

Contents

List of Contributors	xv
Acronyms	xxi
1 Earthquake Disaster and Expectation for Robotics	1
<i>Satoshi Tadokoro</i>	
1.1 Frequent Occurrence of Large-Scale Earthquakes	1
1.2 Damage Caused by Earthquake Disasters	5
1.3 Japanese Government Disaster Management Plan	6
1.4 Examples of Countermeasures	9
1.5 Urban Search and Rescue (USAR)	10
1.6 Current Advanced Equipment for Urban Search and Rescue	12
1.7 Expected Contribution of Robotics	13
1.8 Conclusions	15
References	16
2 An Overview of the DDT Project	17
<i>Satoshi Tadokoro, Fumitoshi Matsuno, Hajime Asama, Masahiko Onosato, Koichi Osuka, Tomoharu Doi, Hiroaki Nakanishi, Itsuki Noda, Koichi Suzumori, Toshi Takamori, Takashi Tsubouchi, Yasuyoshi Yokokohji, and Mika Murata</i>	
2.1 Objective of the DDT Project	18
2.2 Roadmap for Practical Solutions	19
2.3 Disaster Response Scenario Using Developed Robots and Systems	22
2.4 Brief Overview of Major Results	24
2.4.1 Aerial Robot System MU	24
2.4.2 Information Infrastructure MU	25
2.4.3 In-Rubble Robot System MU	26
2.4.4 On-Rubble Robot System MU	27
2.4.5 Integration of Gathered Information	29
2.4.6 Verification Experiments and Exercise	30

2.5	Conclusions	30
	References	31
3	Disaster Information Gathering Aerial Robot Systems	33
	<i>Masahiko Onosato, Satoshi Tadokoro, Hiroaki Nakanishi, Kenzo Nonami, Kuniaki Kawabata, Yasushi Hada, Hajime Asama, Fumiaki Takemura, Kiyoshi Maeda, Kenjiro Miura, and Atsushi Yamashita</i>	
3.1	Introduction	34
3.2	Aerial Robot Systems for USAR	34
3.2.1	Utilization of Aerial Robot Systems	34
3.2.2	Information Gathering from the Sky	35
3.2.3	Distinctive Aspects of Aerial Robot Systems	35
3.3	Designing Aerial Robot Systems	37
3.3.1	Three Phases of USAR Operations	37
3.3.2	Aerial Robot Team for USAR	37
3.3.3	Action Scenario of Aerial Robot Systems for USAR	38
3.4	Aerial Robot Systems Developed by AIR MU	40
3.4.1	Autonomous Unmanned Helicopter (Medium-Sized Vehicle)	40
3.4.2	Autonomous Unmanned Helicopter (Small Vehicle)....	42
3.4.3	Autonomous Blimp-Type Robot System	43
3.4.4	Cable-Driven Balloon Robot System	44
3.4.5	Captive Balloon Robot System	47
3.4.6	Image Clearing for Field Camera Systems	48
3.5	Field Test of Aerial Robot Systems at Yamakoshi	49
3.6	Summary of R&D Results by the AIR MU	52
3.7	Conclusions	53
	References	54
4	Information Infrastructure for Rescue Systems	57
	<i>Hajime Asama, Yasushi Hada, Kuniaki Kawabata, Itsuki Noda, Osamu Takizawa, Junichi Meguro, Kiichiro Ishikawa, Takumi Hashizume, Tomowo Ohga, Kensuke Takita, Michinori Hatayama, Fumitoshi Matsuno, and Satoshi Todokoro</i>	
4.1	Introduction	58
4.2	Rescue Infrastructure	58
4.2.1	Information Collection and Sharing in the DDT Project ..	58
4.2.2	R&D Activity Overview in Infra-MU	59
4.3	Development of Ubiquitous Devices for Collecting and Providing Information	60
4.3.1	Development of Rescue Communicator	60
4.3.2	Verbal Victim Search by R-Comms	61
4.3.3	RF-ID-Based Emergency Information Collection and Delivery System	63
4.4	Disaster Information Collection and Data Integration Using Dynamic Communication Networks	65

