INUKTUN SERVICES LTD. – SEARCH AND RESCUE ROBOTICS

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ABSTRACT

Locating, stabilizing, and removing victims trapped in confined spaces at the scene of an environmental or terrorist disaster is critical for Urban Search and Rescue (USAR) teams. The Variable Geometry Tracked Vehicle (VGTV) and MicroTracs robots, manufactured by Inuktun Services Ltd., Canada, are the smallest robots available to assist in the USAR process.

This paper provides a brief overview of the USAR field, gives an example of an USAR environment where robots work, and describes the tasks USAR robots fulfill. The USAR field is a challenge for robotic technology. Given the variety of disaster situations and environments in which robots must function, adaptability and multifunctional capabilities are critical. The lessons learned from USAR incidents involving robots, such as the Inuktun VGTV and MicroTracs, during rescues have been invaluable in improving robotic design and progressing robotic technology.

The tragic disaster at the New York World Trade Center in 2001 was the first time robots were used to assist USAR teams in the technical search process. This paper addresses the impact that the Inuktun VGTV and MicroTracs had on this rescue operation, the performance of the robots, and the lessons learned.

1. INTRODUCTION

Urban Search and Rescue (USAR) is a multi-disciplined field responsible for helping in emergencies. These emergencies include natural disasters such as earthquakes, hurricanes, tornadoes, floods, and storms. Other emergencies include building collapses, hazardous materials incidents, mine collapses, trench incidents, and terrorist attacks. USAR tasks include locating, extricating, and providing immediate medical treatment to trapped victims. While these rescue tasks are critical to victims' survival, they are not easy to execute [7]. USAR is constantly looking for safer and better ways to conduct search and rescue. Recent technological advances within the USAR field have equipped professionals with new sensors and tools that better assist them in locating and extricating victims. However, in any rescue situation, USAR professionals are constantly looking for improved methods and equipment to assist with USAR tasks. Robotic technology is one such improvement.

The use of robots in search and rescue is relatively new. Inuktun Services Ltd. conducted the first documented investigation of using robots for search and rescue robots in 1993. In 1995 the devastating disasters of the Oklahoma City bombing and the 1995 Kobe, Japan earthquake motivated the robotics community to consider USAR as a potential field for robotic technology. The further loss of life from the Turkey and Taiwan earthquakes in the same year solidified the need for USAR robotic development. From 1995 until 2001 USAR robotics technology developed mainly as a research topic within the academic and research communities. Then September 11, 2001, happened. The response to the World Trade Center disaster marked the first time rescuers used robots as a tool for rescue and recovery [1][2]. Retired Lt. Col. John Blitch led military and research groups from around the nation and their robots to assist in the response effort. Although the robots used in the search were not originally designed for USAR use, their successful performance during the response proved robots' value as tools in USAR incidents.

2. URBAN SEARCH AND RESCUE FIELD FOR ROBOTS

The USAR field is a challenging one for robots in terms of environmental conditions and task executions. The USAR environment is a dynamic, difficult setting due to terrain, hazards, and weather. USAR task forces comprise the army of individuals that work to locate, extricate, and treat victims. The task forces are organized into four branches that define the tasks the rescuers are to execute and, in turn, define how the robot equipment is used.

2.1 Environmental Conditions

Each disaster presents a unique environment [3][5][6]. For purposes of this publication, the World Trade Center (WTC) disaster environment is used as an example of an USAR environment. Paper, dust, and metal were the three main materials found in the rubble pile at the WTC. The WTC complex included seven buildings. The main rubble pile was the result of the collapse of WTC1, WTC2, WTC3 and WTC7. WTC4, WTC5, and WTC6 were partially erect but were highly unsafe. Surrounding buildings remained standing but were damaged and unsafe to search. Figure 1 shows images of the damaged buildings surrounding the main rubble pile.

Figure 1 - Views of the main rubble pile at the World Trade Center. ***Photos courtesy of the Center for Robot-Assisted Search and Rescue.***

The rubble terrain greatly challenged the robots' mobility. Because the robots could not traverse the rubble terrain, robot operators had to carry the equipment onto the rubble pile to get near voids or areas needing to be searched. Figure 2 shows a below grade area approximately 2.5 stories deep. The robot operators had to haul the equipment down ladders, walk across the bottom of the area, and climb up the other side to search the assigned void. Extreme heat sources deep within the pile caused the robots' tracks to soften, leading to immobilization during the eighth deployment.

