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Abstract - *This paper describes Canine Augmentation Technology (CAT) for use in urban search and rescue (USAR). CAT is a WiFi enabled sensor array that is worn by a trained canines deployed in urban disasters. The system includes, but is not limited to, cameras that provide emergency responders with real-time data to remotely monitor, analyze and take action during USAR operations. An analysis is made of the current tools available to USAR workers including rescue robots and canine search teams. From this analysis came the design of CAT--a system that extracts the strengths of each available USAR tool and combines them to compliment each other. Our experiments yield promising results that CAT may provide significant help to rescuers.*

Keywords: CAT, USAR, WiFi, Mesh Network

1 Introduction

Two crucial factors in search and rescue operations are time and data acquisition to establish situational awareness. In a fluid progression emergency responders locate casualties and develop rescue plans, as timely response usually leads to more saved lives. The main challenge is to rescue casualties quickly without emergency responders being injured in the process, in a harsh and often unpredictable environment. There are several tools that are commonly used in the process of gathering information. One such tool is the canine team. Consisting of a human handler and one or more dogs, the teams are highly effective in locating casualties and are often the "search" part of search and rescue [7]. However, due to the limits of communication between the handler and canine, information about casualties may be incomplete or inadequate. In other words, the dog may know something about a casualty and not be able to communicate it to the handler.

Recently, another tool capable of providing data about the disaster site has become available in the form of response robots that can be fitted with a variety of sensors [6, 10]. However, artificial sensing is currently no match for the natural ability of dogs capable of detecting casualties by their scent. A principal limitation of robot search is their inability to traverse challenging terrains such as those strewn with rubble along with the added complication of controlling these robots in such conditions. Essentially, these facts make a dog hard to replace.

CAT forms a nexus between natural and artificial systems that attempts to exploit the best features of both [1]. The application of CAT is the assistance of search and rescue workers in gathering data promptly and efficiently from locations and situations they would not normally have access to, using tools with which they are already familiar. In this paper we discuss how CAT combines the innate abilities of canines and the strengths of robots into one system to provide a better tool to support USAR operations.

The rest of the paper is organized as follow. Section 2 describes the challenges that response robots and canine teams face in USAR operations. A detail description of CAT system, its inner working components, and how they interact is presented in section 3. In section 4, we present the tests we conducted on CAT to determine its ability to function in a real USAR environment. Section 5 shows the findings in our experiments performed in a near real USAR situation. Finally, in section 6 we gave our conclusions and plans for further development of CAT.

2 USAR Challenges

2.1 Response Robots Challenges

Response robots are used in environments that are too hazardous or constricted for humans to enter. However, some environments are hazardous for the robots as well. Even the best designed land robots with wheels or tracks can encounter difficulties with rubble, debris, and even stairs. There has been recent progress in robot designs that utilize shape-shifting [9] and marsupial abilities [3] to overcome difficult surfaces. One such robot is shown in Figure 1.

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Figure 1 Variable geometry tracked response robot

Figure 2 Example of rubble pile

However, they are not versatile enough for all types of terrain that may be encountered in real disaster situations which commonly include similar to that shown in Figure 2.

The Intelligent Systems Division of National Institute of Standards and Technology (NIST) is investigating how to measure the performance of response/rescue robots. The main goal of the research is to determine how to evaluate robots in operation in an USAR environment [4]. More recently NIST continued their work on developing performance standards for many other categories of robots [5]. The robots are evaluated on their mobility, sensing ability and overall system performance (durability, communication, power). Despite all the work being done in this area, robots still cannot match the mobility of a dog. This is unlikely to change in the near future.

Dogs have agility that can be enhanced through training and are thus able to overcome what would be serious barriers to robots. Because motor control is intrinsic to the animal, navigation can be done without explicit, time-consuming control from a human operator as would be required with a teleoperated robot. Dogs provide another advantage in that their keen sense of smell can be utilized to locate casualties covered by debris or behind obstacles that would otherwise be missed by an operator relying solely on video transmitted from cameras. In a sense, the handler can let the dog do the driving as the dog is equipped with many of the autonomous characteristics that many robot proponents can only dream of.

