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Robot-Assisted Risky Intervention, Search, Rescue and Environmental Surveillance

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Abstract: Technology has become the solution to many long-standing problems, and while current technologies may be effective, it is far from fully addressing the huge, complex, difficult and challenging tasks associated with disaster missions and risky intervention. The challenge is in finding creative, reliable and applicable technical solutions in such highly constrained and uncertain environment. In addition, it is necessary to overcome constrains on resources by developing innovative, cost effective and practical technology. Robotics can play important intelligent and technological roles that support first response equipment in harsh and dangerous environments while replacing rescue personnel from entering unreachable or unsafe places. Robotics solutions that are well adapted to local conditions of unstructured and unknown environment can greatly improve safety and security of personnel as well as work efficiency, productivity and flexibility. Solving and fulfilling the needs of such tasks presents challenges in robotic mechanical structure and mobility, sensors and sensor fusion, autonomous and semi autonomous control, planning and navigation, and machine intelligence. This paper categorizes the source of disasters and associated missions, and highlights the needs for suitable and reliable technology and technical and functional requirements of robotic systems to fulfill task objectives. In addition, it shows that robotic technologies can be used for disasters prevention or early warning, intervention and recovery efforts during disasters with all possible kinds of relevant missions while ensuring quality of service and safety of human beings. Some of these missions may include: demining, search and rescue, surveillance, reconnaissance and risk assessment, evacuation assistance, intrusion/victim detection and assessment, etc.

Keywords: Service Robots, Disasters, Search and Rescue, Security, Surveillance, Robot-Assisted Risky Intervention, UGV, UAV, USV, Space Robot, Medical Robot

1. Introduction

It is possible to categorize disasters into, natural disasters, human-made disasters, and human induced disasters. Natural disasters are inevitable and it is almost impossible, to fully recover the damage caused by it. It is a well known fact that natural disasters strikes countries, both developed and developing, causing enormous destruction and creating human sufferings and producing negative impacts on national economies. Sudden natural disasters are often believed to cause not only widespread death but also massive social disruption and outbreaks of epidemic disease and famine that leave survivors entirely dependent on outside relief. However, it is not possible to avoid completely the natural disasters, but the sufferings and potential risks can be minimized by developing disaster early warning strategies, disaster preparedness, management of disasters through application of various technical tools, prepare and implement developmental plans to provide resilience to such disasters and to help in rehabilitation and post disaster reduction. Early successful warning systems are a direct result of the ability to collect, interpret, and disseminate reliable and timely information to populations at risk (Helm, 1996; Smith, 1996; Stenchion, 1997). Common natural disasters are earthquakes, floods, volcanic eruptions, floods, tsunamis, hurricanes, tornados, typhoons, avalanches, tropical storms, forest fires, etc. These disasters may cause collapse of buildings resulting in large rubble piles, toxic gases and radiation, land and mud slide or crater. Specific disasters might occur due to different geographical features of a region (Alexander, 1993, IFRC, 1998; UN-ESC, 2005). Catastrophic natural disasters have caused dollar losses in more than $1000 billion during the past two decades. Human made disasters may include nuclear power plants accidents, wars, minefields, etc. Other hazards may include environmental pollution, extreme weathers, oil spills, chemical, diseases, radiation, etc. Disaster management and risk assessment is an applied science, which seeks, by systematic observation and analysis of disasters, to improve measures related to prevention, mitigation, preparedness, emergency response and recovery. It seeks to motivate societies at
risk to become engaged in conscious disaster management. Disaster reduction is a multi-sector and interdisciplinary in nature and involves a wide variety of interrelated activities at the local, national, regional and international level. Access to information is crucial for the effective management of disasters (Helm, 1996; Smith, 1996; Stenchion, 1997). The players in disaster management team may include governments and international organizations along with a wide range of local players and at all levels. Crisis response includes the logistics of getting medical care, food, water, awareness, shelter, and rescue teams to the scene. Regional, global, local and other resources can be provided to assist those affected. The recovery should encompass both short-term activity intended to return vital life-support systems to operation and longer-term activities designed to return infrastructure systems to pre-disaster conditions. To be prepared for unforeseen events, the integrated players must make contingency plans and coordinate their planning with other agencies and parties involved.

