Gathering and Applying Guidelines for Mobile Robot Design for Urban Search and Rescue Application

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Abstract. Robotics technology can assist Urban Search and Rescue (USAR) by allowing to explore environments inaccessible or unsafe for a human team [1]. This creates the need to develop a better understanding of the USAR procedures and specific requirements in order to guide the design of the robotics technology which will be accepted by USAR professionals. The current paper explores the specific requirements for the assistive technology, and extracts design guidelines for development of the robotic technology to be used during USAR operations. Design guidelines are derived from both literature review and from a qualitative study performed with Vancouver Heavy Urban Search and Rescue Task Force (HUSAR), focusing on usage scenarios and specific requirements for communication, control and user experience. The study revealed that the most crucial factors for the design of the robot are speed, robustness, reliability, weight, affordability, and adaptability to different environments and tasks, as well as ability to provide a two-way audio/video communication. For the interface, the most important characteristics are its learnability, immersiveness, and ability to afford a high sense of spatial presence. We further discuss how the above requirements were implemented though a case-study of the development of the "TeleSpider" (a hexapod tele-operated walking robot), and assess its effectiveness during the field testing at the Vancouver HUSAR warehouse. Failing to meet a number of the discussed requirements will likely result in the technology to be rejected by the USAR team, and never being used during actual deployments as has happened with a number of existing technologies.

Keywords: Urban Search and Rescue · Participatory design · Design guidelines · Robotics · Telepresence

1 Introduction

Search and Rescue (SAR) and Urban Search and Rescue (USAR) are important, often dangerous, life-saving operations. The assistance of modern technology can substantially improve the speed and safety of these operations. SAR is an operation of search

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for missing people, often in large natural areas, such as forests and mountains. Robotics technology could be sent out to explore the potential area, where the missing person might be located, which is faster and cheaper than sending a human search team or a helicopter [2]. USAR is an emergency response to a natural or mankind induced disaster, such as an earthquake or a terrorist attack, which destroys urban structures, resulting in people being buried under heavy and unstable debris. In this scenario, a USAR team will be deployed to the site of the disaster to locate, extricate and provide with the initial medical aid the victims. Robotics technology is of a great assistance in USAR operations, as it can go into places, which would be considered unsafe for a human to enter [1, 3]. A robot could be sent to scout the area, identify locations of victims, establish a communication channel with victims, or deliver items like water, snacks or blankets. Robotic technology has also been evaluated to be effective for Marine search and rescue, which is a smaller scale search and rescue operation of extricating victims from ships that sank nearshore [4].

Urban Search and Rescue operations are very time- and error-sensitive, and they impose a lot of stress and cognitive and physical exhaustion on the team – the delays and errors can cause human lives. Technology seems an obvious choice to provide assistance for the USAR team and make the operation go more efficiently. However, this introduces a very challenging task for the designers of the technology, as during USAR operation there is very low tolerance for unreliability of technology or the cognitive demands it imposes on the operator. In other words, there is a high responsibility put on the designers of the technology to make it perfectly suitable for the USAR domain, or otherwise it will get immediately rejected by the users. Technology can be useful for USAR at different stages of the operation: acquiring initial information of the state of the environment, search for victims, providing victims with support, while they are being rescued, and extricating victims [5]. A lot of the technology designed for USAR, is designed with the search stage in mind. That is an important stage to focus on, given that the safety of the USAR team members is of high priority, so the team will not be sent inside the buildings to look for victims until the supporting structures are built and it is ensured to be safe to go in and search for survivors. This delays the rescue process, which can potentially cost victim's lives. However, the robotics technology is disposable, and can be sent into the unsafe environment to scout for survivors, before the collapsed structure was stabilized, and made safe to enter, thus allowing to start the search earlier [6, 7].

The robot, which will be sent to search for the survivors buried under debris, will replace a search and rescue professional, who would have gone into the environment if it were safe enough. That is, the operator can via a tele-presence robot virtually explore the environment – "extend the sense into the interior of the rubble or through hazardous material" while staying in the safety of the base [8]. This can possibly be best achieved if the interface for the robot focuses on creating a sense of "telepresence" - an experience on being present in a distant environment through the medium of technology, thus the experience of actually physically being in that environment [9].

