenario: IRS-U turns out for an emergency call to rescue a victim from a crushed house after a big earthquake.
   Devices used: BENKEI, BENKEI-2, a jack robot, a cutter robot, intelligent search cam, IRS Souryu, Rescue Dummy and RFID tags.

2. Indoor experiment and training on June 24, 2006

   Place: Tachikawa training building in 8th Fire District of Tokyo Fire Department.
   Scenario: IRS-U turns out for primary scouting activity because of an emergency call for NBC disaster suspicion with bad smell for unidentified reason and nausea sufferer. The mission of IRS-U is to confirm the existence of victims and the identification of suspicious material.
   Devices used: ACROS, TP03, Rescue Communicators, and RFID tags.

3. Outdoor experiment and training on October 3 and 4, 2006

   Place: outdoor training field in the Hyogo Prefectural Emergency Management and Training Center
   Scenario: same as item 1.
   Devices used: IRS Souryu, cutter robot, Rescue dummy, KURUKURU, and RFID tags.

4. Indoor experiment and training on November 5, 2006

Place: underground town of Kawasaki Station of Japan Railway (JR) East.
Scenario: just after a big earthquake, injured victims remains in the underground town. IRS-U and Kawasaki City Fire Department turn out. IRS-U offers primary scouting activity to investigate the inside situation and to identify the victims by operating rescue robots from the ground-level entrance. After receiving the report of the investigation and identification, the members of Kawasaki City Fire Department perform the rescue operation to save the victims.
Devices used: IRS Souryu, Hibiscus, KOHGA2, and IC tags.

5. Indoor experiment and training on November 23, 2006

Place: Collapsed House Simulation Facility of IRS Kobe laboratory.
Scenario: same as item 1.
Devices used: UMRS-NBCT, IRS Souryu, Hibiscus, Rescue Communicator, Fiber scope with propulsion by cilia, and RFID tags.

9.5 Details of Experiments and Training at the Underground Town of JR East Kawasaki Station

This was the first experiment and training realized in the real environment in cooperation with the maintenance company of the underground town, Kawasaki City, Kanagawa Prefecture and Kawasaki City Fire Department. It was a very important event because of the following:

1. It was conducted in a real environment and by the members of IRS-U that developed the robots under the DDT project.
2. It was a cooperative training scenario in which not only the members of IRS-U but also the special rescue members of Kawasaki City Fire Department (Kawasaki CFD) participated and operated the robots.

The fact of cooperation with the Kawasaki CFD seems to have been effective in obtaining publicity of the rescue robots to general members of fire departments. In the scenario: (a) IRS-U offers primary scouting operation; (b) the special rescue members of the Kawasaki CFD share the information from the scouting by the IRS-U; and (c) the rescue members perform the rescue operation, while IRS-U performs the backup operation.

9.5.1 Scenario and Snapshots of the Experiments and Training

The detailed scenario with snapshot pictures is as follows:

A big earthquake has occurred. The IRS-U by chance turned out voluntarily to the underground town at JR Kawasaki Station as the IRS-U was in a training session at the IRS Kawasaki laboratory, which is very near to the station. The members of the Kawasaki CFD took some time to arrive at the town because of several locations where the rescue activities were called for, though Kawasaki CFD covers the underground town under the service area. Therefore, the IRS-U was the first party that arrived at the underground town.

IRS-U decided to begin the primary scouting service. According to the investigation of the ground-level entrance, the inside of the underground town seemed to be dangerous. The IRS-U decided to use and operate the rescue robots as scouting devices. After the scouting service was started by IRS-U, the menbers of Kawasaki CFD arrived at the town.

After the robots were set up (Fig. 9.4 (a)), the IRS-U started to operate the three robots from the entrance of the ground level through the stairs (Fig. 9.4 (b)). In the figure, IRS Souryu appears on the left; KOHGA2, in the center; and Hibiscus, over the stair fence. All the robots arrived at the underground level and scouting operation was started to search for remaining victims and to investigate the inside situation of the town (Fig. 9.4 (c)). Figure 9.4 (d) presents KOHGA2 (fore side) and Hibiscus (hind side), which performed the search operation in the corridor of the underground town, and Fig. 9.4 (e) presents the Hibiscus operator of IRS-U.

An injured victim was found by KOHGA2 (Fig. 9.4 (f)). The operator of the KOHGA2 at the ground level called one of the Kawasaki CFD to rescue the victim; the member came to the victim and saved him (Fig. 9.5 (a)). The operator at the ground level watched the entire rescue operation through the monitoring camera on KOHGA2. After this victim was saved, the search operation by the three robots was continued (Fig. 9.5 (b)). In the situation shown in this figure, the monitoring camera of KOHGA2 on the hind side (on the right side in the picture) continued capturing the other two robots in the view angle. Therefore, the operator at the ground level could continue watching the situation.