Figure 2 - A large crater approx. 40ft. deep near WTC 2. ***Photo courtesy of the Center for Robot-Assisted Search and Rescue.***

Environmental conditions include both weather and hazards. Generally, the weather cooperated most of the days during the two weeks after the incident. Temperatures ranged from the 60s at night to mid-70s during the day (as recorded in Federal Emergency Management Agency operations-briefing documents). Asbestos and general dust were the biggest health threats to the rescuers. They were required to wear certified air masks as well as eye protection. When it did rain, the rain added to the precarious structural integrity of the rubble and threatened the safety of both the victims and rescuers. It created slip hazards and began flooding the below-grade areas. The rain did, however, help to decrease the amount of dust in the air and reduce the thick blanket of dust covering the area.

2.2 Tasks

USAR tasks are divided into four groups according to the FEMA task force organization [6]. They are search, rescue, medical, and technical (see Figure 3). Robots have been found to be useful in assisting with three main tasks that fall into three of the four groups: search and inspection, basic victim monitoring, and atmospheric monitoring [1].

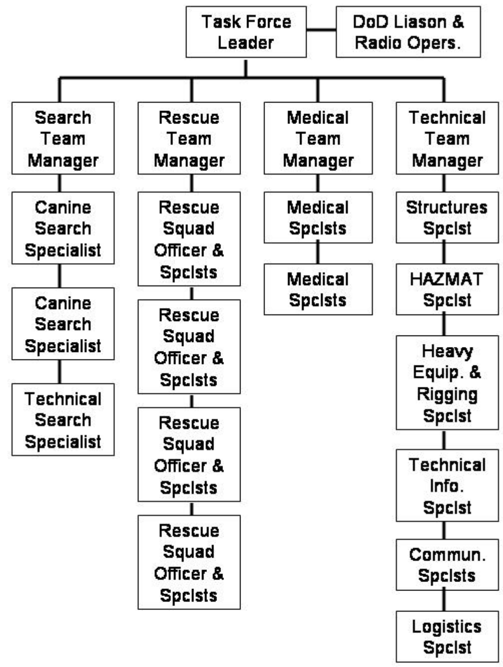

Figure 3 - USAR Task Force organization divides tasks into four groups: search, rescue, medical, and technical.

2.2.1 Search and Inspection

Search and inspection involves using available sensing capabilities to assess a space. When searching and inspecting a space, visual and acoustic sensors are used to locate victims, remains, and hazards or to note the condition of the space and map the area. Access to the space, depending upon its size and shape, may already exist or have to be made. The space may be of any size or shape and is too dangerous and/or inaccessible for people.

When looking for victims, robotic systems, such as the Inuktun VGTV and MicroTracs, provide the means to search remotely a space both visually and audibly. Video from the robot's point of view shows the operator what is in the space and any signs of victims, such as identifiable shapes, skin color, clothing color, and human-related items such as jewelry. Two-way audio allows the operator to execute call-out search methods remotely and to listen for human sounds.

Remote hazard identification is possible with a robotic system. Identifying hazards, such as electrical or chemical, visually and/or audibly allows the operator to inform the safety officer of a potentially dangerous environment. Hazards presenting a threat to the lives of rescue professionals do not lie only on the surface of a disaster, but below grade as well. Below grade hazards are difficult to locate without digging open a space. A robot is a simple means of detecting a hazard early.

An operator may not need to search for victims and identify hazards only but also assess the condition of the space being worked. The robotic system allows the operator to determine the relative size of the space, to determine if there are any openings in the space to larger areas, or to create a rough map of the space for structural specialists.

A robotic system is useful to structural specialists by providing a means of remote structure inspection. The specialists stay at a safe distance while monitoring the condition of the structure and any changes signifying potential hazards. The robots also allow the structural specialists to map the area being inspected for more consistent and accurate monitoring.

2.2.2 Basic Victim Monitoring

Basic victim monitoring is the task of gathering basic information on the victim's condition and observing trends. Basic information includes the status of his/her airway, breathing, and circulation. This information can be obtained through visual observation and verbal contact with an Inuktun robot. If the victim is alert and talking, despite being disoriented, it is safe to assume the victim's airway is patent, he/she is breathing, and he/she is at least getting adequate circulation to the brain. If the victim is not alert, the airway can be assessed visually by watching for the rise and fall of the chest or back (depending on the victim's position).

When a medical professional cannot gain direct access to the victim for assessment because of dangerous or inaccessible space, a robot can gain access and provide methods to remotely monitor the victim's condition. This information is particularly important in a triage situation where multiple victims are located in inaccessible areas and only a limited number of resources are available to extricate the most critical victims.

In the case where a victim cannot be extricated for a significant time, the robot not only can monitor the victim's vital signs but also provide communication between the victim and the operator. This provides the victim with some comfort and can help reduce his/her stress.

