

Chapter 2

An Overview of the DDT Project

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Abstract The DDT Project on rescue robots and related technologies was carried out in Japan's fiscal years 2002–2006 by nationwide researchers, and was organized by International Rescue System Institute. The objective of this project was to develop practical technologies related to robotics as a countermeasure against earthquake disasters, and include robots, intelligent sensors, information equipment, and human interfaces that support emergency responses such as urban search and rescue, particularly victim search, information gathering, and communication. Typical tech-

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nologies are teleoperated robots for victim search in hazardous disaster areas, and robotic systems with distributed sensors for gathering disaster information to support human decision making. This chapter introduces the objective of this project, and a brief overview of the research results.

2.1 Objective of the DDT Project

On the basis of the background outlined in the previous chapter, the DDT Project was launched as follows [1]:

Project manager:	Satoshi Tadokoro, Tohoku University
Managing Institute:	International Rescue System Institute
Period:	August 1, 2002–March 31, 2007
Budget:	approximately 400 M JPY a year
Number of researchers:	more than 100

The following mission statement was defined so that disaster response problems can be solved using robots and related technologies.

DDT Project will research and develop robots, intelligent sensors, information equipment, human interfaces, etc. to support victim search, information gathering, and communications for emergency response such as urban search and rescue in large-scale urban earthquake disasters. These systems and component technologies shall be useful for human disaster response activities and decision making by active intelligent information gathering and network-based information transfer and integration.

Robots are a type of advanced equipment for first responders such as firefighters, policemen, and Self Defense Corps. Such equipment serves the following purposes:

1. substitute for humans in risky tasks;
2. perform jobs that cannot be performed by a human; and
3. enable rapid and sure task execution without fail by humans.

Typical examples are substitution of robots for human tasks in explosive environments and search in inaccessible areas and in narrow gaps.

According to analysis of the Hanshin-Awaji Earthquake, information gathering was the most important issues for first responders. In addition, the technology review showed that robotics is better at information gathering than the other tasks at present and in the near future. Therefore, the DDT Project focused on solutions to the information gathering problem.

Consumer robots, which are expected to become more and more popular world-wide, can have rescue functions added and aid life support in an emergency, although first-responder robots are high-spec systems that are made available in only small numbers to fire departments. Their functions should, for example, complement to ordinary security sensors, alarms at catastrophes, measures for damage reduction, and gathering and transfer of disaster information. For this purpose, the DDT Project researched distributed sensor systems.

Robot technology (RT) has become a popular phrase, denoting technologies related to robots. Its market size is predicted to become 6 trillion JPY in 2025 in Japan. Rescue RT has many common parts with teleoperated or unmanned construction for disaster recovery, plant investigations, maintenance of old facilities, etc. Therefore, the development of rescue technology contributes to disaster mitigation and damage recovery.

2.2 Roadmap for Practical Solutions

The roadmap of the DDT Project is shown in Fig. 2.1. In the first 2–3 years, it concentrated on the trial of technologies that had not been well applied to the disaster problem; the purpose was to enhance the range of applicable technologies. In the last 2–3 years, potential technologies were intensively researched, and integrated systems were developed to serve the expected functions.