Robotics solutions that are well adapted to local conditions of unstructured and unknown environment can greatly improve safety and security of personnel as well as work efficiency, productivity and flexibility. Solving and fulfilling the needs of such tasks presents challenges in robotic mechanics and mobility, sensors and sensor fusion, autonomous or semi autonomous navigation and machine intelligence. Advancement in information and communication technologies along with remote sensing, satellite communication, GPS, and GIS technologies together with the Internet can help a great deal in planning and implementation of hazards reduction measures.

2. Service Robots

A robot is usually an extremely flexible and complex machine, which integrates science and engineering. Each technology used in robotic systems has its own challenges to offer. The opportunity for robotics to help humanity arises when there are not enough skilled people available to do certain tasks at a reasonable price, like elder care. Much thought has been put into development of robotic helpers for the infants and elderly. Advances in micro-technology, microprocessors, sensor technology, smart materials, signal processing and computing technologies, information and communication technologies, navigation technology, and biological inspiration in learning and decision-making capabilities have led to breakthrough in the invention of a new generation of robots called service robots. Service robot is a generic term covering all robots that are not intended for industrial use, i.e., perform services useful to the well being of humans, and other equipment (maintenance, repair, cleaning etc.), and are not intended for rationalizing production. The development and operation of service robots provide invaluable experience as they form an intermediate stage in the evolution from the industrial robot to the personal robot, which is recognized as an important application area for the near future. The new types of robots aim to achieve high level of intelligence, functionality, flexibility, adaptability, mobility, intractability, and efficiency to perform wide range of work in complex and hazardous environment, and to provide and perform services of various kinds to human users and society. Crucial prerequisites for performing services are safety, mobility, and autonomy supported by strong sensory perception. Such robots should be good at what they can do, and have the ability to work at a larger degree of unstructured environments. In addition, human-robot interaction plays a crucial role in the evolving market for intelligent personal robots (Habib, 2006).

Service robots are manipulative and dexterous, and have the capability to interact, perform tasks autonomously/semi autonomously (multi modes operation), and they are portable. Three classes of service robots can be distinguished, the first being robots to replace humans at work in dirty, hazardous and tedious operations, such as working under high temperature, in a radioactive environment, in a vacuum, underwater, fire fighting, space, demining, military, construction, cleaning etc. The second class includes robots that operate with human beings to alleviate incommodity or to increase comfort, such as, entertainment, rehabilitation, assist the elderly and severely disabled, housekeeping, etc. The third class includes robots that operate on human being, such as medical robots mainly for surgery, treatment and diagnosis. Service robots with their free navigation capability target a wide range of applications, such as agriculture & harvesting, healthcare/rehabilitation, cleaning (house, public, industry), construction, humanitarian demining, entertainment, fire fighting, hobby/leisure, hotel/restaurant, marketing, food industry, medical, mining, surveillance, inspection and maintenance, search & rescue, guides & office, nuclear power, transport, refilling and refueling, hazardous environments, military, sporting, space, underwater, etc. Such robots aim to offer a useful service with reasonable cost compared to expected duties (Habib, 2006). It is clear that the development of a unique and universal robot that can operate under wide and different task and environmental conditions to meet requirements is not a simple task. Robotics research requires the successful integration of a number of disparate technologies that need to have a focus to develop: flexible mechanics and modular structures, mobility and behavior based control architecture, human support functionalities and interaction, homogeneous and heterogeneous sensors integration and data fusion, different aspect of fast autonomous or semi-autonomous navigation in a dynamic and unstructured environment, planning, coordination, and cooperation among multi robots, wireless connectivity and natural communication with
humans, virtual reality and real time interaction to support the planning and logistics of robot service, and machine intelligence, computation intelligence and advanced signal processing algorithms and techniques. Furthermore, the use of many robots working together and coordinating their movement and actions will speed up the process, improve the productivity by enabling parallel tasks, enhance flexibility and achieve higher quality of service (Habib, 2006; Habib, 2007a; Habib 2008a and b).