The majority of USAR robots currently in operation are teleoperated through tethered control lines or analog radio frequency (RF) links [8, 5]. The problem with a tether is that it can be caught, snagged, or tangled easily. RF signals are susceptible to interference and also have difficulty with penetrating concrete walls. CAT introduces an alternative to robotic search that shares some of the characteristics of robots and all of the characteristics of canines.

2.2 Canine Team Challenges

Despite the many advantages of dogs as sensor carrying “vehicles”, there are several challenges to overcome in order for them to be effectively utilized in this way. A single canine team consists of a dog and its handler. There are several issues with this human-animal interaction. In terms of physical requirements, the weakest link in this team is the human handler. The handler cannot match the speed and agility of the dog thus potentially slowing down the search process [1]. Another area of concern is the dog’s bark as an indication that it has found a casualty. This may be insufficient if the dog is out of audio range of the handler inside a collapsed structure where the human handler may not be able to follow. Notwithstanding some variation in tone, a dog’s bark provides limited information. Richer information such as a visual depiction of the inside of the structure, more precise location and indication of the condition of any live humans would be helpful. Also, it is difficult to determine the number of casualties in the structure based on barking.

3 CAT Systems

CAT consists of an architecture of related hardware and software modules. Figure 4 displays a block diagram of the CAT system. Figure 3 is a photograph of one such operational implementation.