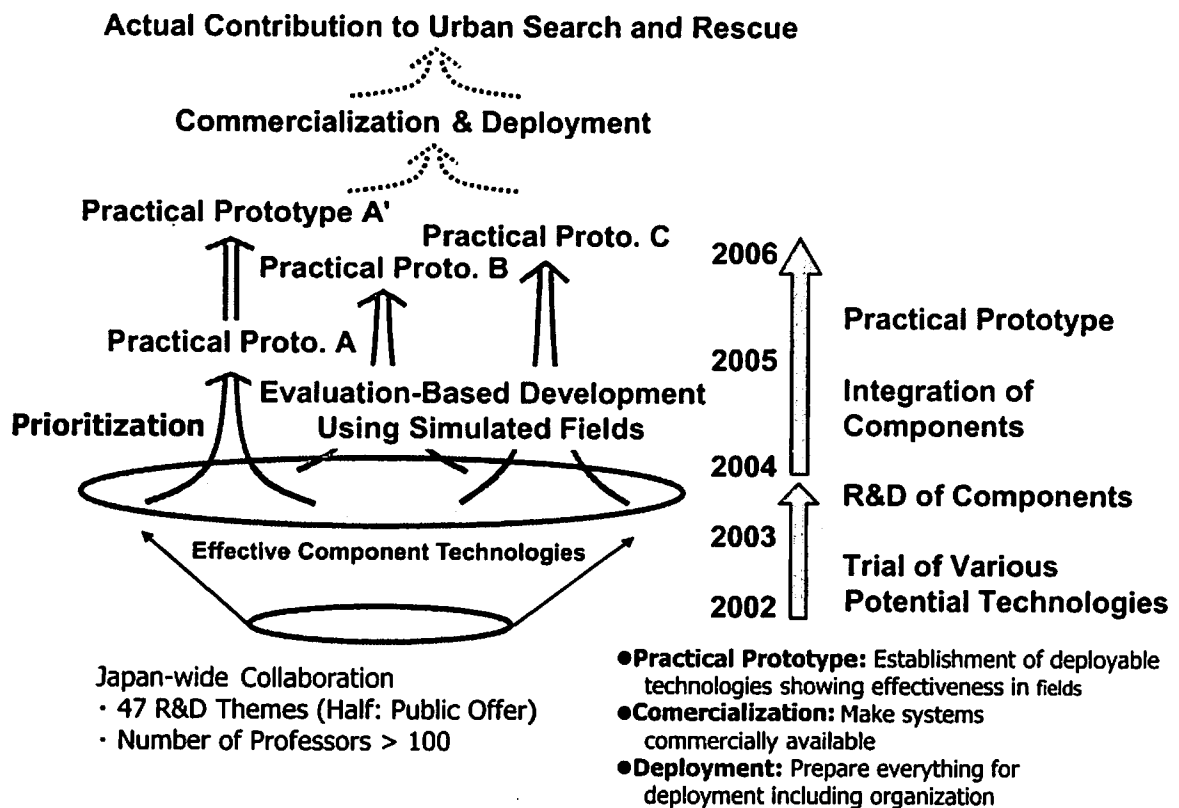


Fig. 2.1 Roadmap of the DDT Project

For this project, International Rescue System Institute (IRS) established two laboratories in Kawasaki and Kobe, as shown in Figs. 2.2 and 2.3. These laboratories have test fields for developed systems that simulate disaster situations. The Collapsed House Simulation Facility in the Kobe Laboratory, shown in Fig. 2.4, is a collapsed wooden house as observed in the Hanshin-Awaji Earthquake. The func-

tions of these test fields are to conduct repetitive experiments and develop improved systems, in addition to the demonstration of developed systems and technologies in realistic situations at every stage of the project. In other words, the laboratories and facilities were used not only to achieve academic/technical results but also for practical deployment of systems and technologies in the future.

Fig. 2.2 Kawasaki Laboratory of International Rescue System Institute (IRS)



Fig. 2.3 Kobe Laboratory of International Rescue System Institute (IRS)



Fig. 2.4 Collapsed House Simulation Facility of IRS Kobe Laboratory



The DDT Project has performed intensive on-site experiments and demonstrations. Experiments at the site of Niigata-Chuetsu Earthquake, training site of Tokyo Fire Department Hyper Rescue, training sites of Federal Emergency Management Agency task forces, Collapsed House Simulation Facility, Kawasaki Laboratory, and Kobe Laboratory have produced a wide spectrum of lessons and knowledge for researchers and first responders. Practical demonstrations given at the World Conference on Disaster Reduction, training site of the International Disaster Relief Team of Japan, National Rescue Meet, Search and Rescue Workshop, disaster drills, expositions, and exhibitions have brought rescue robots to the recognition of first responders and general public.

