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Risky Intervention and Robotics Challenges

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ABSTRACT

Disasters can be categorized into three groups: natural disasters, human-made disasters, and human-induced disasters. Natural disasters resulting from natural hazards are inevitable and it is almost impossible with the current technologies to fully predict most of them and recovering the damage caused by it. Solving and fulfilling the needs of such tasks presents challenges in robotic mechanics and mobility, sensors and 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. 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.

1. INTRODUCTION

Natural and human made disasters represent a serious disruption of life activities and societies functions, and the risk is the product of vulnerability and hazard that pose threat to people and economy. Disasters can be categorized into three groups (Habib and Baudoin, 2010): natural disasters, human-made disasters, and human-induced disasters. Natural disasters resulting from natural hazards are inevitable and it is almost impossible with the current technologies to fully predict most of them and to recover the damage caused by it. Some of the natural disasters, such as, cyclones, snowstorms, thunderstorms, tsunamis, typhoons, hurricane, and floods can be predicted (AGA, n.d.). 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. 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 warning strategies, disaster preparedness, disaster management supported by 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, 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; International Federation of Red Cross and Red Crescent Societies (IFRC), 1995; UN-Economic and Social Council, 2005).

Recent worst natural disasters example may include: global pandemic (HIV pandemic) (since the 1980s till now), and the H1n1 pandemic (2009), Gujarat earthquake (2001), India, Indonesia-Ache earthquake and associated Tusnami (Indian Ocean) (2004), Hurricane Katrina, USA (2005), Pakistan earthquake (2005), Cyclone Nargis (2008), China, earthquake in the capital of Sichuan (2008), Cyclone Nargis in Burma and Bangladesh (2008), Haiti earthquake (2010), Tohoku earthquake, Japan (2011). The increase in death toll, causalities and economical damages during natural disasters and its aftermath makes impact reduction and prevention of disasters an urgent priority. As it was mentioned in the literature and stated by Gilbert White that, “Floods are acts of nature; but flood losses are largely acts of man”. Hence, it is important to address how advance planning and education affects the impacts of disasters (below). The planning should cover all cycle of disaster (before, during and after) (Bowem and Thomas, 2009). This is achievable if resources and invested by authorities to develop new technologies and by having a better land usages, and environmental and urban planning. Human (man) made hazards or anthropogenic hazards reflect the threats having an element of human intent, negligence, or error, or it involves failures of a man-made system. Examples of recent disasters of this type may include nuclear accidents due to human error (operational or design), hazardous materials leak, such as radiation oil spills, chemical, and radiation and ecological, etc. Finally, human-induced disasters are wide and not fewer than the natural disasters. Human-induced hazards may took place in the form of civil wars, military invasion such as in Iraq and Afghanistan, terrorist attack such as in 11 September 2001 the attack on World Trade Center, land and sea mines, environmental pollution, chemical war heads, etc.

Disaster management and risk assessment is an applied science dealing with the step before, during and after disasters. It seeks, by systematic observation and analysis of disasters for the purpose to improve measures related to prevention, mitigation, preparedness, emergency, response and recovery. It seeks to motivate societies at risk and enhance their awareness 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 and policies at the local, national, regional, and international levels. Access to information is crucial for the effective management of disasters (Helm, 1996; Smith, 1996; Stenchion, 1997; Acheroy, 2006). 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 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.

In general, technology has become the solution to many long-standing problems, and while current technologies may be effective at some levels, it is far from fully ready combating the huge, complex, difficult and challenging tasks associated with disaster missions and risky intervention. The witnessed disasters during the first 15 years of the twenty-first century urging governments and research communities related to the field of emergency search, rescue and hazardous intervention to cooperate and be generous to support the development of novel technology that enhance the efficient of humanitarian operations, save life of people and prepare better environment for living. There is no excuse anymore for governments and relevant international organization to avoid concentrating on this issue and extend the required financial support and expenditure for such technological development and humanitarian relief operations.