2.2.3 Atmospheric Monitoring

Atmospheric monitoring is the task of using sensors to determine the condition of the air in a designated area. It is crucial to monitor the atmosphere of an area in which people are working to ensure as safe a work place as possible. Sensors, such as gas meters, are used to determine the condition of the air. Certain gas meter models provide readings for oxygen levels, carbon monoxide and dioxide levels, hydrogen sulfide levels, sulfur dioxide levels, low explosive levels, and volatile organic compound concentration.

In the situation where the assigned work area is suspected of being hazardous, a robot can be used to quickly determine whether or not the atmosphere is hazardous. In the case where there is a known hazardous environment, the robot establishes what the hazard is. This allows professionals to better prepare themselves (such as the choice of the type of protective wear) to enter the environment if needed. Using a robot to quickly recon an area reduces precious preparation time for professionals.

A robot equipped to monitor the atmosphere is useful in the case of a confined space or area requiring continuous monitoring. This allows the operator to determine the condition of the air in a confined space and continually monitor it if professionals need to enter the space. Allowing another source of monitoring in a confined space increases the level of safety for people having to work in the confined area.

2.3 Inuktun Variable Geometry Tracked Vehicle (VGTV)

The Micro Variable Geometry Tracked Vehicle (VGTV) is a small, tethered, tracked vehicle (see Figure 4). Its unique feature is its ability to adjust the shape of the platform's chassis when raising or lowering the sensor pod located at the front of the vehicle. This ability to change shape, or polymorph, is achieved through the use of an accordion-like outer chassis that can push the inner structure upward while reducing the track footprint. The raised position has the advantage of increasing the viewpoint height. However this increased height also decreases the platform's stability due to the higher center of gravity or high centering. Conversely, the lower position is highly stable on angled terrain but suffers from limited camera viewpoint.

Figure 4 - Inuktun Variable Geometry Tracked Vehicle (VGTV) robot for USAR use.

Specifications relative to the robot's ten requirements, defined in [2], enumerate this robot model's capabilities. These requirements are: communication, runtime, size, speed, sensing capability, construction material, ground clearance, traction, payload capability, and self-righting [2]. The communication method for this robot is a 100-foot tether. Since the battery is provided outside of the robot chassis, the runtime is limited only by the longevity of the power source. The power source can be in the form of three twelve-volt batteries or an AC to DC power supply. In the robot's lowered, tank-like position, the VGTV's height is 2.5 inches and has a footprint of 6.5 x 12.5 inches. In the raised triangular position the height is increased to 10 inches, and the footprint is reduced to 6.5 x 7.5 inches. Two drive motors allow it to operate at speeds up to 15 feet per minute. The sensor suite includes a microphone, a speaker, a motor-driven manual-focus CCD camera, and a camera tilt unit that incorporates halogen lighting. The chassis is manufactured out of milled aluminum, the tracks are made of rubber belt material, and multiple components contain molded plastic coverings. Clearance is approximately 1.0 inch. Traction is provided via two rubber belt tracks with cleats for additional traction. Payload capability is limited by weight and balance of the robot. The VGTV does not have self-righting capability.

2.4 Inuktun MicroTracs

The MicroTracs vehicle is the smallest robotic vehicle for remote inspection in confined space environments. Although it is small, one of its unique features is the strength of its two drive units, given their size and weight. These drive units are attached to the bottom of the chassis plate. The track units provide 15 pounds of force per track and can operate at speeds up to 30 feet per minute. This is twice the speed with much greater torque when compared to the small VGTV platform. Since the VGTV is not rated for pulling capability, any task requiring a strong, small robot will be best served by the MicroTracs vehicle.

Figure 5 Inuktun MicroTracs robot used for USAR.

This robot model's capabilities are enumerated according to the ten robot requirements [2]. The unit is typically deployed using a 100-foot tether for communication but has the strength to pull longer lengths if needed. Since the battery is provided outside of the robot's chassis, the runtime is only limited by the longevity of the power source. This can be in the form of three, twelve-volt batteries or an AC to DC power supply. The MicroTracs's height is 5 inches and the platform's fixed shape and size occupies a 7 x 6 inch footprint. Two MicroTracs drive units allow it to operate at speeds up to 30 feet per minute. The sensor suite includes a microphone, a speaker, a motor-driven manual-focus CCD camera, and a camera tilt unit that incorporates halogen lighting. The camera, lights, and microphone are enclosed in a cylindrical tilt unit on the top front of the vehicle. The chassis is manufactured out of milled aluminum, the tracks are made of rubber belt material, and multiple components contain molded plastic coverings. This platform has 2.25 inches of ground clearance. Traction is provided via two rubber belt tracks with cleats added for additional traction. Payload capability is limited only by weight and balance constraints. The control box on top of the robot provides adaptability for multiple payload configurations. Finally, this robot has no self-righting features.