Search and Rescue forces have some technology in their disposal, including some robotic technology, assisting them in the search component [8]. However, a lot of the robotic technology currently used in Urban Search and Rescue is borrowed and then appropriated from a different domain like cameras from construction or lifedetectors from military, and as a result it does not fit the search and rescue environment perfectly. To the best of our knowledge there was not any participatory design reported in the literature for robotics for urban search and rescue. As a result, technology currently available to be used in urban search and rescue does not always meet the requirements of the stakeholders. This motivates a clear need for a deeper understanding of the practices and needs of the USAR professionals by the developers of the technology to be used in USAR operations. To this end, we designed and report here a qualitative pilot study conducted to develop a set of guidelines for the design of the robotics technology for USAR. We collected interview and observations data about USAR practices and experience with technology, to motivate and guide the design of the TeleSpider robot and the interface, which is then analyzed as a case-study.

2 Related Literature

When analyzing research on technology for urban search is rescue, it is important to keep in mind the limitations associated with the methodologies researchers have to use. Due to the nature of the domain, such research is challenging to perform since each disaster cite and conditions are always very different from the previous one, so technology has to be highly adaptable, and the testing environments need to be able to assess that. Another challenge comes from the difficulty to acquire real-world usage data, or to even create a realistic simulation of a USAR operation with comparable levels of stress and exhaustion, and, thus, most of the research may be lacking ecological validity. The opportunities to do on-site research are very rare, but provide very valuable data [3, 7], which still may not generalize to a different disaster scenario. Other data comes from robotic competitions [10–12], which assess the task performance capability of the robot fairly well, however less attention is paid to the usability of it, and how it will fit into the procedures of USAR response.

Hancock and colleagues [13] reported that the most important factor determining the trust in and, consequently, the usability of the robot is the reliability of its performance. It is important to keep the technology very intuitive and fast to learn because the USAR members do not have a lot of time to dedicate to learning a novel interface for the new technology. And, giving the stress level and cognitive exhaustion at the time of the operation, USAR team will not use the technology that requires them a lot of cognitive effort to figure out how to control [3]. Many of the existing robots for USAR were also found to require multiple people to operate, which previous research unanimously considered to be a major disadvantage [3, 14]. Another common issue with the existing technology was its size, because a number of robots were cumbersome, heavy, and may require multiple people to carry them [3], which can be addressed with a solution where a larger “mother” robot carries smaller robots to the site [15].

When operating a robot for search and rescue, it was also reported that some participants would find it hard to perform both the navigation and the search tasks at the same time [16]. This last finding highlights the importance for better interface for navigation, which can reduce the cognitive load required for staying oriented and controlling the movement, and free up the resources for the search process. Another solution would be to create a partially autonomous robot, which receives some direction from the human, but still allows the operator to mostly focus on the search [17–19]. Besides shifting the navigation tasks mostly onto an autonomous robot, it was shown to be beneficial to design the robot to assist with the search as well, by providing cues to the human operator of possible locations of the victim based on heat, skin color, color contrast and motion [20]. Tejada and colleagues [21] explored different levels of robot autonomy used in search and rescue, and reported the level of autonomy will depend on the particular role the human-robot team is performing, and therefore the optimal setup is to have the capability to switch between the modes.

Another problem was associated with the position of the robot – most of the robots designed for search and rescue are low to the ground making it harder for the user to feel immersed and maintain spatial awareness because they look at the environment from an unusual angle for a human. Burke and colleagues [14] have suggested that users need to develop a new cognitive model in order to comprehend the environment in terms of the robot. Also, spatial and situational awareness was challenging to maintain because of the fast or large rotations of the camera, or the operator not keeping track of the relative orientation of the camera to the body of the robot – both led to a loss of orientation [22]. Adding different components to the interface can moderate this situational awareness problem, indicating various states of the robot: relative location, orientation of the robot body and camera, camera used, health state of the robot, etc. [23]. There was also a difference in the ease of learning of the new interface. Novel users have less problems with learning a new interface, while experienced users will prefer the interface to be similar to something they are already familiar with [22, 24]. This is important to consider when modelling an interface for a robot for USAR from an existing interface used for modern video games and other entertainment technology, and as such hoping to increase the familiarity and shorten the learning curve. A lot of USAR team members are likely to have little experience with modern video games, and will not have an extensive experience with popular controllers. This is because most of the USAR members are over the age of 30, because prior to becoming a USAR specialist they have to get training and work experience in another field (e.g. firefighting), and only then go through the specialized training for USAR: as a result, they will have little experience with modern interfaces, because the technology was less available or common when they were children, and now their work and training schedule makes it challenging to explore it at their spare time.