4.4.1	Protocols for Rescue Information Collection and Common-Use Database for Data Integration	65
4.4.2	Experiments on Rescue Information Collection and Integration	66
4.5	Conclusions	68
	References	68
5	In-Rubble Robot System for USAR Under Debris	71
	<i>Koichi Osuka, Tomoharu Doi, Satoshi Tadokoro, Naoji Shiroma, Takashi Tsubouchi, Hideyuki Tsukagoshi, Shigeo Hirose, Fumitoshi Matsuno, Takumi Hashizume, Masamitsu Kurisu, Hiroyuki Kuwahara, Toshi Takamori, Yasuyoshi Yokokohji, Shugen Ma, Tatsuo Arai, and Koichi Suzumori</i>	
5.1	Collection of Information Under Debris	72
5.2	In-Rubble Search System	73
5.2.1	In-Rubble Search Robot System: Hyper Souryu IV	73
5.2.2	Advanced In-Rubble Searching Tool	75
5.2.3	Carrier Vehicle for Rescue Materials and Equipment for Operation on Irregular Surfaces	76
5.3	Components of In-Rubble Searching System	78
5.3.1	Development of In-Rubble Searching Serpentine Robot Souryu IV	78
5.3.2	Generation of Three-Dimensional Map of Rubble by Mobile Robot	79
5.3.3	Development of Built-In-Type Multiple Vision System	81
5.3.4	Bird's-Eye-View Synthesis Control System	83
5.3.5	Flexible Sensor Tube	86
5.3.6	Hyper Souryu IV	87
5.4	Advanced Tools	88
5.4.1	Human-Powered Moving Search Cam	88
5.4.2	Jack Robot, Compact Jack Robot, and Cutter Robot	90
5.4.3	Jack-Up Mobile Body (Bari-Bari-I and II)	92
5.4.4	Intelligent Search Cam	93
5.4.5	Pneumatic Jack	96
5.4.6	Active Scope Camera	97
5.5	BENKEI-2: Carrier Vehicle for Rescue Materials and Equipment for Operation on Irregular Ground Surfaces	98
5.6	Conclusions	102
	References	102
6	On-Rubble Robot Systems for the DDT Project	105
	<i>Fumitoshi Matsuno, Takashi Tsubouchi, Shigeo Hirose, Iwaki Akiyama, Takao Inoh, Michele Guarnieri, Kenji Kawashima, Takahiro Sasaki, Naoji Shiroma, Tetsushi Kamegawa, Kazunori Ohno, Satoshi Tadokoro, Noritaka Sato, Yoshikazu Inoue, Takahide Takeuchi, Hideyuki Tsukagoshi, Masashi Sasaki, Ato Kitagawa, Takahiro Tanaka, Yasuhiro</i>	

Masutani, Haruo Soeda, Koichi Osuka, Masamitsu Kurisu, Tomoharu Doi, Tadahiro Kaneda, Xin-Zhi Zheng, Hiroshi Sugimoto, Noriyuki Matsuoka, Teruaki Azuma, and Masahiro Hatsuda

6.1	Introduction	106
6.2	Development of HELIOS	107
	6.2.1 HELIOS VII Concept	107
	6.2.2 Development of HELIOS VIII	109
6.3	Development of HELIOS Carrier	109
	6.3.1 HELIOS Carrier	109
	6.3.2 HELIOS Carriers Connected with an Arm Using Pneumatic Artificial Rubber Muscles	111
6.4	Development of Leg-in-Rotor-V	111
6.5	UWB Radar System	115
	6.5.1 Equipments	115
	6.5.2 Experiments	115
6.6	Rescue Dummy	118
	6.6.1 Development of Integrated Model	118
	6.6.2 Whole-Body Tactile Force Sensor System	120
	6.6.3 Simulation of Body Temperature Using MEPCM	120
	6.6.4 Passive Musculoskeletal Model of Shoulder Complex	121
	6.6.5 Quantification of Pains by Pressure Stimulus	122
6.7	Human Interface	122
	6.7.1 Robot Teleoperation	122
	6.7.2 Synthesis of Bird's-Eye-View Images to Improve Remote Controllability	123
6.8	3D Map Building and 3D Virtual Bird's-Eye-View for Control Interface	125
	6.8.1 3D Scanner and 3D Map Building Method	126
	6.8.2 Virtual Bird's-Eye-View for Control Interface	126
	6.8.3 Dense 3D Map Building and Its Coloring	128
6.9	Concluding Remarks	128
	References	129