This research aimed at creating various practical technologies to establish the fundamentals of disaster mitigation assisted by robots at the end of the project. The definition of the word *practical* in this project is to realize technologies applicable to disaster so that experiments at real or realistic test sites demonstrate the effectiveness of developed robots and systems. The following activities are necessary in order for these technologies to be used in a real disaster.

Research:	researchers create new functions.
Development:	first responders recognize satisfactory functions after improvement by researchers and engineers to practical level.
Commercialization:	cost and reliability are improved, and first responders can purchase the solution.
Deployment:	first responders and responding organizations can use the solution any time.
Training:	first responders can use the solutions effectively and smoothly.
Actual Results:	first responders have used the solutions and believe their good performance.

Most research members of the DDT Project were from universities. The market for developed robots and systems is not established at present, and private companies hesitate about commercialization. Procurement and deployment are dependent on government policies. First responders' opinions and evaluation are important. Under this situation, the duration of the DDT Project is too short to complete all the above activities, although it has made huge efforts on these items as part of the program. Further effort must be continued by company–government–academia–private collaborations.

The DDT Project consisted of the following four mission units as research groups in 2005–2006:

1. **Aerial Robot System Mission Unit (ARS)** Intelligent helicopters, balloons, image processing, and human interface.
2. **Information Infrastructure System Mission Unit (IIS)** Distributed sensors, RFID tags, integration protocol, database, and mapping.
3. **In-Rubble Robot System Mission Unit (IRS)** Serpentine robots, advanced rescue tools, advanced search cams, advanced fiber scopes, sensors, and human interface.
4. **On-Rubble Robot System Mission Unit (ORS)** Tracked vehicles, jumping robot, ultrawideband (UWB) radar, semi-autonomous movement, ad-hoc com-

munications, self-localization and mapping, human interface, and sensor data processing.

At the beginning of the project, 47 research themes were explored by 31 groups in order to assess various technologies according to the roadmap. In 2004, the themes were merged or abolished into nine tasks consisting of six task forces (TFs) defined by types of robots (Aerial Robot System TF, Information Infrastructure TF, In-Rubble Robot System TF, Advanced Tool TF, On-Rubble Robot System TF, Underground Robot System TF) and three TFs defined by common technologies (Control Human Interface TF, Communication and Data Format TF, Field and Evaluation TF) so that system integration is accelerated. In 2005, the TFs were integrated into the above four MUs in order to promote further collaboration of research members.