3. IMPACT OF THE INUKTUN ROBOTS DURING THE RESPONSE

The September 11, 2001, attack on the World Trade Center towers resulted in a mass casualty incident requiring the resources of search and rescue teams from across North America, volunteers, large equipment companies, and specialized equipment. Robots were part of the specialized equipment needed. For the first time, robots were used for technical search tasks in an Urban Search and Rescue (USAR) effort.

3.1 Response Operations

Eight robot deployments took place from September 11 - September 20. A deployment is defined as an instance when a team is directed to the area immediately encompassing the disaster site to either work within the site or wait until needed. Eight drops took place during four of the deployments. A drop is defined as an instance when the robot is used.

The task for the eight drops was to search and/or inspect voids. The voids were essentially holes that were too dangerous or small for rescuers to enter (see Figure 6). The purpose of searching these dangerous voids was to determine if the void led to an open place underneath where victims may have been able to survive. Such a place was inaccessible from the surface of the disaster site. However, it was crucial to quickly determine where victims could survive by searching the voids and minimizing the time victims would spend in dire conditions.

Figure 6 – During the eighth deployment this void's opening, measuring 2ft x 4 ft, was explored using the MicroTracs and VGTV robots. ***Photo courtesy of the Center for Robot-Assisted Search and Rescue.***

3.2 Inuktun Robots vs. Other Robots

Seventeen robots, including the Inuktun VGTV and MicroTracs robots, were available for use during the World Trade Center response September 11 - September 20. The Inuktun VGTV and MicroTracs were used for *seven of the eight drops*, making them the choice robot for use on the rubble pile. The Inuktun robots were successful in traversing the voids to determine whether the voids led to survivable spaces (see Figure 7). While inspecting the voids, the Inuktun VGTV and MicroTracs were used to identify, at most, five sets of human remains. The purpose of identifying remains was to notify the appropriate officials of their location so that the remains could be retrieved later for identity tests.

Figure 7 - The Inuktun MicroTracs's view of a void. ***Photo courtesy of the Center for Robot-Assisted Search and Rescue.***

The Inuktun robots had the advantage of being small, lightweight, and easy to use. The rubble pile terrain during the World Trade Center response was difficult for people to traverse, and even more so for the robots. Even the large-wheeled robots could not travel into the midst of the seventeenacre disaster site. Robot operators had to carry their robotic equipment into the hot zone. The size, weight, and number of operators needed suddenly mattered greatly. The Inuktun robots were easily packed in a backpack and transported by one person, while other robots required two or more people to transport them. The Inuktun robots, as well as the other equipment, required two operators. One operator controlled the robot while the other operator managed the tether.

The Inuktun robots were an ideal choice for deployment for three reasons. First, all personnel working on the rubble pile needed to work in teams of two for safety reasons. Robot operators were automatically paired up when deployed, satisfying the number of operators needed to deploy an Inuktun robot. Second, the Inuktun robots were small enough and light enough to be transported in a backpack by one person. This allowed the person's hands to be free while trying to climb to the designated spot to be searched. The team of two operators each carried a robot pack, providing one robot for backup. Third, the Inuktun robots were simple to set up and operate. This was particularly crucial considering the average time spent searching a void was six minutes. This short search time was due to mission urgency and safety hazards. There was not much time to waste on setting up the robot.

3.3 Lessons Learned

While many lessons were learned from using Inuktun robots during the World Trade Center disaster, seven prioritized lessons are described. For further detail on lessons learned, refer to [1][2].

A deployment system is needed. One of the most valuable lessons learned at the World Trade Center disaster was the need for the robots and their accessories to be packable and quickly deployable. The packability of a robot is its ability to be carried on the body of the operator, or operators, that will be performing the search. The deployability is the ease and amount of time that it takes to go from a packed and mobile state to full deployment into a hole. The Inuktun robots were initially packed in hard shell cases. The weight and the awkwardness of these cases made their use not feasible once it was determined how far the equipment had to be carried into the rubble pile before even deploying it. The rescuers who were working with the robot operators did not have time to stand around and wait for the robots to be set up and deployed. As a temporary solution, personal backpacks were sacrificed to use in transporting the Inuktun robots. A ruggedized packing and deployment system is required for USAR robots to be truly useful.