There is a number of factors to consider, when developing technology for the domain of USAR: reliability, cognitive load, human-robot ratio, access to information about the state of the robot, position of the camera, and stakeholders experience with modern technology.

3 Study Methodology

In order to inform the development of a robot and the interface for it, which will fit the practices of USAR the best and maximize the ease of use, we used a participatory design method. For this preliminary pilot study which aims to gather functional requirements for the robot and the interface, we conducted a semi-structured interview and informal group interview with USAR professionals. This allows us to develop a better understanding of the possible usage scenarios and functional requirements for the robotic technology. Understanding how urban search and rescue team members navigate through the emergency site, how they search for the victims, and how they communicate with their colleagues, will give suggestions on how to integrate the exiting strategies being used by the USAR Task Force into TeleSpider design and make it more intuitive and easy to learn. We also sought information about the existing technology being used by USAR, what works well, and what kind of issues they encounter, in order to minimize these problems in the design.

3.1 The Interview Guide

For conducting the semi-structured interview, we developed an interview guide (see Appendix), focusing on particular areas of USAR practice, which are important to understand in order to inform particular aspects of the robot design (see Fig. 1 for the relationship between interview questions and design implications). The Interview Guide contained three sections: introduction, questions about the practice and the procedures of a USAR operation, and questions related to the use of technology. The guide was designed to develop an understanding of the practices and experience of the USAR team, which will motivate our design decision for the robot and the interface. See the full interview guide in the appendix.

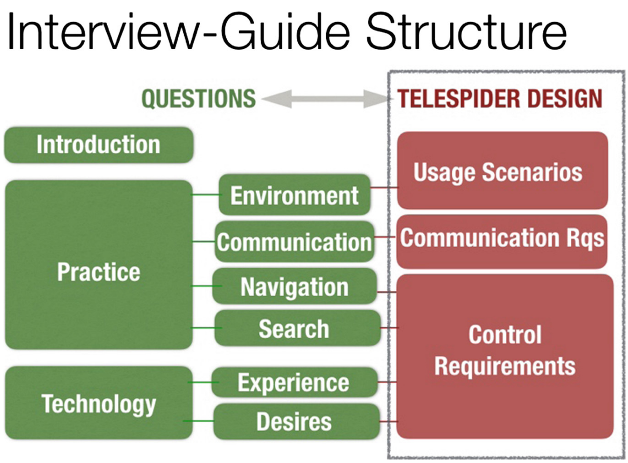

Fig. 1. Power distribution of channel at 1555 nm along the link of 383 km (Source: LNCS 5412, p. 323)

3.2 Participants

We contacted Vancouver Heavy Urban Search and Rescue and went to visit their warehouse where we conducted a semi-structured interview and observations with fields notes with six Urban Search and Rescue professionals. We had one participant for semi-structured interview and five participants for observation and informal group interview. All participants were males and have a background in firefighting. They participated voluntarily and have not received any monetary compensation for their time.

4 Findings

We report the findings as the summary from the background research, field notes and audio recordings from the interviews.

4.1 The Team

The search and rescue is a very complex multi-staged operation. In the Vancouver Urban Search and Rescue Task Force there are about 120 professionals of various expertise. Team members are coming from the following departments:

- Vancouver Fire and Rescue Services
- Vancouver Police Department
- City of Vancouver Engineering Department
- Vancouver Park Board
- BC Ambulance Service

Then, they undergo specialized training for urban search and rescue, on top of their original training in firefighting, paramedics, etc. As a result, different team members will have various expertise and different roles. On a particular deployment about 70–120 team members are sent, and a few people may coordinate the operation from the warehouse in Vancouver.

4.2 USAR Procedure

When there is a big disaster somewhere in the world, the Vancouver Urban Search and Rescue team may be sent there on a deployment along with USAR teams from other countries. When going on a deployment, USAR will ship most of their warehouse with them to create an autonomous base near the disaster site.

Once the Task Force arrives at the destination of their deployment, they first do a "360" – they walk around the collapsed structures to get a sense of the environment. After the "360", the engineering team assesses the structure and the level of damage. Then, the search team will proceed to searching for survivors. However, because the safety of the team is the highest priority, no team members will be entering any buildings until supportive wooden structures are built to ensure that nothing is going to collapse any further.