2. SERVICE ROBTS: THE INITIATIVE, ROLES AND APPLICATIONS

During the 60s up to the end of 80s, most robotics were related to industries and manufacturing and these robots were called industrial robots that were mainly intended for rationalizing production at a manufacturing site. A robot is usually an extremely flexible and complex machine, which integrates science and engineering. Each technology used in the robotic system 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 infirmed 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 wellbeing 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. 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, firefighting, space, demining, military, construction, cleaning, etc. The second class includes robots that operate with human beings to alleviate in commodity 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 and harvesting, healthcare/rehabilitation, cleaning (house, public, industry), construction, humanitarian demining, firefighting, medical, mining, surveillance, inspection and maintenance, search and rescue, hazardous intervention, assist in recovery from disasters, hobby/leisure, hotel/restaurant, marketing, food industry, entertainment, guides and office, nuclear power, transport, refilling and refueling, hazardous environments, military, sporting, space, underwater, etc. Such robots aim to offer useful services with reasonable cost compared to expected duties (Habib, 2006, 2007, 2008b).

3. LANDMINES: THE PROBLEM AND THE ROLE OF ROBOTICS IN HUMANITARIAN DEMINING

Landmines (anti-tank (AT) and anti-personnel (AP)) are prominent weapon and they are so effective, yet so cheap, and easy to make and lay. Landmines are many in terms of type and size. They are made from a variety of materials, metallic and non-metallic. Most AP mines can be classified into one of four categories: blast, fragmentation, directional, and bounding devices. These mines range from very simple devices to high technology. A mine is detonated by the action of its target (a vehicle, a person, an animal, etc.), the passage of time, or controlled means. AP mines can kill or incapacitate their victims and to deny access to land and its resources. Besides this, the medical, social, economic, and environmental consequences are immense. AP mines can be laid anywhere and can be set off in a number of ways because the activation mechanisms available for these mines are not the same. Activation methods can be classified into three categories, pressure, electronic, and command detonation (remote control). There is variety of delivery modes for rapid emplacement of AP mines.

These modes range from manual emplacement to launchers on vehicles and through both rotary and fixed-wing aircraft. AP mines vary from each other by the explosive load, activation mean, action range, shape and size and the effects they have on human body. The estimated number of emplaced mines is between 60 and 100 million that are scattered in more than 60 countries around the world that need to be cleared (Habib, 2007, 2008a).

Humanitarian demining aims to detect and clear all forms of dangerous battlefield debris (landmines and explosive remnants of war), and other unexploded ordnance that are scattered indiscriminately from the infected are efficiently, reliably and as safely and as rapidly as possible while keeping cost to minimum. This involves a great effort and time, and large risk, which results in high clearance cost per surface unit (Habib, 2008a, b).

The main available demining techniques are: manual (prodding) and it is always associated with the use of metal detector with dogs and other animals; mechanical uses motorized mine clearer, detection techniques and robotization. There are many methods to detect explosives and landmines, such as, electromagnetic, electro-optic, acoustic, biosensors, nuclear quadrupole resonance, thermal, chemical, etc. However, most of them are limited by sensitivity and/or operational complexities due to type of terrain and soil composition, climatic variables, and ground clutter, such as, shrapnel and stray metal fragments that produce great number of false positive signals and slow down detection rates to unacceptable levels. Hence, it is essential to fuse information from more than one sensor and develop data fusion algorithms, and human-machine interface concepts for the elaboration of a multi-sensor system to detect, localize and classify AP landmines.

A portable handheld mine detection approach to sensor movement is slow and hazardous for the individual deminers. Armored vehicles may not thoroughly protect the occupants and may be of only limited usefulness in off-road operations. Most people in the mine clearance community would be delighted if the work could be done remotely through teleoperated systems or, even better, autonomously through the use of service robots. Remote control of most equipment is quite feasible. However, the benefit of mounting a mine detector on a remotely controlled vehicle should have careful considerations that lead to decide whether the anticipated reduction in risk to the operator justifies the added cost and possible reduction in efficiency.