3. Robot for Harsh, Demanding or Dangerous Environments: Role and Requirements

Research in search and rescue robotics represents a challenge for technology and techniques to benefit human being and enhance quality of services. Robotics solutions properly sized with suitable modularized mechanized structure and well adapted to local conditions of unstructured and unknown environment can greatly improve safety and security of personnel as well as work efficiency, productivity and flexibility. Intelligent Mobile Robotics Systems begin to emerge in applications related to security and environmental surveillance: prevention of disasters, intervention during disasters with all possible kinds of mission ensuring the safety of the human beings, etc. The application of mobile robots rescue search is actively evolving tools that deal with systems that support first response equipment in disaster missions and risky interventions. Some of these applications may include: the use multiple robots as a team for the purpose to support firemen during firefighting; police during accidents, crimes, rescuing; and disaster agencies with reconnaissance, site evaluation, and human detection, etc.; security agency to support bomb detection and disposal, chemical and biological agent detection, entering collapsed structures to check and detect survivors, etc. In addition, it would be good to mention to the well known EOD and IEDD missions already entrusted to military services in charge of the localization, neutralization and/or removal of explosive devices: humanitarian de-mining campaigns and intervention/inspection by terroristic threats are typical examples of missions that may be conducted with the support of mobile robots.

Inspired by the evolution of robotics in terms of technology, sensors, techniques and application, the International Advanced Robotics Programme (IARP) was established. The general objective of the IARP is to encourage development of advanced robotic systems that can dispense with human work for difficult activities in harsh, demanding or dangerous environments, and to contribute to the revitalization and growth of the world economy. Through several specialized technical workshops, the IARP working groups: HIUDEM (Robotics Assistance to Mine-clearing), SSRR (Safety, security, Rescue Robotics) and RISE (Risky Interventions and Surveillance of the Environment) were focusing on the exchange of informations related to the development of new Robotics systems and applications within the relevant domains.

There are several key specifications and functional requirements that need to be considered when designing an quality robots that suit different missions associated with search and rescue applications. Some of these specifications and functionalities are:

a. The robot should be capable of detecting obstacle, explore its surrounding and reliably navigating collapsed structures. In addition, robots should have the capability to build up reliably maps and localize themselves within the constructed map,
b. the robot should be operational in multi-modes, such as: remotely teleoperated, semi-autonomous, and autonomous modes,
c. Robots within a team should be heterogeneous supporting different physical functionalities, shapes and sizes, and sensing/detection capabilities,
d. Human(s) can be a member within a team of robots and can be assigned flexible role, such as cooperator/coordinator within robotic team,
e. The developed robot should be modularized and reconfigurable,
f. Robots should integrate necessary sensors supported by sensor fusion techniques. This enable the robot to gather information about task environment, task itself, structures and victims covered by debris or trapped and be able to determine their state of health as quickly as possible,
g. Robot should be able to detect audio clues and interpret its meaning successfully,
h. Robots should be able to identify, monitor and report any critical and dangerous circumstances,
i. All selected mechanism, actuators and sensors should be able to function under the critical conditions and range of unknown factors,
j. Robots should have reliable and wideband real-time communications capability to received and disseminate reliably gathered information to the relevant destination,
k. It is important for the robots to have reliable and quality Human-Robot interaction to support awareness, communication, coordination and cooperation,
l. The robot should has the ability to learn and deal with situations in which the task or part of the task may not been fully understood during the development time of the robot,
m. Robots should be protected from waters, chemicals, gases, heat and as relevant to the target application,
n. The developed robot should be compact. Low maintenance, portable and low cost,
o. Robot deployment should be fast with less logistical needs,
p. The robot should be robust and tolerate noise and some level of technical failures.
4. Sensor Systems for Surveillance, Security and Mission Planning

The development of systems allowing environmental surveillance or the optimal execution of missions related to the security implies the design of information tools (Acheroy, 2006). Earth-observing remote sensing systems can be powerful tools for observing:

- Economic activities
- Security activities (change detection – boundary enforcement, etc)
- Environment protection
- Disaster mitigation (rapid all-weather flood assessment – rapid earthquake damage assessment)
- Humanitarian operations

Satellites and high-Altitude unmanned or manned airships (HAAS) are the most adequate mapping tools but present significant differences summarized by the next table (1).

