Continuing Progress in Augmenting Urban Search and Rescue Dogs

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ABSTRACT
Canine Augmentation Technology (CAT) is a telepresence system worn by search canines to be used in Urban Search and Rescue (US&R) operations. The intended purpose of CAT is as a tool for search teams and emergency managers to sense the situation when the dog finds a survivor in a collapsed structure. Data about the environment is transmitted to searchers and managers from the dog who may be able to penetrate further into a rubble pile than humans. Certain critical information can help the rescue team by allowing them to understand the situation around the victim before they actually attempt the rescue. This paper describes the latest developments in the CAT prototypes as well as discusses the improvements from previous versions and makes comparisons to other telepresence systems used in US&R operations.

Categories and Subject Descriptors
B.4.1 [**Input/Output and Data Communications**]: Data Communication Devices

General Terms
Design, Experimentation, Theory

Keywords
US&R; Canine; Augmentation; Technology; Telepresence; WiFi; Wearable computing; Embedded Computing

1. INTRODUCTION
In urban disasters, buildings often suffer structural collapse. When a building collapses, "voids" are often created. Voids are pockets of space underneath rubble where live trapped survivors may be found. An US&R operation involves the location of these survivors, their medical stabilization and their extraction to safety for further treatment.

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Disaster sites involving structural collapse are dangerous environments. Resulting post-collapse structures can be extremely unstable and disturbances may cause additional secondary collapses resulting in further injuries or deaths. As a prerequisite to rescue, first responders must locate survivors and stabilize dangerous structures. They then carefully remove debris and structural elements that impede the search for human survivors. To prevent further collapse while ensuring the safety of workers and survivors, the rescue effort is by necessity planned and performed cautiously. Often this takes several days or weeks. This delay in actual rescue is not without consequences as the survival rates of trapped individuals go down over time.

Ideally, emergency responders would like to gain awareness about dangerous areas, to see and confirm the presence of survivors, and determine their states. If there are trapped people, a map of survivors' locations and data concerning the state of surrounding structures would be very useful.

Canine teams are excellent at finding survivors. Dogs can quickly search an area and provide an indication of the presence of live people. However, they cannot communicate the locations of survivors if the handler cannot be physically present, nor can they indicate the condition of the survivor or the state of structures around them. They are fast, accurate and agile but all they can do is bark.

The concept of CAT is to utilize the effective search capabilities of dogs and combine it with the information gathering capabilities of sensors that turns the device into an effective telepresence systems. Currently, the latest version of the CAT prototype consists of a canine wearable embedded computer system, two Universal Serial Bus (USB) cameras and a WiFi adapter. The WiFi communication was designed to be used in a Wireless Mesh Network (WMN) environment which has the ability to expand and be deployed in an ad-hoc manner as well as the capability of streaming large amount of data wirelessly. The system is designed such that a wide variety of sensors can easily be integrated. This paper describes the lessons learned in developing our various prototypes. It also discusses and compares CAT with other existing telepresence systems used in US&R.

2. TELEPRESENCE SYSTEMS IN US&R
Relatively recently, there has been a lot of research in the development of rescue or "response" robots used for collecting

data about the disaster environment. These mobile robots are generally teleoperated and can be fitted with a variety of sensor[1-3]. Some artificial sensors are not as effective as those found in biological systems, like dogs, and their olfactory system. However, other useful sensor types can be carried by robots and are not found in nature.

The principle limitation of response robots is their inability to traverse challenging terrain such as rubble with the added complication of controlling them in such conditions. Often, the complexity of controlling the robot, finding an accessible path and actually approaching promising voids precludes their use in the actual search for human survivors but often makes them invaluable tools for any recovery operations that follow.

While humans and animals can traverse a variety of terrain using legs, current technology in walking robots is far less capable. The majority of rescue robots employ wheels or tracks for mobility. There has been recent progress in robot designs that utilize shape-shifting or variable geometry [4, 5], marsupial abilities [6], and biologically inspired architectures to overcome difficult surfaces.