Once a general location of a survivor is identified and confirmed, which usually requires two independent positive signals unless its unambiguous, the search team will start gathering the more detailed information regarding the specific position and the state of the victim. Based on that information and with the help of the engineering team, the plan for making a safe access to the survivors will be created. The rescue process usually involves slow and careful cuts through concrete, and therefore takes a long time (i.e., multiple hours), depending on the complicatedness of the case. If the environment allows for that, then there will be an attempt to pass water, protein bars and blankets to the victims, to help them survive while they are waiting to be rescued. The team tries to maximize the number of saved victims in the shortest time, and, as a result, the USAR team will first make a quick assessment of the amount of the required effort for a particular rescue, and may make a sacrifice of not proceeding with this rescue, if there is a different area, requiring less time and resulting in higher number of people saved.

4.3 Practice

Environment

The environment, in which search and rescue operations are held, can differ a lot. As most of the USAR operations are responds to natural disasters, such as earthquakes and floods, the affected areas tend to be of a big scale (one or several towns), however after terrorist attacks the area will usually be smaller. The level of the destruction can vary a lot, however usually it will be a very challenging terrain for the robot (See Fig. 2 for an example of the training environment). Often the team does not have to dig deep under the destroyed concrete of a building, as it is assumed that there are unlikely to be any survivors any deeper than a few meters. Often there might be a lot of noise in the environment, especially once the rescue starts, accompanied with drilling through and cutting the concrete. When the Task Force is sent on a deployment, they are getting some minimal crucial information about the state of the site they are being sent to. Therefore, the interviewees have expressed an interest in getting a better overview of the site prior to the deployment, which could be realized, for example, through sending drones to the site in advance.

Design Implications: Considering the scale of the area that needs to be investigated for potential survivors, the speed and the range of search becomes a very critical parameter of the assistive technology. Adaptability to different terrains is also of high importance.

Communication

Communication was reported to be a very crucial part of the USAR practices. Communication is usually performed through radio or texting, and tends to be succinct and periodical. A person in the field will report to their captain the main information, such that he is going in or detecting a survivor. Once a survivor is located, the team will try to have a constant communication with them if possible. The team cannot always rely on having service in the area of disasters, so radio is the default medium of communication. Once a victim is located, if the environment allows for that, the rescue team will try to establish a continuous periodical communication with him/her to check on their needs and state and keep them calm, while they are being rescued.

Fig. 2. The training environment at Vancouver HUSAR.

Design Implications: Robot should have a good connection with it's control interface independent of having service in the area and be powerful enough to send signals through a level of obstruction (i.e., usually layers of concrete), as well as being robust to occasions of loss of signal. It may be worth exploring incorporating autonomous backtracking through the path a robot walked in case of the connection loss until it is re-established. One of the interviewees also expressed an interest for a 2-way audio and video connection to the robot, allowing a multimodal conversation with victims. In this usage scenario, a robot will seat with the survivor it found until the survivor is being extricated.

Navigation

USAR team uses the system similar to cardinal directions: they will assign letters to the sides of the building and will refer to them to communicate directions and locations. They will also leave tape marks on the building, if they need to note and later refer to a specific location. The interviewees reported rarely to have problems with getting lost in the environment, which often can be explained by the fact that the environment in most cases does not allow for a human to walk inside the building and explore it for a long time, and most of the search happens from the surface. However, one participant reported getting lost once in an underground parking in a fire, where he could not see the environment because of the smoke. He found his way out by going in the direction of the voices of his team members.

When the location of a survivor was identified, the search team will find an existing or drill a new hole to put a camera through and gather information about the surroundings of the survivor. In order to do that, the team member will have to manipulate the camera (see Fig. 5) by turning it around and try to derive from the image from the camera the actual specific location of the objects on the other side of the hole. The interviewees have reported to have difficulty sometimes remaining oriented when using those cameras after making multiple turns. To cope with this issue, they will usually have to take the camera out and put it back in to reconfirm their understanding of the positions of the objects, as well as using a landmark (e.g. a chair) on the camera stream to map the relative positions of everything else. So, they will “home” all of the key objects they find to the landmark they have chosen. One of the interviewees has expressed an interest for those cameras to have some kind of display of the specific camera rotation on the handlers.