Another victim who was under the debris was found by IRS Souryu (Fig. 9.5 (c)). The operator at the ground level called the victim through the intercom installed on IRS Souryu to confirm consciousness of the victim. If the victim was conscious, the operator would continue the voice contact to encourage safe rescue. During the activity, the operator also checked the temperature and CO_2 content of the air at the site. This information was shared by the members of IRS-U and Kawasaki CFD. The members of Kawasaki CFD began the rescue operation for the victim (Fig. 9.5 (d)). The members confirmed the situation of the victim. The robot operators turn the heads of the robots to the scene, and the rescue operation was broadcast to the ground operation manager through the monitoring cameras installed on the robots. One of the rescue members reported the operation by voice, utilizing the intercom facility of IRS Souryu.

Figure 9.6 (a) presents the monitor screen for the operator of Hibiscus. The monitor displayed the image captured by the camera of Hibiscus, which appears in Fig. 9.5 (d) (lower left). It was a "new" experience because the operators at the ground level could monitor the operation inside the underground town. KOHGA2 was situated at a rear location to broadcast the entire rescue operation (Fig. 9.6 (b)). Figure 9.6 (c) presents a snapshot of the rescue operation. The debris was lifted up

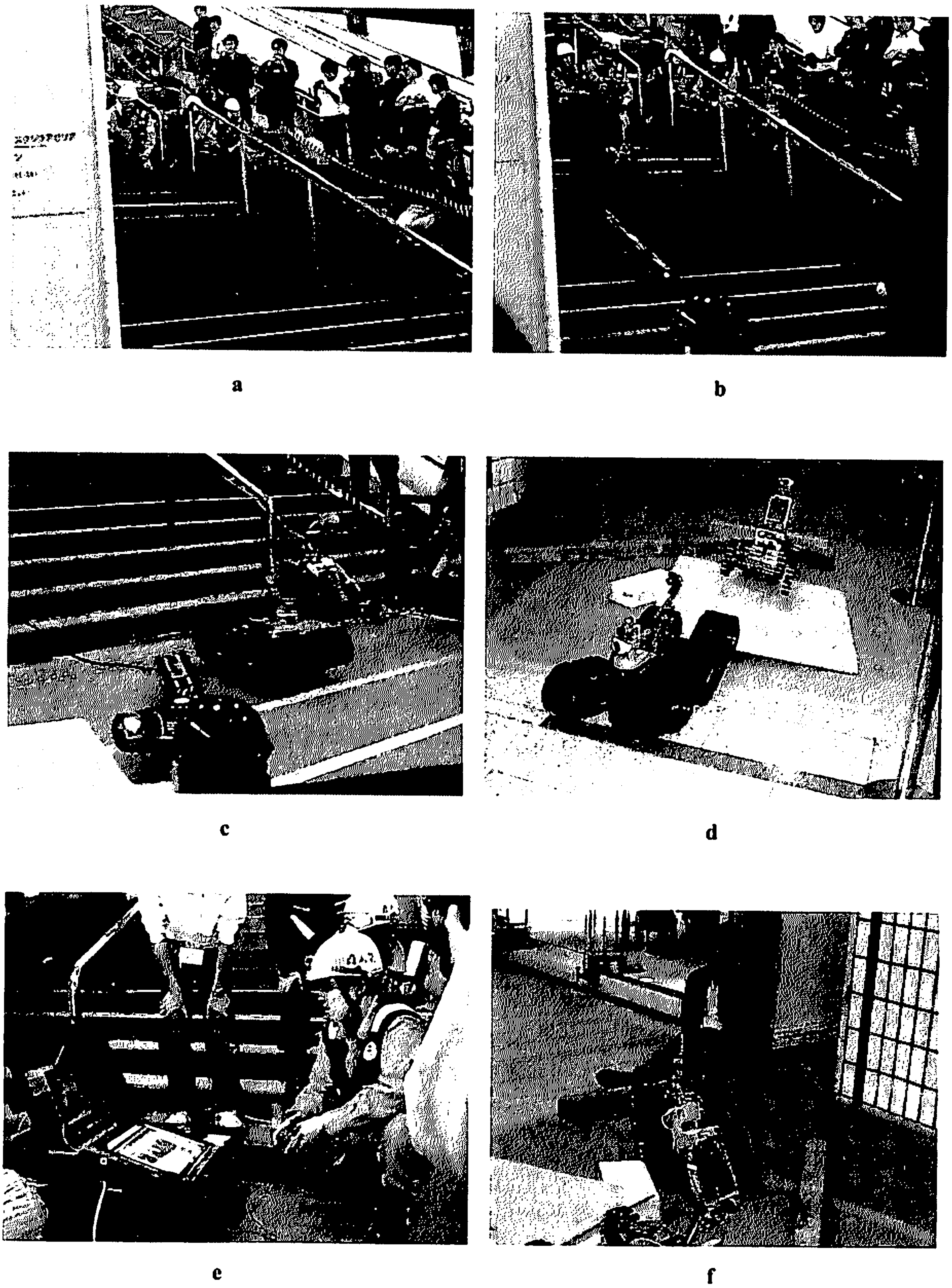


Fig. 9.4 Snapshots of the experiments and training in the underground town. **a** Setting up robots. **b** Robots going down the stairs. **c** Robots arrive at underground level. **d** Search operation. **e** Hibiscus operator. **f** A victim is found