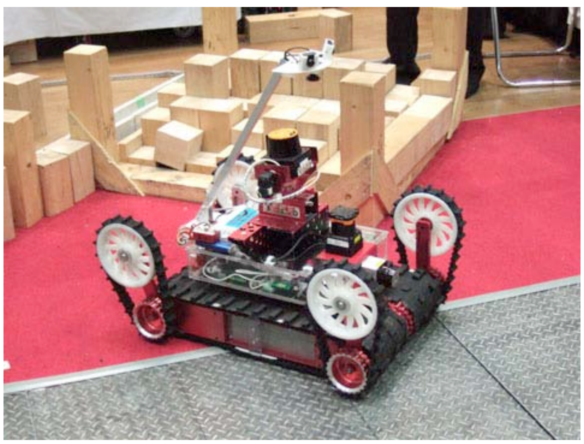

Figure 1. 6-crawer mobile robot Kenaf

The Intelligent Systems Division of the National Institute of Standards and Technology (NIST) of the U.S. Department of Commerce, sponsored by the FEMA and DHS, in a multi-year program, is investigating how to measure the performance of rescue robots. The main goal of the investigation is to determine how to evaluate robots in operation in an US&R environment [7] through the use of common metrics.

Metrics are important because they allow a shared understanding of what it means to refer to a rescue robot’s capabilities. In this way, different vendors can sell robots whose expected performance can be understood by everyone and specifically purchased by emergency task forces as part of their standard equipment Caches. NIST has developed performance standards for many categories of characteristics of robots [8] through the ASTM standards process, E54 Task Group [8-10].

Robots are evaluated on various performance characteristics including mobility, sensing and overall system performance (durability, communication, power) as well as fundamental physical characteristics like “Cache Packaging”—indicating the physical size of the robot and related equipment which must be transported by a task force to an operation.

While there are niche areas where robot mobility is quite impressive, their performance in traversing open rubble does not approach the mobility characteristics of dogs in rubble and is generally quite poor. This is unlikely to change in the near future as there is no proposed NIST response robot standard for mobility in rubble.

3. CANINE AUGMENTATION TECHNOLOGY

The concept of CAT was first introduced in 2006 [11] and positive results from the first prototype CAT 1.0 was presented in [12] CAT 1.0 consisted of a head-mounted wireless analog camera. The two main issues with this prototype were “dogonomic” (our analog to ergonomic) and radio signal interference. In order to deal with these challenges a refined CAT architecture was developed along with the CAT 2.0 prototype [13].

3.1 CAT 3.0

Although CAT 2.0 was an improvement over CAT 1.0, it still lacked robustness, expandability, was overly complex to place on dogs and was inherently unreliable. CAT 3.0 was developed as the successor to CAT 2.0 with improvements to address some of these concerns.

CAT 3.0 was a complete redesign starting with the protective camera domes. There were two main problems with camera domes on CAT 2.0.

The first was the miniature pan and tilt servos motors. Since they were small, they were also fragile and as the dog wearing the equipment run and jump around during its search the motors would stop working. These motors were replaced with a fixed 160 degrees wide-angle lens cameras.

The second issue was with the round clear plastic outer domes. Once again, while the dog performed a search, it can be rough on the equipment, as it does not have an awareness of it. The clear plastic outer domes would be badly scratched an on one occasion even cracked and punctured. The scratch marks and cracks completely block the view of the camera lens. CAT 3.0 replace the outer domes with a hemisphere domes with a small flat clear plastic plate to protect the camera lens. This is shown in Figure 2.

Figure 2. Camera dome of CAT 3.0

The clear plastic plate is protected with a clear film normally used in mobile device such as cellular phones. When it does get scratched, it can easily be replaced instead of replacing the entire dome. This dome is also equipped with an array of 24 infrared (IR) light emitting diodes (LED) that could illuminate an area of

10m in front of the camera—more than sufficient for the envisioned working environment.

Aside from the domes, the electronics of CAT 3.0 were redesigned. The new design started with the concept of a main computer unit. Many different single board computers were examined. The FOX Board LX832 made by Acme Systems was chosen for its features that include USB host interface for camera and WiFi adapter, different serial interfaces, it was compact and power efficient. The FOX board was a Linux-based system that came with a complete Software Development Kit (SDK).