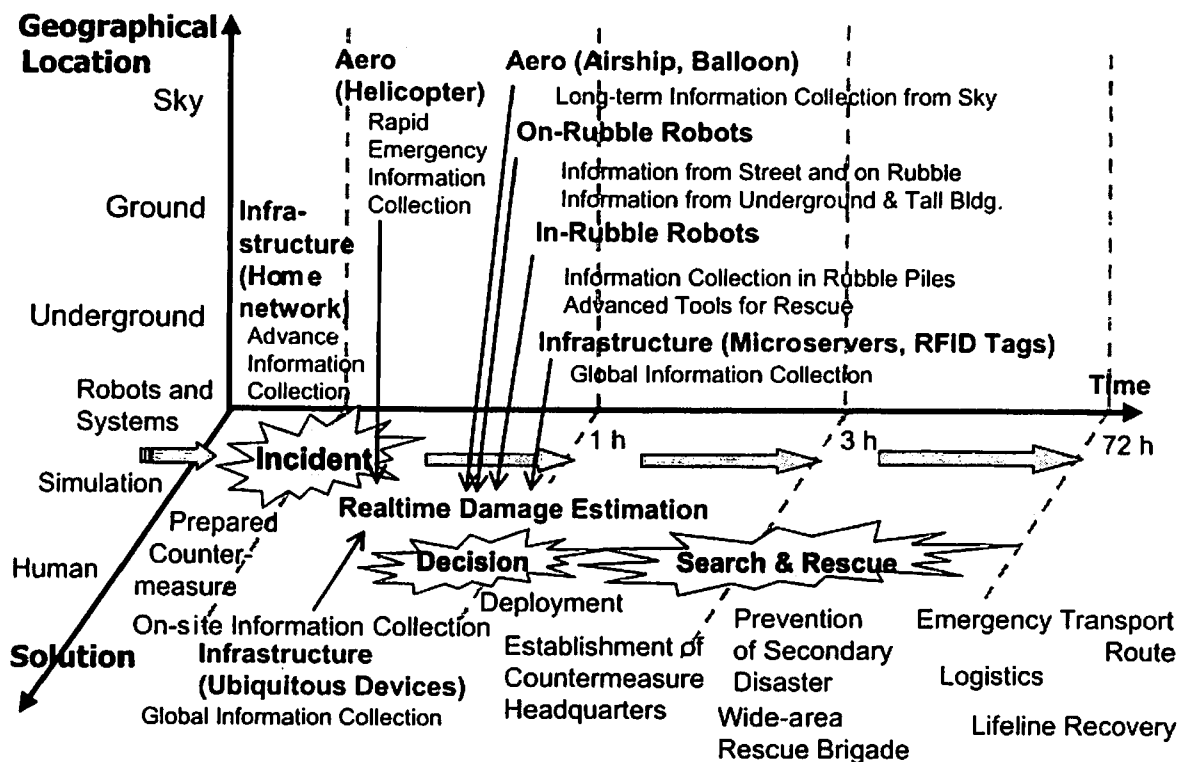


Fig. 2.5 Scenario by which research results are used in disaster

2.3 Disaster Response Scenario Using Developed Robots and Systems

The research results of the DDT Project are classified according to their usage as follows:

1. **Equipment and systems for first responders** Serpentine robots (Souryu, MOIRA, KOHGA, etc.), tracked vehicles (HELIOS, ACROS, Hibiscus, Alibaba, etc.), jumping robot (Leg-in-Rotor), advanced rescue tools (jack robot,

Bari-Bari, etc.), advanced search cam (KURUKURU, intelligent search cam, etc.), advanced fiber scope (Active Scope Camera, etc.), ultrawideband radar, wireless triage tags, etc.

2. **Technologies for equipment and systems** Methods for sensor information processing and image processing, algorithms for semiautonomous motion, human interface, etc.
3. **Equipment and systems for disaster response organizations** Intelligent helicopters (intelligent aerorobot, etc.), balloons (InfoBalloons, etc.), database (DaRuMa), protocol (MISP), etc.
4. **Infrastructure for houses** Distributed sensors (Rescue Communicator), etc.
5. **Information support for refugees** RFID tags, etc.

The phase of a disaster changes as time passes. The DDT Project assumes the following scenario for each phase, as shown in Fig. 2.5:

1. **Preparedness and detection of ominous presence** Watching for human existence in buildings using distributed sensors and home appliances.
2. **Response** Disaster information is quickly gathered by the distributed sensors and autonomous intelligent helicopters and is provided to emergency headquarters via GIS.
3. **Emergency countermeasures** Robots and advanced equipment are used for victim search in rubble piles and underground structures. Balloons and air ships perform fixed-point observation from the sky. IC tags support rescue activities.
4. **Recovery support** Moving state of refugees is monitored by IC tags.