7 Design Guidelines for Human Interface for Rescue Robots 131

Yasuyoshi Yokokohji, Takashi Tsubouchi, Akichika Tanaka, Tomoaki Yoshida, Eiji Koyanagi, Fumitoshi Matsuno, Shigeo Hirose, Hiroyuki Kuwahara, Fumiaki Takemura, Takao Ino, Kensuke Takita, Naoji Shiroma, Tetsushi Kamegawa, Yasushi Hada, Xin-Zhi Zheng, Koichi Osuka, Taro Watasue, Tetsuya Kimura, Hiroaki Nakanishi, Yukio Horiguchi, Satoshi Tadokoro, and Kazunori Ohno

7.1	Introduction	132
7.2	Guidelines for Display Design	133
	7.2.1 Multiple Image Display	133
	7.2.2 Situational Arrangement of Windows	137

- 7.2.3 Visibility of Display Devices 138
- 7.2.4 Pointing Device and Dust/Water Proofing 139
- 7.3 Standardized Interface 140
 - 7.3.1 Window Arrangement Utility 140
 - 7.3.2 High-Intensity Display 141
 - 7.3.3 Optical Touch Screen 141
 - 7.3.4 Standardized Interface Prototype 141
- 7.4 Conclusions 143
- References 144

8 Information Sharing and Integration Framework Among Rescue Robots/Information Systems 145

Itsuki Noda, Yasushi Hada, Jun-ichi Meguro, and Hiroki Shimora

- 8.1 Motivation 145
- 8.2 Information System in the DDT Project 146
 - 8.2.1 Requirements for the Rescue Information System 146
 - 8.2.2 Mitigation Information Sharing Protocol 148
 - 8.2.3 DaRuMa 149
 - 8.2.4 Advantage of DaRuMa/MISP 149
- 8.3 Flexible Representation for Disaster Information 151
 - 8.3.1 Representation for Sensed Data 151
 - 8.3.2 Flexible Time Representation 152
- 8.4 System Integration via DaRuMa/MISP 154
- 8.5 Conclusions 157
- References 158

9 Demonstration Experiments on Rescue Search Robots and On-Scenario Training in Practical Field with First Responders 161

Takashi Tsubouchi, Koichi Osuka, Fumitoshi Matsuno, Hajime Asama, Satoshi Tadokoro, Masahiko Onosato, Yasuyoshi Yokokohji, Hiroaki Nakanishi, Tomoharu Doi, Mika Murata, Yuko Kaburagi, Ikuko Tanimura, Naoko Ueda, Ken'ichi Makabe, Koichi Suzumori, Eiji Koyanagi, Tomoaki Yoshida, Osamu Takizawa, Toshi Takamori, Yasushi Hada, and Itsuki Noda

- 9.1 Introduction 162
- 9.2 Who Is the User? 162
- 9.3 Progress of the Development of the Rescue Search Devices and IRS-U 163
- 9.4 Toward Practice Experiments and Training 166
 - 9.4.1 Policies 166
 - 9.4.2 Commentaries 167
- 9.5 Details of Experiments and Training at the Underground Town of JR East Kawasaki Station 168
 - 9.5.1 Scenario and Snapshots of the Experiments and Training 168
 - 9.5.2 Observation Report from the IRS-U Staff 171
 - 9.5.3 Overall Evaluation from the Robot Development Team .. 173
- 9.6 Conclusions 174

- 10 Summary of DDT Project, Unsolved Problems, and Future Roadmap** 175
- Satoshi Tadokoro*
- 10.1 Summary of DDT Project 175
- 10.2 Unsolved Technical Problems 178
 - 10.2.1 Collection of Overview Information of Disasters 179
 - 10.2.2 Search and Diagnosis of Victims and Quantitative Investigation of Structural Damage 179
 - 10.2.3 Physical Rescue of Victims and Prevention of Damage Propagation 182
- 10.3 Common Problems of Robot Technologies 182
 - 10.3.1 Mobility and Task Execution Performance 182
 - 10.3.2 Human Interface for Teleoperation and Information Transfer 183
 - 10.3.3 Wireless Communications 183
 - 10.3.4 Localization, Information Mapping, and Integration 184
 - 10.3.5 Cooperative Task Execution 184
 - 10.3.6 Reliability in Disaster 184
 - 10.3.7 Evaluation Metrics 185
 - 10.3.8 Improvement of Fundamental Performance 185
- 10.4 Future Roadmap 185
 - 10.4.1 Roadmap for 2010 185
 - 10.4.2 Roadmap for 2015 187
- 10.5 Conclusions 189
- References 189

- Index** 191