Design Implications: Having a mini map view on the interface for the robot may help with disambiguating its position and orientation in the environment. Specifying customized “cardinal” directions and landmarks on the map would help keep it consistent with the established system in the USAR, which will allow for easier communication of spatial information to other team-members, who are not using the robot. The robot could have a functionality of leaving marks on landmarks on the map analogously to the tape marks used by the team. The rotation of the camera in relation to the body of the robot should also be clearly identified on the interface. The camera on the robot should also be equipped with a light, since the environment is usually very dark.

Search

A significant portion of the search is performed from the surface, and relies on the responses from the survivors. Search teams will work around the disaster area and yell to let the survivors know that the USAR team is there and then listen for any responses and cries for help from the victims. Survivors are advised to knock, if they cannot respond vocally, so the search team listens to a rhythmic knocking as well as voices.

Design Implications: If the robot is used for this initial stage of the search, it should have the functionality to broadcast the message that it is there on the rescue mission to the potential survivors to encourage them to start signalling that they need help. It should also be able to listen for the sounds in the environment, and be able to identify the direction from which the sound is coming from, to continue the search in that direction. Having the 3rd sound system would be especially important for this purpose. Having an automatic system for identifying voices or knocking could be an asset.

4.4 Technology

Experience

Most of the technology used in USAR is borrowed from a different field, e.g. construction and then appropriated to the needs of USAR. Some technology gets inherited from military: when military gets new technology, they can pass the older models to USAR. The lack of USAR specific technology is partially explained by relatively low budget of HUSAR and high costs of technology designed specifically for USAR, when analogous gadgets from a different field can have a lower price.

Technology used for the search can be divided into 3 functional groups:

(1) Assisting with detecting survivors (large range)
(2) Assisting with determined specific position and condition of a survivor once they have been detected (small range)
(3) Assisting the interaction with survivors, while they are being rescued

For the first function USAR uses: K-9 units (search and rescue trained dogs), life detectors (acoustic) and life detectors (vital signals).

K-9 units are the fastest and most efficient, however they can get tired and there are only two of them in the Canadian HUSAR.

Sound life detectors were reported to be somewhat slow to use, and they do not work that well if the noise level gets too high.

Life detectors, based on vital signals such as heart rate, have yet to be used by the interviewees in the field. But, they see a lot of potential in this technology. It is likely to be slower than K-9 units, but faster than sound detectors.

Some of the interviewees also mentioned drones, that they do not have at the warehouse, but have seen presentations with them. Drones were evaluated as a potentially very helpful piece of technology that can significantly speed up the search process at the very initial stages even prior to the deployment. Drones can provide a quick overview of the whole site of the operation and they will not have to overcome the obstacles of the harsh terrain as any on-land technology. One of the participants also mentioned the immersiveness of the technology as an interesting and enjoyable experience.

For the second function USAR team is equipped with a variety of cameras, which can be pushed through a small hole, which is usually made by drilling through the concrete), and then turned around to get an understanding of the details of the immediate surroundings of the survivors, his/her relative position and physical and emotional condition. All of the above is important to assess in order to refine the rescue plan, to ensure that the survivor does not get hurt through the process of rescue.

At the third stage, depending on what the environment allows for, a K-9 units may be sent to deliver blankets, water and power bars to the survivor. A communication through radio or audio-visual device like Facetime™ may be established with a survivor to ensure that they know that they are being rescued and inquire them regarding their needs.

Design Implications: The robot design should concentrate on a particular function to ensure it's best fitness. The participants saw the potential for the robot to be used in any of those three stages. However, for the first functional application the speed and robustness to the terrain will need to be the main focus of the design. For the second function, the focus should be more on the smaller size and good video stream and lighting. For the third function it will be important to find the optimal size to allow the robot to carry small loads but still fit through narrow holes, as well as have a reliable two-way audio and video communication. For this function also some attention should be put on the appearance of the robot, as well as affordability.

Requirements and Assets

Interviewees have emphasised the following criteria as being the most important for a new piece of technology:

(1) Fast to operate
(2) Fast to learn
(3) Robust (hard to brake)

(4) Light to carry
(5) Affordable price

All of the participants have reported preference to a low-level control of a robot to the level of whole robot-body movement over the options of the control of limbs, or high-level control of the end location. However, we should note that the literature has suggested the advantage of partially autonomous robots [17–19].