If the research results are applied to a real earthquake disaster in the future, the following disaster response will be possible:

1. All the systems have been deployed and used in regular training. Common Geographic Information System (GIS) is ready in addition to the robotic systems.
2. Systems of IIS are continuously monitoring the situation in houses.
3. Large-scale urban earthquake disaster occurs.
4. Information about residents which has been gathered by distributed sensors, Rescue Communicators of IIS, is transferred to disaster response organizations immediately after receiving Earthquake Early Warning (EEW)¹ before the event.
5. Intelligent helicopters, intelligent aerorobot of ARS, automatically fly to gather overview information of the affected area by cameras and laser profilers rapidly within 30 min.
6. Human first responders make decisions on the basis of the information gathered. Human responders carrying the developed systems are put in action.
7. InfoBalloons of ARS fly and stop in the air or move slowly. They gather victim information using infrared cameras in cooperation with IIS Rescue Communicators and mobile phones, collect overview information using cameras and laser

¹ EEW system of Japan Meteorological Agency (JMA) provides advance announcement of the estimated seismic intensities and expected arrival time of principal motion using the difference of speed between the primary wave and the secondary wave of an earthquake.

- profilers, and support human responders and the other robotic systems by position identification and communication transfer.
8. ORS Robots are brought by first responders to the disaster site. They move 50 m in rubble piles and on rubble piles to collect victim information and to investigate structural damage and hazardous materials using camera, infrared camera, temperature sensors, gas sensors, and so on, and report to the first responders. They enter 200 m into underground structures and buildings which have limited damage.
 9. IRS Robots and advanced tools are carried by first responders to the side or the top of rubble piles. They enter 30 m into the rubble piles via narrow clearances using teleoperation to gather information by the sensors.
 10. All the information gathered is recorded and mapped on to a GIS, DaRuMa, using a standardized protocol (Mitigation Information Sharing Protocol; MISP) so that the first responders and disaster managers can use it for decision making and operational support.

2.4 Brief Overview of Major Results

Major results are briefly introduced in this section. Details are given in other chapters and in papers in references.

2.4.1 Aerial Robot System MU

MU leader: Masahiko Onosato, Hokkaido University

MU subleader: Hiroaki Nakanishi, Kyoto University

2.4.1.1 Intelligent Helicopter, Intelligent Aerorobot

The small-size autonomous unmanned helicopter shown in Fig. 2.6 takes off immediately after the shake to gather information at less altitude with lower noise than manned helicopters. Technologies for stable flight in strong wind and simple teleoperation have been developed.

2.4.1.2 Balloon for Stationary Measurement, InfoBalloon

InfoBalloon, shown in Fig. 2.6, is airborne for a long period for stationary measurement and information support of ground operation. Robustness against wind is an advantage of this balloon.

Fig. 2.6 Experiments on intelligent aerorobot and InfoBalloons in Yamakoshi Town, which was struck by Niigata-Chuetsu Earthquake in 2005



2.4.2 Information Infrastructure MU

MU leader: Hajime Asama, The University of Tokyo

MU subleader: Itsuki Noda, AIST

2.4.2.1 Distributed Sensor, Rescue Communicator

Rescue Communicators shown in Fig. 2.7 are installed in houses as distributed sensor equipment, and they gather survivors' information by verbal contact. The information is transferred to disaster mitigation organizations by a home network and an ad-hoc network.

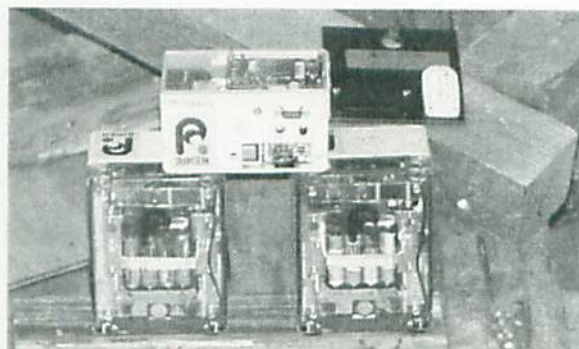


Fig. 2.7 Rescue Communicator and wireless triage tag (upper right)

2.4.2.2 RFID Tags for Triage Tag and Rescue Completion Tag

The wireless triage tag shown in Fig. 2.7 contributes to efficient logistics for rescued survivors using an RFID tag. The rescue completion tag is hung on the rescue site and stores the search and rescue information. This helps to avoid repetitive operations and thereby improves the efficiency of the overall operation.