| Optical sensors         | Satellites | HAAS      |
|-------------------------|------------|-----------|
| Revisit time            | 1-26 days  | Continuous|
| Sensor system weight for a given resolution | High       | Low       |
| Optical system quality for a given resolution | High (smaller IFOV) | Lower (larger IFOV) |
| Power requirements      | Low power is required | Low power is required but |
| Possible payload        | High       | Limited (blims volume) |
| Stabilization           | Low (stabilization on trajectory) | Motion compensation is mandatory (effect of wind, etc) |
| Image cost              | High (especially when priority is needed) | Low |
| Image availability      | Difficult  | Immediate |
| Flexibility             | Very low   | High      |
| Possibility to recover the instruments | NO | YES |
| Possibility to adapt and/or enhance the instruments | NO | YES |
| Life time               | Typically 5 years | Can be very long |
| Dedicate to specific application | Low | High |
| Earth coverage          | Global     | Local     |

Table 1. Key differences between Satellite and HASS.

Obviously communication systems with appropriate data link and data storage are key-issues in order to allow the management of the intervention missions that may follow the detection of abnormal and/or risky environmental conditions (minefield, forest fire, earthquake, flood, mud and landslides).

5. Selected Robot Development for Harsh and Risky Environment

Wide range of robots have been developed for different purposes and application domains. Main categories are:

- Unmanned Aerial Vehicles (UAV)
- Unmanned Ground Vehicles (UGV)
- Under Sea Vehicles (USV)
- Space Robots,
- Medical Robots.

Let's have some highlights on the first four categories:

5.1. Unmanned Aerial Vehicles (UAV)

Today high altitude Long Endurance Aircrafts and Airships (Hendrickx & Lavi, 2006) as the Global Observer UAV (20 km altitude; one week + endurance) , the Heron High Altitude UAV (10 km altitude; 50 hours endurance), the Mercator High Altitude UAV (17 km altitude, 70 hours endurance, are, beside the normal use of satellites, considered for their specific advantages, namely:

- Can loiter for lengthy period at optimum altitude
- Above all normal air traffic and winds.
- Line of sight to the horizon is still considerable ~ 500 km
- Can operate in relays
- Generally produce better data resolution than satellites
- Closer to area of interest - therefore less aberrations
- Inherent repositioning capability
- Compared to satellite which is bound to its orbit, ability to recall platform to replace the payload

UAV system must comply with rigorous certification and airworthiness procedures, including communications, flight controls and ground stations, they also have to demonstrate safety in relation to loss of communication with air vehicle, resistance to jamming & correct failure-mode recovery; Sense-and-avoid technology will almost certainly be required.

5.2. Unmanned Ground Vehicles (UGV)

The development and production of inspection and intervention mobile robots, intended for the use by the anti-terrorist units, in particular by police, takes place for many years. Those remote controlled unmanned vehicles consist of a mobility platform with sensors, computers, software (including modules for perception, navigation), power system, transmission link and additional equipment – depending on the purpose of the vehicle.

As an example, the SR-10 Inspector, developed by PIAP (Maslowski, 2006) is equipped with crawler drive with variable geometric structure (See Figure 2). The developed robot can move under difficult terrain conditions, inside of rooms, and also on stairs with maximum speed of over 16 km/h.
While discussing the possibilities of such a robot for executing certain autonomous functions, it should be pointed out, that the peculiarity of the application of this equipment, first of all requires fulfillment of the appropriate procedures and requirements pertaining to the equipment for the Security Services, and also absolute obedience of robot according to the guidance of the operator.

The choice of the sensors is an important parameter by the design of UGV: thanks to the use of distance sensors, robot can react unaided to the appearing obstacles, can avoid collision, can independently move in front or behind operator, or at the defined distance from wall (which is crucial under conditions of heavy smokiness, when the legibility of the image from cameras is limited).

Possible are also more advanced procedures enabling independent movements of robot in an unknown environment, or along a determined path. Thanks to this, such a robot can independently execute the task consisting in monitoring of the areas (e.g. affected by chemical or bacteriological contamination) or in the case of fading of radio transmission, return to the operator independently.