Many efforts have been recognized to develop effective robots for the purpose to offer cheap and fast solutions. Three main directions can be recognized: teleoperated machines, multifunctional teleopeated robot, demining service robots, and unmanned aerial vehicles and airships (Habib, 2007).

Robotics solutions properly sized with suitable modularized mechanized structure and well adapted to local conditions of minefields can greatly improve the safety of personnel as well as work efficiency, productivity and flexibility. Robotics solution can range from modular components that can convert any mine clearing vehicle to a remote-controlled device, to prodding tools connected to a robotic arm, and to mobile vehicles with arrays of detection sensors and area mine-clearance devices. The targeted robot should have the capability to operate in multi modes. It should be possible for someone with only basic training to operate the system. Robots can speed up the clearance process when used in combination with handheld mine detection tools, and they are going to be useful for quick verification and quality control. To facilitate a good robot performance in the demining process, there is a need to employ mechanized systems that are able to remove obstructions that deter manual and canine search methods without severely disturbing soil. Solving this problem presents challenges in the robotics research field and all relevant research areas.

Furthermore, the use of many robots working and coordinating their movement will improve the productivity of overall mine detection and demining process through the use of team of robots cooperating and coordinating their work in parallel to enable parallel tasks (Gage, 1995; Nicoud and Habib, 1995; Habib, 2007). The possible introduction of robots into demining process can be done through surface preparation, mapping and marking, speeding-up detection, and mine removal or neutralization. However, the cost of applying service robot's technologies and techniques must be justified by the benefits it provides. It is clear that the development of a unique and universal robot that can operate under wide and different terrain and environmental conditions is not a simple task. In the short term, it appears that the best use of robotics will be as mobile platforms with arrays of mine detection sensors and area mine clearance devices. Teleoperations are promising but are limited too, because their remote human controllers have limited feedback and are unable to drive them effectively in real time. A possible idea in using robots for demining is to design a series of simple and modularized robots, each one capable of performing one of the elementary operations that are required to effectively clear a minefield. An appropriate mix of such machines should be chosen for each demining task, keeping in mind that it is very unlikely that the whole process can be made fully autonomous (Habib, 2007, 2008b, 2011).

4. ROBOTICS FOR RESCUE, SEARCH, AND HAZARDOUS INTERVENTION

Research in developing robots for rescue, search, and hazardous intervention represents a key 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 (Habib and Baudoin, 2010).

During and after any natural and some human made disasters, there will be large-scale of infrastructure damage, such as collapsed buildings, rubbles, road damages, etc. Current rescue, search and hazardous intervention equipment is often blocked by twisted steel and extrusive objects, rubbles, etc. The use of heavy machinery in such incidents is prohibited because they would destabilize the structure, risking the lives of rescuers and victims buried in the rubble (Ko and Lau, 2009).

During the 1990s, the Awaji earthquake in Japan showed that robotics would be highly effective for urban search and rescue (Tadokoro*et al.*, 1997). However, few researchers at that time had developed robots for urban search and rescue. In 11 September 2001 New York, mobile robots of different sizes and capacities were deployed. These robots range from tethered to wireless operated, and from the size of a lunch box to the size of a lawnmower (Snyder, 2001). In the last Tohoku earthquake, tsunami and nuclear incident in Fukushima (2011), we can easily recognize aerial and water-based aspects of disasters. Robotics was deployed: Westinghouse used the Honeywell UAV to sample radiation and get close up views of structural damage. Marine robots have been used to monitor pollution in the sea. In addition, remotely operated vehicles have been used helping to gather forensic data on sinking's and support divers repair and refloat ships. In Fukushima, decontamination robots are heavily in use after the disaster. Teleoperated search and rescue robots that can navigate deep into rubble to search for victims and to transfer critical field data back to the control station has gained much interest among emergency response institutions. Experiences show that current robots are not designed to cope with nuclear disasters efficiently, due to the vulnerability of sensors and integrated circuits in general to radiation. In addition, teleoperated robotic system facing critical problems in communication when they are inside nuclear plant due to shield impact on communication and visibility problems. In addition, robots developed to deal with coal mining accident; radio control is a challenging problem facing them when they work underground.