When the participants were asked to brainstorm freely about what they would want the robot to do in the "ideal world", they have suggested the following ideas:

- lifting itself up to fly over obstacles
- bring water, protein bars and blankets to the survivors
- leave a metronome (a device producing knocking sound) at the location where victims are found so they can be located more easily later on
- have a two-way video camera (e.g., facetime) to talk to victims
- assess the quality of the air
- have life detectors (vital signals)
- have a real-time language translator (as most of the deployments are international)
- have a "mind-control" mode

More Details on the Used Technology

K-9 Units (Specially Trained Dogs for Search and Rescue)

K-9 unit (See Fig. 3) is a team of an USAR professional and a specially trained dog who uses her sense of smell to locate the victim. Once the victim is located, the dog will bark to draw attention to the area where they found them. K-9 units will only respond to a stationary victim, as otherwise, they will assume that the person is fine and does not require a rescue. This way, K-9 units will not respond to finding other search team members. False-positive signals are relatively frequent. So, before making a decision to proceed to the rescue stage after one positive signal from a K-9 unit, the team will bring the second dog to reconfirm the location. In the case where a dog can reach the victim, they may be used to bring a blanket, water bottle and a protein bar to the survivor to help them sustain themselves before they get rescued, which may take hours. K-9 units are very fast and efficient, and there is currently no technology in

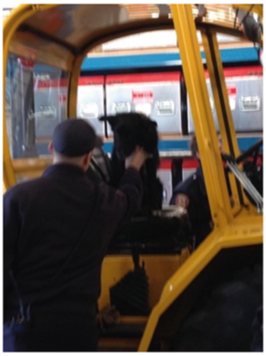

Fig. 3. K-9 unit – specially trained dog.

which USAR would prefer to use over K-9. However, a different assistive technology is required as well, as dogs get tired, or they can die during a rescue. K-9 s are also expensive and take half a year to get trained. As a result, USARs do not have enough K-9 resources to perform search with their help only. Another issue with K-9 units is that no one except for the dog has any knowledge of the environment the dog has searched through. Our interviewees express an interest in putting a robot or a camera on the K-9 unit, so that a human team member can see the environment the dog is navigating through. However, the problem with that suggestion is that dogs usually have to work “naked”, to ensure that they do not get stuck in the debris or get caught on a strap.

Delsar Life Detectors (Acoustic)
Sound based detectors (See Fig. 4) are used to refine the location of the victim based on the vocal signals or knocking. A search team member will place the detectors to encompass the area of the search, and listen to the acoustic signals from victims. Then, he will slowly narrow down the area of the sound source by moving the detectors closer together. This method is very slow, but it could be used when K-9 units are not available, or when a more precise location is required.

Fig. 4. Acoustic life detectors.

Cameras
Once a general location of a victim is determined, the rescue team will drill a hole in the concrete and they will put a camera (See Fig. 5) through the hole to examine the environment and the precise condition and position of the victim. The cameras are equipped with diodes to light up their view and a monitor either on the handle or in a separate box, which is carried on a strap around the neck (the monitor get placed at a belt level). One of the camera types also has a second monitor that is left in the base,

Fig. 5. Cameras. The left camera is designed specifically for USAR. The right camera is normally used in construction.

and often is not used. However, in some cases a second person looking at the monitor may use the radio to point out to the person in the field that he has missed something.

5 Summary of Requirements

From the collected data we suggest the following guidelines for the development of the technology to assist in USAR operations:

1. Identify the specific stage(s) and functions of the operation, where the robot will be able to assist the team. Preferably a niche where it can outperform alternative solutions.
2. Maximize the speed, robustness and adaptability to different environments.
3. Minimize the price, as the robot won't be rescued if it gets stuck or buried.
4. Use iterative participatory design to get feedback on the prototypes at different stages of the development from the stakeholders.

Vancouver HUSAR has shown a lot of interest in the project and further collaboration.

6 Case Study

To test and refine the described requirements, we designed and built a hexapod robot ("TeleSpider") that was after several in-lab design iterations brought out to a local USAR training environment for testing. The Telespider design is focusing on implementation of a biologically inspired hexapod locomotion system allowing for better adaptability to challenging unpredictable terrain than wheel-based robots [25–27] and telepresence enhancing interface. Due to constraints in the context of student projects and funding the requirements were not implemented in the order of priority, but in the order of complexity of the task. Therefore, our first approach was to design a hexapod robot that can perform robust walking patterns in unknown environments including debris and obstacles.