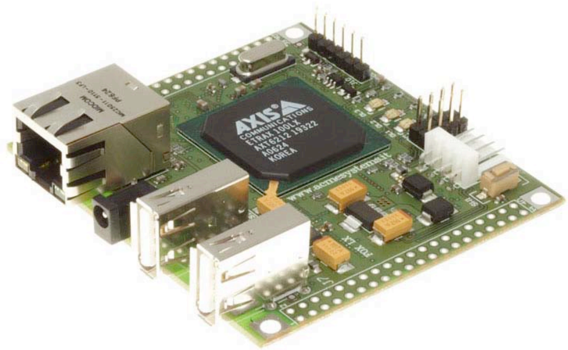

Figure 3. FOX Board LX832

Since the new system was based on a Linux kernel, the USB camera and WiFi adapter were chosen with Linux driver compatibility in mind. The camera was a Logitech Quickcam for Notebook Deluxe and the WiFi adapter was a DWL-G122 Wireless USB adapter made by D-Link.

The Central Processing Unit (CPU) on the FOX board was a 100 Mhz linux optimized Axis CPU. It performs well in streaming video feeds through WiFi but is limited to just one video feed at a time. CAT's design called for two camera streams, one from the each side of the dog, so CAT 3.0 is a redundant system with dual FOX board, cameras and WiFi adapter. The redundancy has the additional feature of robustness. Figure 4 shows a block diagram of CAT 3.0 hardware.

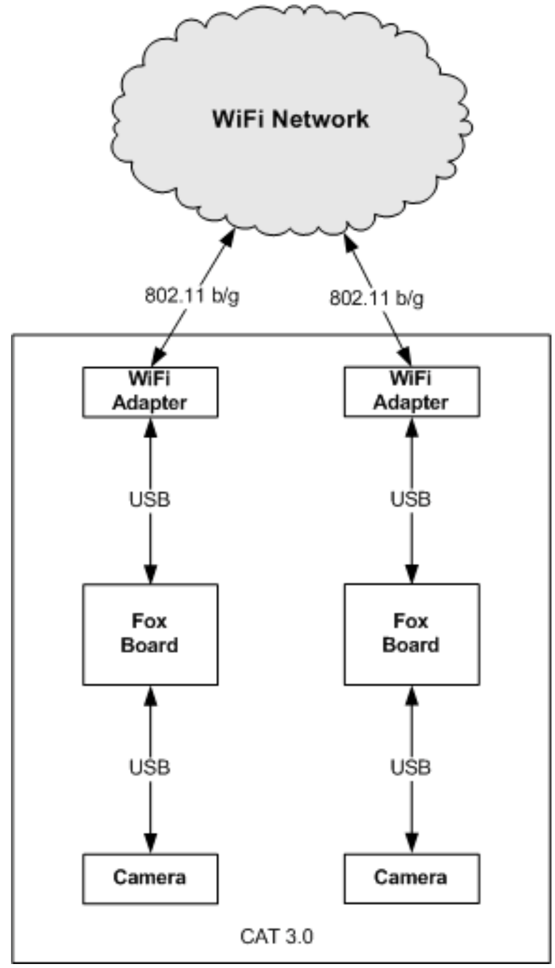

Figure 4. CAT 3.0 Hardware Block Diagram

The FOX boards' ability to run a full Linux kernel was a major advantage from the limited Linux based operating system (OS) of the WiFi router of CAT 2.0. With the SDK, firmware on CAT can be developed quite effectively. The different serial connections allow interfaces with sensors and other embedded devices.

As the results of the new hardware, CAT 3.0 is also very power efficient. The entire system's power consumption was 4W, much less than the 15W required to run CAT 2.0. We also wanted to improve the system further by switching to the more energy dense and efficient lithium ion battery pack instead of alkaline batteries in previous version.

3.2 CAT 4.0

As much as CAT 3.0 was a leap forward from CAT 2.0, there still were some useful features that could not be implement on the hardware. The limitations were the lack of CPU power and storage space. There could be occasions when a dog travels outside of the signal range or when it roams from one mesh node to another. To prevent data loss during those times, a useful feature to have on the system would be on-dog video recording as well as providing for a live stream. Another useful feature is the ability to run image recognition applications to tag certain areas of interest in the video stream to help alert a human operator that an area of importance is shown on one of the video feeds. This is quite an important feature as dogs rarely sit still and video from them tends to be quite choppy and difficult to watch. CAT 4.0 was designed to address these issues.

Instead of the dual FOX board configuration, CAT 4.0 used a powerful low-cost Linux-base single board computer called the Beagle board.