The developed of mobile robots for search and rescue operations should be rugged in design and equipped with different functionality and accepted level of autonomy for survival to address the disaster domain constraints. However, current mobile robots are not ready to work in different environment associated with disasters and they are often deterred by narrow passages and rubbles. In spite of lack of research funds in this area trying to find solutions to the problem of disaster response, especially urban search rescue and hazardous intervention in large-scale earthquakes and other type of disasters (Ko and Lau, 2009; Shiroma *et al.*, 2004; Tadokoro, 2010).

5. ROBOT DEPLOYMENT SHOULD BE FAST WITH LESS LOGISTICAL NEEDS

The deployment of the required the robotic systems and technologies with minimum logistical needs and its readiness for quick actions are essential to the success of risky intervention and rescue tasks and assure high quality achievement and efficiency. The outcomes will be further enhanced by deploying flexible intelligent modular/reconfigurable mechanism, reliable multi-dimensional mobility equipped with various type of intelligent sensors. All selected mechanism, actuators and sensors should be able to function under the critical conditions and range of unknown factors. The robot should be robust and tolerate noise and some level of technical failures. In addition, robots should have reliable and wideband real-time communications capability to received and disseminate reliably gathered information to the relevant destinations. Robots should be protected from waters, chemicals, gases, heat, and radiations.

Robotics research community working to develop robotics for disasters and interventions focuses on wide spectrum of research and development activities. It is possible to categorize some of development in the following areas: aerial robot, information infrastructure system supporting efficient human robot/machine interface, data processing and fusion, in-rubble robot to go through narrow space, and on-rubble robot to overcome difficulties through it, decision making and autonomy, intelligent locomotion system supporting quick recovery, mapping and localization, cooperation and coordination between robots and equipment within multi-robotic system, efficient communication protocols. In addition, the system should be able to reconsider task situation and its dynamical changes to reformulate actions and possible adopt new strategy toward success. Dynamic role assignment is essential in problem solving with a multi robotic system structure.

Multi robotic system aims to provide sufficient artificial abilities by homogeneous/heterogeneous team of robots so that they can autonomously, communicate, coordinate and cooperate to overcome difficulties and optimize solutions when facing certain challenges.

6. CONCLUSIONS

Risky intervention and environmental surveillance robotic systems represent major challenges for technologies and techniques as well as decision makers and also for politician for the sake of human being and quality of life and better services. The witnessed disasters during the first 15 years of the twenty-first century urging government and research communities in the field to assign generous funds and seeking for novel technology that enhance operational efficiency in the field and improve quality of life. Robots are identified as good candidates to step into search and intervene to assist human rescuers. Currently, robotic systems are potentially good solutions when there is secondary damage as its usage will save more lives. In addition, there is a serious need for pre-, during and post disaster management techniques and policies that are accurate and reliable to help reducing disaster risk.

Due to the importance of robotics for rescue, search and hazardous intervention and the associated recent experience is using available robotic systems, there is a need that the robotic development should fulfill the challenge that reflects reality.

REFERENCES

Acheroy, M. (2006), “Appropriate remote sensing tools for improving risk management”, paper presented at IARP Workshop on Risky Interventions and Environmental Surveillance, Brussels

AGA, C. (n.d.), “Worst natural disasters, at Buzzle com”, available at: www.buzzle.com/articles/worst-natural-disasters.html (accessed July 28th, 2015).