Fig. 9.5 Snapshots of the experiments and training in the underground town (continued). **a** A victim is saved. **b** Search activity by three robots. **c** Another victim is found. **d** Sendingimage of the rescue activity by robot

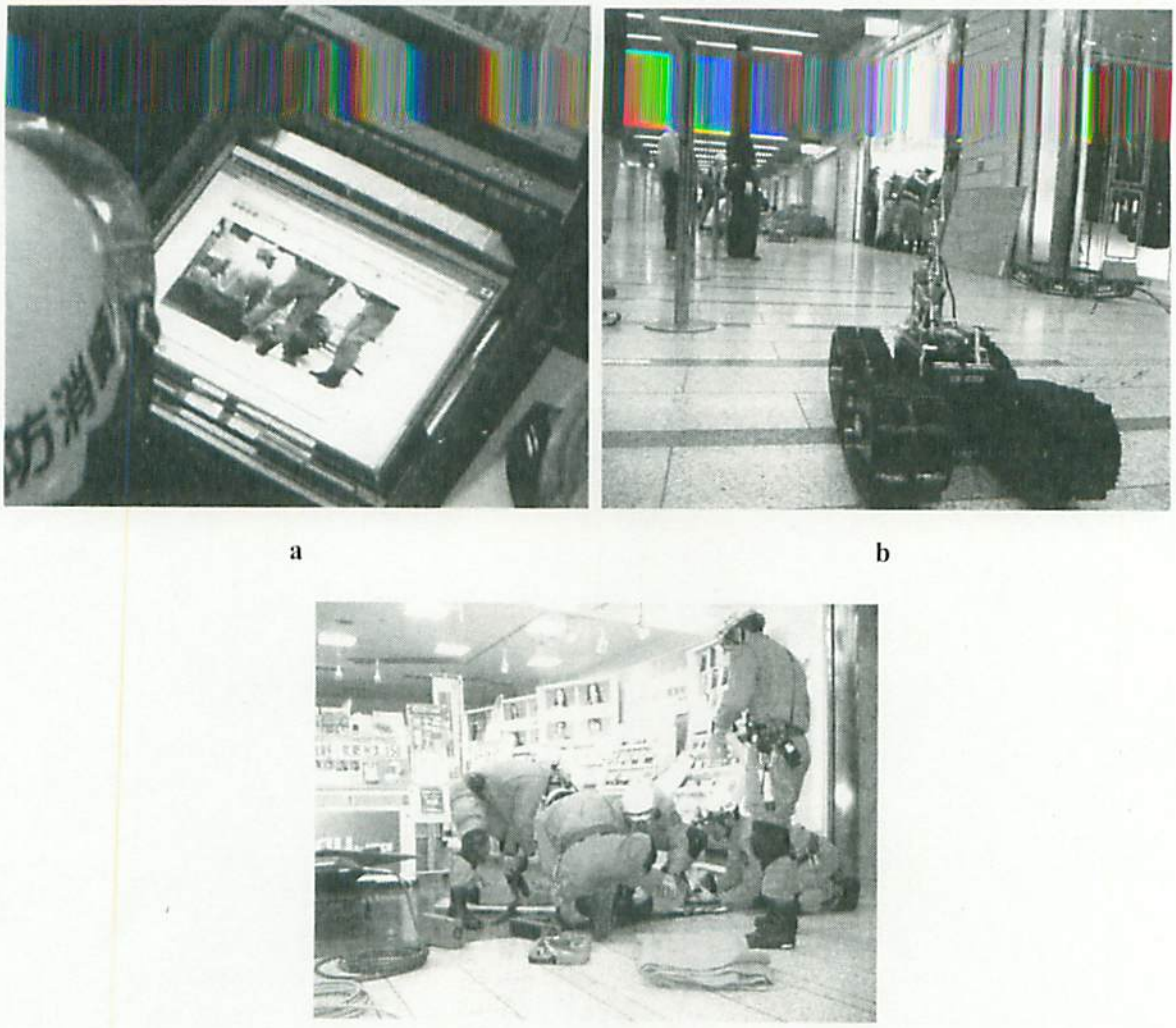
by an air jack. The victim was saved after supporting his backbone with a special support device.