After a brief market review, the initial design decision fell onto off the shelf components for the mechanical design (due to low cost) with a minicomputer (Raspberry PI) due to having both a flexible programming environment as well as many connectors to sensor equipment.

The first prototype was brought on a field trip to the USAR training site in Vancouver (see Fig. 6) to perform under best available real world conditions. This demonstrated the inability of the robot to walk uphill on loose material, which had not been tested under lab conditions beforehand. However, the robot could:

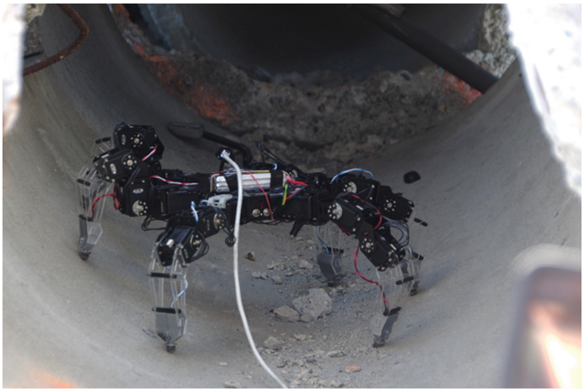

Fig. 6. First functional TeleSpider prototype on the USAR training site inside a tube.

1. Walk over and climb across smaller obstacles, but failed with steps higher than approx. 8 cm.
2. Walk in uneven terrain (a concrete tube) and return.
3. Carry a stereo camera and a variable set of batteries.
4. Carry additional loads about its own weight (2.5 kg) during the operation (tested under lab conditions)
5. Be controlled by a custom build radio controller with an effective distance up to 100 m.
6. Be robust to some environmental hazard as having mostly water resistant electronics.
7. Walk at a speed of about 2 cm per second with a battery life time of about 20 min.

The transmitted video stream was technically stable but contained all the vibrations and jitter from the walk pattern. In addition, the latency in the control for gaze direction motivated us to shift towards 360-degree camera alternatives.

Under lab conditions, the smallest passage the robot can currently cross with the appropriate gait-pattern measures 75 $\times$ 260 mm (height x width). The biggest step it can go up keeping still an upright position and not touching ground is about 180 mm. Potentially, the robot can cross gaps with a size up to 350 mm. The gait patterns for those behaviors are still under development and these estimates are based on the mechanical design of the robot construction.

The combination of speed, payload and battery lifetime of 20 min needs improvement, since normal operations would last much longer and the operators should not have to spend time to change batteries. The overall payload of about 3 kg suggests that the robot could extend the operating time up to 3 h given additional battery packs. In lab conditions, we could produce walking speeds up to 4 cm/sec which would allow a distance up to 50 m over the lifetime of one set of batteries ($\sim$20 min with 2200 mAh).

However, the first prototype also failed on some requirements, which were thus shifted towards later implementation stages: Supporting reorientation, transmission of audio signals, form a map layout during exploration. Further necessary improvements were gathered to improve the design:

1. Stabilize the body during walk behavior and during stationary periods to smooth the video signal.
2. Make the user see the transmitted video in first person perspective while controlling the robot, thus making use of the effortless self-orientation proclaimed by the project.
3. Carry a 360° camera system (not tested on USAR training site) and transmit control signals alongside the pictures over standard Wi-Fi.

Actually building and testing the robot in a fairly realistic yet safe USAR environment allowed us to not only better understand necessary next steps to designing a more suitable USAR robot, but also allowed us to come up with the revised and refined requirement and design recommendations described above.

7 Conclusions

This initial study expanded on our understanding of the current practices in Urban Search and Rescue and their challenges and needs. The USAR has also expressed an interest in the TeleSpider, even though it is currently only in an early stage of its development with a number of yet to be resolved issues. Our procedure has highlighted the high importance of the field testing of the technology, as the controlled in-lab environment cannot provide the same range of challenges as a real world scenario. There is a number of challenging trade-offs to balance when developing technology for USAR, as it needs to be both highly reliable and low-maintenance, while also remain low-cost since there is a high risk of it to be stranded and abandoned on top of a generally low budget of USAR departments.