2.4.3 In-Rubble Robot System MU

MU leader: Koichi Osuka, Kobe University

MU subleader: Koichi Suzumori, Okayama University

Tomoharu Doi, Osaka Prefectural College of Technology

Yasuyoshi Yokokohji, Kyoto University

2.4.3.1 Serpentine Robots, IRS Souryu, MOIRA, KOHGA, etc.

Various types of serpentine mobile mechanisms were researched and tested. The objective of these developments is to enable search in narrow clearances wider than 30 cm in collapsed structures. The developed robots have been intensively tested in rubble piles.

2.4.3.2 Hyper Souryu IV

A wide range of component technologies, which include a cable-type positioning system FST, a multi-camera system, a bird's-eye-view synthesis system using a past image, a multi-range finder, and a driving mechanism for pivot turn, were integrated into a new serpentine robot Hyper Souryu IV, as shown in Fig. 2.8. The mobility, teleoperability, position identification, and situation awareness were improved from its previous version, IRS Souryu.

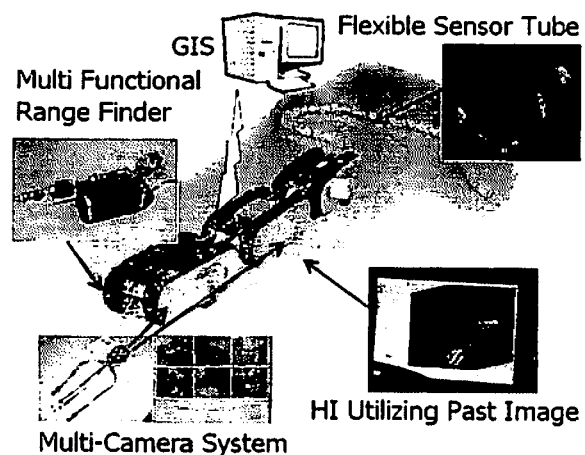


Fig. 2.8 Hyper Souryu IV with integration of component technologies

2.4.3.3 Advanced Rescue Tools

In order to improve firefighter's equipment, an intelligent search cam that measures the shape of a void in rubble piles, a search cam Kurukuru that is powered by hand

electric generator, a jack robot for search and rescue inside rubble piles, another jack robot Bari-Bari for prying open a narrow clearance, a pneumatic jack, a cutter robot, etc. were developed.

2.4.3.4 Advanced Video Scope, Active Scope Camera

Adding actuators on to the surface of the cable of the rescue video scope gives Active Scope Camera (ASC) (shown in Fig. 2.9) which moves by itself into clearance more than 3 cm wide. The accessible distance was significantly improved.



Fig. 2.9 Experiments on Active Scope Camera at the Collapsed House Simulation Facility of IRS Kobe Laboratory

2.4.4 On-Rubble Robot System MU

MU leader: Fumitoshi Matsuno, The University of Electro-Communications
MU subleader: Takashi Tsubouchi, University of Tsukuba

2.4.4.1 Mobile Vehicles for Rough Terrain, HELIOS VIII, HELIOS Carrier, ACROS, FUMA, Hibiscus, Ali-baba, etc.

HELIOS VIII is an information gathering tracked UGV for damaged buildings with large space and has high environment resistance. HELIOS Carrier shown in Fig. 2.10 was developed by connecting two tracked bodies in order to improve mobility at steps and by integrating component technologies, which include a bird's-eye-view synthesis system for teleoperation human interface using a past image shown in Fig. 2.11, an image vibration reduction system for avoiding virtual reality

sickness,² autonomous 3D map generation, and a teleoperation interface using the 3D image. Various types of UGVs such as ACROS, FUMA, Hibiscus, and Ali-baba were developed.