9.5.2 Observation Report from the IRS-U Staff

The following statements were provided by members of IRS-U after the experiments and training.

9.5.2.1 Performance of Robots in Experiments and Training

After the Hyogo experiments, IRS Souryu was improved to equip it with a back view monitoring camera, which had been requested by a member of IRS-U. This



a b c

Fig. 9.6 Snapshots of the experiments and training in the underground town (continued). **a** Monitor the operation through the camera on the robot. **b** Watch the operation with KOHGA2. **c** Rescue the victim

camera was actually useful to gain the view for reverse motion, which improves the mobility of the robot under teleoperation. A member of IRS-U rated highly the mobility, portability, and ease of operation from the point of view that the member as a beginner of the robot operation could operate the robot easily.

In this experiment, the effectiveness of the intercom facility installed on IRS Souryu, which consists of microphones and speakers, was demonstrated. This wired intercom facility offers bidirectional aural communication like the telephone. In conventional rescue operations, rescuers use transceivers that require them to press the "press to talk" switch to talk with another team member. This requirement forces a talker to momentarily stop work while pressing the switch. On the other hand, the intercom of IRS Souryu enabled rescuers to continuously talk with each other without interrupting the rescue operation and to report the real-time situation to the operators and the commander at ground level while performing a rescue task. It is very important to report real-time changes in the condition of victims. Thus, the intercom enables easy and uninterrupted communication between a victim, a rescuer and other rescuers on the ground.

KOHGA2 was rated highly because of its wide crawlers, high mobility, perticularly on debris and stairs, and the ability to change the angles of the four crawler units relative to its body. A disadvantage reported was that there was a slight delay in receiving images from the camera because of the delay in the digital communication line. Therefore, taking account of this characteristic, the commander assigned KOHGA2 to a mission to watch the situation and the on-going activity in an environment. A zoom function has been requested for the camera on KOHGA2.

The camera image of Hibiscus, displayed on the screen of a teleoperation console, was very clear. The touch panel on the screen was also useful for robot operation. The ability of Hibiscus to overcome debris and to climb stairs was rated high. The subcrawler arm and its motion to change the angle helps increase the mobility. However, some of the IRS-U members report that training and practice with the crawler arm operation is necessary. From the viewpoint of mobility, it appears that Hibiscus can be deployed. However, it is necessary to improve the water and dust proof ability of its body.

9.5.2.2 Overall Evaluation

For IRS-U, there were many "first experiences." It was the first time that experiments were conducted in a real underground town, that there were victims in the scenario, and that the rescue operation was performed in cooperation with other fire departments whose staff were not familiar with the robotic devices for rescue activities. IRS and IRS-U gained valuable experience throughout the experiments and training.

The environment assumed in the scenario was an underground town. The first responders consider an underground town an environment that prevents them from performing activities with high mobility during a disaster because of dangerous factors such as dense smoke and high temperature due to fire, the crowds of people during peak hours, and difficulty in accessing the underground because of the limited number of entrances. As an underground town is surrounded by walls, high-fidelity or high-reliability radio communication becomes impossible. Technology development to overcome this limitation is urgently required. In this scenario, the three robots were assigned with independent missions for the purpose of cooperation. This arrangement of the three robots at the time of the victim rescue operation provided useful information to members and the commander at ground level. This helped the responders to maintain safety.

9.5.3 Overall Evaluation from the Robot Development Team

The experiments revealed that it is most important to establish communication channels between a teleoperated robot and the operating console or operator. It is desirable to maintain high quality, wide bandwidth, high reliability, and no delay. IRS

Souryu used a wired communication channel. On the other hand, KOHGA2 and Hibiscus used a wireless LAN. In the experiments, the air station of the wireless LAN was placed at the underground level to maintain the reliability of communication via the LAN. However, at a more realistic site, this may not be possible. The success of the experiments tends to rely on providing good conditions for the wireless LAN. We should keep this fact in mind.

It appears that the developed robots have high mobility not only on a plane surface but also on debris and stairs. The dust and water proof design of these robots is the next step of the development.

9.6 Conclusions

Experiments and training activity using the devices and robots developed under the DDT project were reported. It is remarkable that in this project, the developed devices were tested in a realistic environment. The development was strongly motivated to have achieved the level of deployment of these devices to first-responder organizations. IRS and its related researchers gained much experiences.

It is remarked that the IRS staff contributed to the arrangements of all the experiments and training. For the arrangements, there were many negotiations and discussions among different organizations. This was a very tough task, which could not have been accomplished by researchers alone.

Rescue Robotics

DDT Project on Robots and Systems for Urban Search and Rescue

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