Alexander, D. (1993), *Natural Disasters*, UCL Press, London

Bowem, S. and Thomas, E.A. (2009), *Preventing Human-caused Disasters*, Vol. XXXIV 2, Natural Hazards Center, Institute of Behavioral Science, University of Colorado, Boulder, CO, pp. 1–8-9

Gage, D.W. (1995), “Many-robot MCM search systems”, *Proceedings of the Autonomous Vehicles in Mine Countermeasures Symposium, Monterey, CA, April*, pp. 9.56–64

Habib, M.K. (2006), “Service robots and humanitarian demining”, in Lazinica, A. (Ed.), *Mobile Robotics: Toward New Applications*, ARS-pro literature Verlag Publishers, Mammendorf, pp. 449–80 (chapter 23)

Habib, M.K. (2007), “Humanitarian demining: reality and the challenge of technology – the state of the arts”, *International Journal of Advanced Robotic Systems*, Vol. 4 No. 2, pp. 151–72

Habib, M.K. (2008a), “Humanitarian demining: difficulties, needs and the prospect of technology”, *IEEE International Conference on Mechatronics and Automation ‘ICMA2008’, Takamatsu-Kagawa, Japan, August 5-8*, pp. 213–18

Habib, M.K. (2008b), “Humanitarian demining: the problem, difficulties, technologies and the role of robotics”, in Habib, M.K. (Ed.), *Humanitarian Demining, Innovative Solutions and the Challenges of Technology*, ARS-pro literature Verlag Publishers, Mammendorf, pp. 1–56 (chapter 1)

Habib, M.K. (2011), “Humanitarian demining: mine detection and sensors”, Proceedings of IEEE International Symposium on Industrial Electronics (IEEE ISIE), Poland, July 4-7, pp. 2237–42

Habib, M.K. and Baudoin, Y. (2010), “Robot-assisted risky intervention, search, rescue and environmental surveillance”, *International Journal of Advanced Robotic Systems*, Vol. 7 No. 1, pp. 3–11 (special issue)

Helm, P. (1996), “Integrated risk management for natural and technological disasters”, *Tephra*, Vol. 15 No. 1, pp. 4–13

International Federation of Red Cross and Red Crescent Societies (IFRC) (1995), *World Disasters Report*, available at: www.ifrc.org/pubs/wdr/95

Ko, K. and Lau, H.Y.K. (2009), “Robot assisted emergency search and rescue system”, *International Journal of Advanced Science and Technology*, Vol. 3, February, pp. 69–78

Nicoud, J.D. and Habib, M.K. (1995), “The Pemex-B autonomous demining robot: perception and navigation strategies”, Proceedings of the 1995 International Conference on Intelligent Robots and Systems (IROS’95), Pittsburgh, PA, August, pp. 419–24

Shiroma, N., Chiu, Y.-H., Kamegawa, T. and Matsuno, F. (2004), “Development of rescue robotic systems for both daily and emergency use”, paper presented at the First IEEE Technical Exhibition Based Conference on Robotics and Automation (TExCRA’04), pp. 85–6

Smith, K. (1996), *Environmental Hazards: Assessing Risk and Reducing Disaster*, 2nd ed., Routledge, London

Snyder, R. (2001), “Robots assist in search and rescue efforts at WTC”, *IEEE Robotics Automation Magazine*, Vol. 8, pp. 26–8

Stenchion, P. (1997), “Development and disaster management”, *The Australian Journal of Emergency Management*, Vol. 12 No. 3, pp. 40–4

Tadokoro, S. (Ed.) (2010), *Rescue Robotics, DDT Project on Robots and Systems for Urban Search and Rescue*, Springer, New York, NY

Tadokoro, S., Takamori, T., Tsurutani, S. and Osuka, K. (1997), “On robotic rescue facilities for disastrous earthquakes – from the Great Hanshin-Awaji (Kobe) earthquake”, *Journal of Robotics and Mechatronics*, Vol. 9 No. 1, pp. 46–56

UN-Economic and Social Council (2005), “Third annual report of the information and communication technologies task force”, E/2005/71, United Nations, New York, NY, June