2.4.4.2 Jumping Robot

A jumping robot Leg-in-Rotor-V with super mobility on rubble can move for a long period using a new type of pneumatic power source utilizing the triple point of carbon dioxide by which dry ice can supply a sufficient volume of air at constant pneumatic pressure.

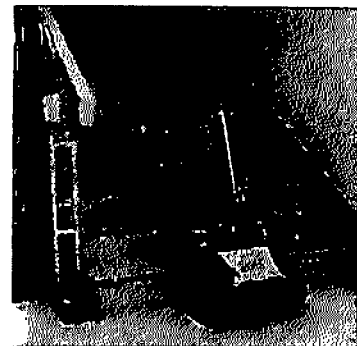


Fig. 2.10 HELIOS Carrier climbing up steps

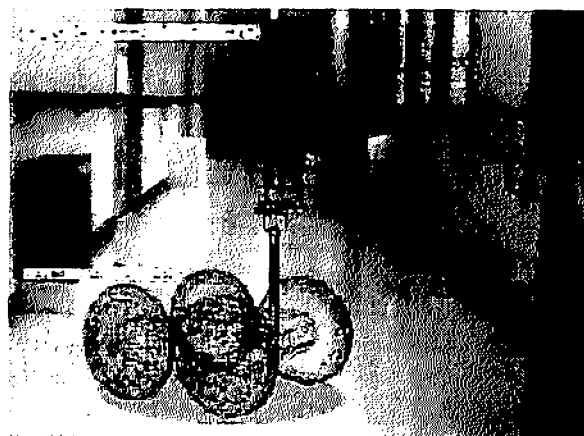


Fig. 2.11 Virtual bird's-eye-view synthesis system utilizing past image for teleoperation to enable easy navigation

2.4.4.3 Ultrawideband Radar

An ultrawideband radar sensor and signal processing technology improved the performance of detecting human breathing in rubble piles.

² When human uses virtual reality devices or makes teleoperation of moving vehicles for a long time, a symptom like car sickness sometimes appears. It is called virtual reality sickness.

2.4.4.4 Human Interface

A guideline for a human interface was developed aiming at future standardization.

2.4.5 Integration of Gathered Information

All the gathered data are integrated into the distributed database DaRuMa (DAtabase for RescUe Management) via an XML-type standardized protocol MISP (Mitigation Information Sharing Protocol), and can be referred to and searched by SQL commands and viewers such as Google Earth™, as shown in Fig. 2.12. The information in the database can be attributed, added, and processed later via internet. It will improve the efficiency of decision making. Verification experiments in Yamakoshi Town and the Collapsed House Simulation Facility demonstrated the integration capability of data sent from various robots.