For the future studies we will refine the research methodology, and develop a more targeted interview guide to explore specific parts of the search and rescue procedures with members of the corresponding sub teams. We will also perform user testings of teleoperation interfaces with the USAR team accompanied by interviews and observation in order to gage an understanding of the specific factors in this particular demographic, that would have an influence on the use of the telepresence technology.

In order to ensure that an assistive robotic technology fulfills the needs of the stakeholders, we need to focus on making it robust to harsh and fluctuating terrains and also fast. Another important consideration is to determine a specific scenario, where the robot will have a competitive advantage over other technology and K-9 s, e.g. going through very small holes into the environment, which is otherwise unreachable for anything as big as a dog, or environments where the level of oxygen and toxins is not determined. The robotic technology has a high potential of improving the efficiency of search and rescue operations and contributing to a lot of humans lives saved, but it has to be designed to meet the specific needs and practices of a USAR team in order to be adopted in the team.

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Appendix

Interview Guide – Example Questions

Introduction

Personal story/Understanding the interviewee

- Why did you decide to become a search and rescue professional?
- What do you love and not so much about your work?
- Who would you have become if you were not a search and rescue worker?
- Tell me about your most challenging rescue?
- Was there a significant moment in your work experience, which you would not mind sharing?
- Describe how you feel when you save a person?
- How often do you get calls?
- How do you spend your time when there are no emergency calls?

Usage Scenarios/Transition

Environment and process of urban search and rescue operations

- Describe the **setting** of a typical search and rescue operation?
- How do you **asses the condition** of the environment?
- What is the **noise** level like normally?
- How **long** does the operation take on average?
- How does a search and rescue operation normally progress?
- How **many people** are usually involved?

- What kind of **information** will you need to **gather** about the space/environment in the emergency state?
- What kind of information would you **ideally** like to have, but which is hard to get currently?
- What are some of the **main challenges** you face during a search and rescue?
- What are some of the important things **to do first** once you arrived at a place of emergency?
- Do you have any formal **safety procedures**?
- How do you deal with stress and **cognitive exhaustion**?

Dangerous situations

- What type/levels of dangerous situations can occur during USAR?
- How do you assess them? How do you deal with them?
- How do you ensure your own and your partner`s **safety**?

Communication Requirements

Collaboration and inner team interaction

- How do you **communicate** with your colleagues during a search and rescue operation?
- How do you provide and receive **support** from your team?
- What is the **relationship** between team communication and a **successful** rescue operation?
- Any interesting stories about how an interaction went? Examples of **seamless** communication? **Communication failure**?

Interaction with Victims

- What do you **feel & think** once you have just spotted a buried victim?
- What **procedures** do you need to follow?
- What some of the important things to **communicate to a victim**, once you found him?
- If a victim is conscious, how do you ensure their physical and **emotional safety**?

Navigation Control Requirements

Movement and Navigation

- How do you **move** through a collapsed building?
- How do you **navigate**? Do you study the **map** of the building before going in?
- How do you know where to go?
- How do you remain oriented?
- Is it easy to get **lost**? If so, why?

- Is there an information you wish you had in those situations?
- How do you **communicate** the plan of the collapsed building to your colleagues?

Process of Search for survivors

- How do you perform a **search** in a collapsed building?
- What kind of things do you need to pay attention to?
- How do you ensure the thoroughness of the search?
- Is there any information you **ideally** would like to have to assist you in the search process which is not currently available for you?
- Can you **compare a search experience** to any other activity?
- How do you **communicate the location** of a victim to the rest of the team?
- Do you often find yourself getting **false positive signals**?
- What type of things make the search harder?

Technology Specific Requirements

Use of technology to assist Search and Rescue operations

- Have you ever used any **technology** to assist you in search and rescue?
- Could you describe your experience?
- What did you like/ dislike about it?
- What kind of **features** did it have and what worked/ did not work?
- Do you think technology (such as robots) could be useful for search and rescue operation?
- What **kind of tasks** could it be useful for? Where you don't think that it may be used?
- **How much control** would you want to have over navigation of a remote robot?
- How would you like to control it ideally?
- How should it **feel** like to operate a remote robot?
- Have you ever felt fully **immersed** in some kind of virtual experience? What was it? Can you describe your experience? What were the factors invoking the sense of immersion?

Final Questions

- Quick introduction of the TeleSpider concept
- What are your first thoughts?
- From what we have discussed, what in your opinion are the most important aspects to be considered in the design of the TeleSpider robot?

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