An auto focus camera with zoom capability is needed. The Inuktun robots were equipped with a manual focus camera. This required the operator to spend precious time focusing the camera. During the second deployment, an Inuktun MicroTracs reached a point in the void where it could not pass due to an obstruction. The void looked as though it may have opened up beyond the stopping point. A zoom camera would have been useful to see beyond the area where the robot was resting.

A longer tether with the strength to withstand tension is needed. The Inuktun robots were equipped with a 100-foot tether. The tether was used to lower the robots into voids, despite the tether not being rated for such activities. The 100-foot tether was just enough. However, there were instances when the tether was coming near its end. The void explored during the fourth deployment was a near vertical drop. The second operator had to keep constant tension on the tether to keep the robot stable for returning video.

An adjustable body clearance is needed. The Inuktun robots operated in rubble varying from pebble sized pieces to tennis ball sized debris. It was common for an object to get caught under the belly of the robot. This caused the robot to get hung up and prevented it from maneuvering. The low ground clearance on the chassis was the main contributor to this failure. This decreased deployment mobility and search efficiency hampered the operation.

Multiple types of tracks to handle varied surfaces are needed. The Inuktun robots were subject to wheel slippage in the environments in which they operated. Wheel slippage occurred when the wheels were not making sufficient contact with the travel surface. This problem was determined by two factors: the robot's tracks and the surface on which the robot was traveling. Unfortunately, the only way to decrease this value was to increase the robot's traction with the traveling surface since the environment could not be changed. Possible avenues for improvement are more flexible tracks and better surface area. A track that can "float" at a sideways angle, relative to the guide wheels, would increase the surface contact area.

A track mechanism preventing track derailment is needed. During the eighth deployment, the Inuktun VGTV lost its track while inspecting a void deep within the rubble pile. The track derailment may have been due to the heat in the void softening the track. The derailment deemed the robot immobile and no longer useful for inspection. A track mechanism designed to secure the track is needed to prevent losing precious time recovering from a derailment.

A waterproofing of the robots is needed. The Inuktun robots were not effectively decontaminated after running in the rubble pile. Disaster environments are not clean. The World Trade Towers were fully functional buildings with both water and septic systems. The rubble pile encompassing the towers contained a large amount of biohazard material and chemicals. During deployments, the Inuktun robots ran through this material. To prevent spreading contamination, the operators wiped down the robots and tether as thoroughly as possible. The best way to decontaminate the robots would have been to submerge them in a 10% bleach solution. The robots would need to be waterproofed to do this.

4. CONCLUSIONS

Urban search and rescue (USAR) is a difficult domain for robots to work. Environmental conditions are harsh. Weather varies from extreme heat to extreme cold, and rain or snow may become factors. Disaster terrains are unstructured environments. Unpredictable rubble challenges robots' mobility. Potential types of hazards include chemical, fire, and collapse. Robots have been found to be helpful in executing three difficult USAR tasks: search and inspection, basic victim monitoring, and atmospheric monitoring.

While smaller is not always better, this certainly was the case in the September 11, 2001, World Trade Center disaster response. The smaller and more agile Inuktun robots were clearly the winners in this particular USAR domain. The Inuktun Variable Geometry Tracked Vehicle (VGTV) and MicroTracs robots were the chosen platform for 87% of the deployments that took place from September 11 – September 20.

The Inuktun VGTV's ability to look over things and climb under debris makes polymorphism a necessity in USAR. In all of the deployments at the World Trade Center, there was a need to look over things to assess the need for further investigation. In other instances, the robot needed to plow through or under material. It would have been advantageous for the robot to provide the operator some explanation as to why it was failing to do what it was designed to do. This would have eliminated the countless time lost on the pile while figuring out what was wrong with a particular feature of the robot. The portability of the robot is normally something that is an afterthought for robot designers, but this was clearly a required feature during the World Trade Center disaster. It is imperative for portability design criteria to be in the initial design criteria for the mechanical engineers. This includes size, weight considerations, and battery characteristics. Deployability must also be integrated into the initial design criteria of the robot manufacturer. Currently, the operators need over a minute to remove the robots from the backpacks, connect operator control units, and begin deployment. This time must be minimized to maximize usefulness.

Since the World Trade Center disaster in 2001, Inuktun Services Ltd. and American Standard Robotics Inc. have been working on improved designs based on the lessons learned in 2001. The Inuktun VGTV is evolving into a more propitious platform for unstructured environments. New VGTV features include an auto-focus, digital zoom camera, multiple traction configurations, variable ground clearance, 300-foot tether, self-aligning traction system, waterproof chassis, and more efficient transport and deployment systems. For more information on the robot platforms for USAR, see www.inuktun.com and www.asrobotics.com.

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