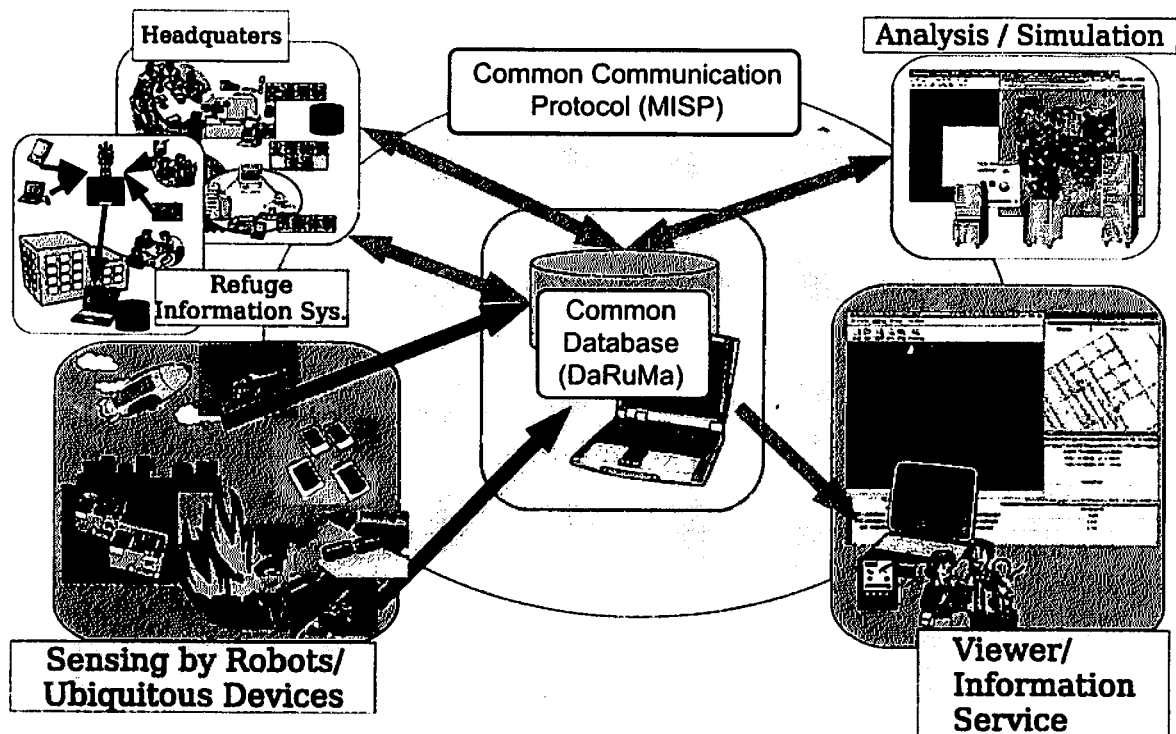


Fig. 2.12 Integration of data gathered by robots and systems using Mitigation Information Sharing Protocol (MISP) into the DaRuMa database

2.4.6 Verification Experiments and Exercise

A number of field experiments, demonstrations, and exercises were performed in order to enable the future deployment of the developed systems and technologies. Firefighters in active service organized a volunteer unit IRS-U, and carried out intensive tests and demonstrations to evaluate research results (Fig. 2.13). First responders in FEMA evaluated the robots at their training sites in meetings to standardize rescue robot evaluation methods and metrics organized by NIST and ASTM (Fig. 2.14). The general public has recognized rescue robotics research through the medium of many exhibitions and demonstrations, and via mass media.



Fig. 2.13 Volunteer unit IRS-U organized by firefighters in active service



Fig. 2.14 Experiments by FEMA first responders at the Texas TF-1 training site, Disaster City of Texas A&M University

2.5 Conclusions

This chapter introduced an overview of the DDT Project including a brief description of major results.

At the time of the Hanshin-Awaji Earthquake in 1995, the phrase “a rescue robot” meant a virtual creature in science fiction and cartoon animation. However, the DDT Project has established rescue robotics research field in Japan by proposing that the disaster mitigation problem is an important application area for robotics. Various systems and technologies have been developed and tested in real/realistic fields by four mission units (MUs): Aerial Robot System MU, Information Infrastructure System MU, In-Rubble Robot System MU, and On-Rubble Robot System MU.

Communication between robotics researchers, first responders and disaster scientists has become smoother through intensive experiments, demonstrations, and exercises.

The research and development of rescue robots and systems should continue to make a real contribution to disaster reduction. We hope this DDT Project has established the fundamentals for progress of this technology.

The authors thank all the people concerned and sincerely appreciate their contributions.

References

1. Tadokoro S et al (2003–2007) Reports of Special Project for Earthquake Disaster Mitigation in Urban Areas, III-4 Development of Advanced Robots and Information Systems for Disaster Response. Ministry of Education, Sports, Culture, Science and Technology, National Research Institute of Earth Science and Disaster Prevention, International Rescue System Institute (in Japanese)