The very essence of the VIEW-FINDER Intelligent Information System is to integrate disparate elements involved in a crisis situation into an info-structure that allows information to be exchanged readily between all of those elements: crisis centres, relevant forces dealing with the crisis (fire fighters, de-bombing squads, police, etc.), robotics platforms and sensors. It implied the implementation of 3D Laser and Stereo-vision reconstruction algorithms, the computation of the traversability of the field wherein the robots move, SLAM algorithms, and an autonomous behaviour based navigation combining way-points trajectories, Joystick correction, obstacle avoidance, chemical sensing and SLAM.

5.3. Under Sea Vehicles (USV)

Underwater robots with many degrees of freedom that can walk and swim flexibly in aqueous or water medium are of great interest for underwater monitoring operations including pollution detection, video mapping, exploration of unstructured underwater environments (Kim et al, 2005; McGovern etal, 2008), cleaning of ship hull and other bodies like cables and pipes. Current research is performed on real time data collection and on remote control in operation of the drones. Surface robots are an answer to dual applications i.e. Defence and Security like Maritime, Mine-Counter-Measures, Maritime Surveillance, Harbour protection, etc.

Examples of such robots are shown in Figure 4. Current research is focused on sensors integration, energy and autonomy, navigation technologies, communication, command, control and information, systems launch recovery, handling and docking.
Interoperability of the component of the various USVs and UUVs under development is also a challenging research topic for the near future. Further challenge is the interpretation of sensor images, especially sonar images. Sonar images are used to find objects under water, like (burried or proud) sea mines, but are often of low resolution and difficult to read by humans. Automated image interpretation would make this difficult and dull job easier and cheaper.
5.4. Space Robots
Space robots have wide and significant range of applications that may include exploration, environmental servicing, assembly, inspection, construction, maintenance, etc. Critical issues that need to be considered when developing space robotics are:

- a. The type of material and necessary protection,
- b. Mobility, and manipulation capabilities,
- c. Teleoperation, hepatic and time delay considerations,
- d. Payload consideration,
- e. Efficient communication and command control structure,
- f. Different type of sensors, sensors integration and sensor fusion,
- g. Level of autonomy and learning capabilities,
- h. Operational power supply and low power consumption,
- i. Etc.

6. Conclusions

The experiences have identified critical technical issues and capabilities of current robots that should be researched and improved. Some of these issues are:

- flexible locomotion system and mobility, intelligent and modularized mechanisms, wireless communications, different sensing capability and techniques for data fusion, learning and decision making capabilities, coordination and cooperation among members of multi robot system, task allocation, power consumption and charging, and human-machine interaction, danger detection and timely decision, etc.

There are many engineering, technical and scientific challenges in the application domains of robotics for disaster missions and risky intervention. Some of the critical challenges are:

- a. When developing search, rescue, and risky intervention robots the application focus should be on using them in places that are either inaccessible by human being or dangerous for human being to work/operate inside it.
- b. Communication and accuracy of date is one of the critical and important issues. Time delay in communication should be kept very small. Reliable communication channels with suitable bandwidth are important.
- c. The physical shape and size of the robot should suit the target application with ability to reconfigure itself into interior spaces. Robots of this type should be heterogeneous with various physical functionalities, hybrid locomotion, and sensing capabilities.
- d. The deployment time should be as short as possible as this will lead to save more lives and avoid dangerous situations.
- e. Navigation, searching, rescuing, operating, task decomposition and achieving strategies should be efficient, robust and reliable.
- f. The robots should have the ability to recognize/detect human and find out his/her health condition including the ability differentiate a person whether he/she is alive for dead, with ability to interact reliably and safely with him/her.
- g. To enable teleoperation under severe circumstances, proper sensor and hepatic interface should be high importance.
- h. The robots should be able to detect, classify and understand the available audio signals within the application environment including speech recognition as relevant.
- i. The robot should have long operational time with a single charging.
- j. Multi-robotic system approach is important to enhance efficiency of task achievement and reduce time required to finish the job. In addition, it will enable proper coordination, communication and cooperation to fulfill the job, issue warning and to reduce possible damage.
- k. It is necessary and important to develop test standard that lead to assure reliable and quality of service. In addition, it is necessary to have information tools to assess the suitability, and availability of technology during the development process.

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