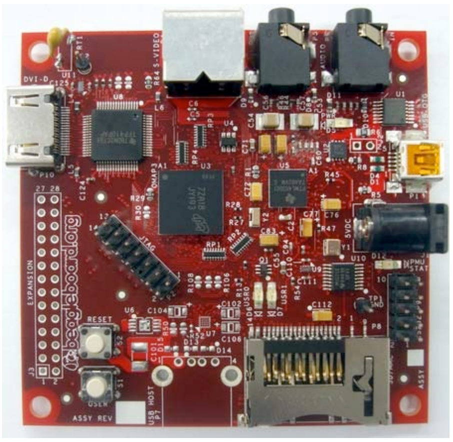

Figure 5. Beagle Board

CAT 4.0 consisted of a single Beagle board connected to the same two USB Logitech cameras and WiFi adapter as CAT 3.0. Since the Beagle board was equipped with only one USB host port, all the devices were connected through a powered USB hub. The SD card slot on the Beagle board expanded the storage space to a maximum of 16 GB which was more than sufficient to record videos where an individual canine search would take an extreme maximum of 30 minutes. The boost of computational power came from both the 600Mhz ARM CPU and the Digital Signal Processing (DSP) core.

4. FIELD EXPERIMENTS

CAT 4.0 has only been developed recently. Its functionality has only been tested in the lab and not in the field. However, field experiments were conducted to test the improved video and night vision of CAT 3.0. This section will present the "tube test" experiment and their results.

4.1 Tube Test Experiment

The tube test was devised by Ryerson University's N-CART lab at the K9 Training Facility of Broward Fire Academy in Fort Lauderdale, Florida during seasonal refresher training for local canine teams as well as training with several FEMA teams and the two teams from the Ontario Provincial Police (OPP). All US&R dog teams are familiar with tube traversal and are exposed to it during both rubble search training and in most agility courses.

Preliminary runs were made in the black plastic sewer tubes used on the canine agility course in order to reacquaint the dogs with the tubes. Typically, experienced dogs will traverse the course of about 20 m in two to three seconds.

Figure 6 depicts the testing environment consisting of 2 black plastic sewer tubes connected to a rectangular wooden box at 90 degrees angle to each other. The wooden box is hollow, allowing a path from one end of a tube through to the other tube. The test was setup so that a target was placed in the rectangular wooden box in between the two black tubes. A dog wearing CAT 3.0 was sent through the path from one end to the other. The video feeds from CAT3.0 were recorded and monitored to determine if targets could be spotted.

Figure 6. Handler getting ready to direct dog into the tube

There were 2 types of targets used, a human "quarry" and a "paper" target. The preliminary test was conducted with 2 different people in the wooden box acting as quarries and 3 different types of "paper" targets.

4.2 Results of the Tube Test

The results were better than expected given the extremely high speed of the dogs. CAT 3.0 performed very well in this test. Figure 7 shows images of human targets recorded by CAT 3.0. Clearly, the humans can be seen and are present in multiple frames. However, the motion of the dog is so fast that spotting the humans might be a task for video post-processing which could be done with CAT 4.0.

Figure 7. Human target spotted

The Figures 8-10 below present the images of the paper targets captured by CAT 3.0. The images from CAT 3.0 clearly show the distinguishing features of the three different paper targets

Figure 8. Centre Fire Shooting Target spotted

Figure 9. Dot-mil Confidence Target spotted

Figure 10. IEA Resolution Chart 1956 Target spotted

5. DISCUSSION

Currently there are two methods of remotely searching for survivors where human searchers cannot go. The first is through the use of rescue/response robots. Their limitations include their inability to traverse rubble and reliance on video systems alone to find survivors. Robots cannot find a person hidden under rubble. The second method utilizes specially selected and trained dogs under the guidance of a human handler to conduct the search. Dogs have the ability to quickly traverse the terrain, squeeze into small openings and use their sensitive sense of smell to allow them to find survivors quickly. However, they are unable to communicate their experiences to humans who cannot follow them. The only indication that they can give is to bark when a survivor is found. More information is needed for rescue workers to find and extract the survivors.

There is current research being conducted on improving robot mobility and semi-autonomous piloting to aid the operator in moving the robot[14]. Our approach is to utilize the dog as an intelligent autonomous robot with the task of searching for survivors.

Work on CAT prototypes has proceeded with the experience we have gained through working with canine teams, speaking with handlers and observing dogs. We are getting closer to a workable system for search rubble that does not impede the dog and allows sensed data to be usefully interpreted.

6. ACKNOWLEDGMENTS

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