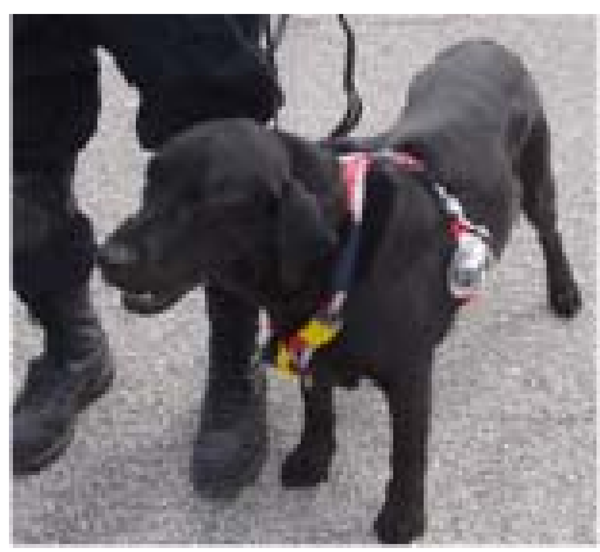

Figure 3 CAT II on a disaster dog

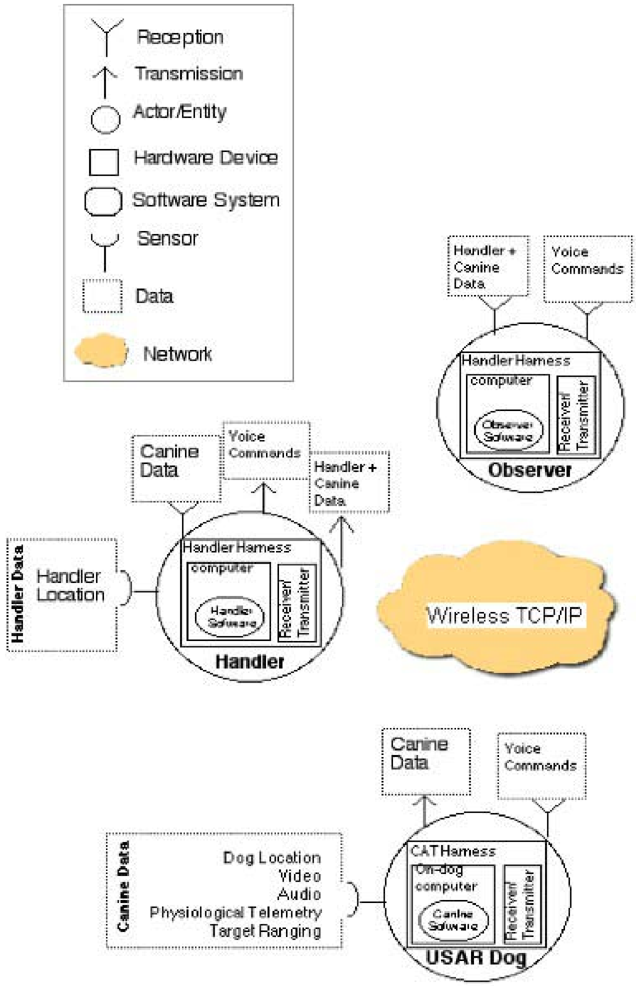

Figure 4 Diagram of CAT's architecture

3.1 CAT Hardware

The hardware that is worn by the dog is comprised of a communication device, sensors, and an embedded computer, held in place by tailored strap webbing. The hardware also consists of the communication device and computer used by human operators. Software consists of separate executable modules for the dog, handler, and observer located either in the embedded computer carried by the dog or in the computers used by the human operators.

3.1.1 CAT Communications

CAT communicates over 802.11b based wireless network. This may change as newer and more practical technology becomes available. The advantages of a digital signal over analog are its potential ability to penetrate many barriers such as concrete structures, ease of extending range through the use of repeaters [2], compatibility with widely available portable computing devices, which ease integration challenges, and built in support for encryption to ensure security.

Currently CAT relies on a mesh network to ensure that information reaches operators reliably. Mesh networks have the advantage of extending the range of communication of individual nodes on the network, thus allowing a larger search area. With the deployment of multiple mesh nodes, less signal loss is experienced through redundancy in the network.

3.1.2 CAT Sensors

While implementation of CAT thus far has utilized only VIS-IR cameras, many types of sensors of various sizes and weights may be utilized depending on mission requirements. In an earlier implementation of CAT, a single camera was employed on canine goggles. While the goggle version was very compact it was problematic in that the goggles interfered with canine vision and all the dogs tested clearly did not find the apparatus very comfortable.

The current implementation of CAT consists of a pair of pan/tilt shoulder mounted and armored infrared video cameras. One of these is depicted in Figure 5.

Figure 5 Pan/Tilt IR camera with protected dome

In addition, microphones have been provided as well as a variety of lights for area illumination and other components as well. We have found that often the audio signal coming from the dog can provide additional information about the situation of simulated casualties as the microphone can picks up sounds from the casualty as well as ambient sounds such as the breathing of the dog—giving clues about the state of the dog.

3.2 CAT Software

3.2.1 Canine Software

Canine software is installed on the embedded computer on the canine harness. It is responsible for collecting sensory data, encoding, transmitting, as well as decoding and executing commands received.

3.2.2. Handler Software

The handler would experience data overload if all CAT data were presented to him while he is directing the canine.

The handler software is responsible for selecting and decoding only the relevant and critical data from CAT and overlaying the data on a display. It is not certain that the handler would actually benefit from any of the information retrieved from the dog as the handler is usually busy enough simply controlling the dog. However, a search teammate can usually make use of the information. The final form of how CAT data is to be presented is an area of ongoing research.

3.2.3 Observer Software

The observer software is to be used by personnel at incident command posts. This software module is responsible for collecting, recording, and performing analysis of all CAT data. Clearly, incident commanders are not interested in the same data that canine handlers might require. To date, we have not fully explored how CAT data might be used strategically by incident commanders. It is likely that the camera data could provide valuable insight about the state of the structure being searched.

4. Tests and Results

To ensure that CAT can be confidently deployed under rigorous conditions, field tests were performed to determine durability, and network reliability.

4.1. Endurance

CAT utilizes many electronic components. The WiFi adapter draws significant power as do the servomotors for the camera pan/tilt mechanism. The WiFi adapter draws up to 1 Amp at peak while each servomotor draws 100 milliamps. There are 4 servomotors total, 2 per dome. The video server device can draw up to 600 milliamps. The entire system draws 1.5 to 2.0 Amps when deployed. With the power supply that is currently used, CAT can run continuously for 2 to 4 hours depending on usage conditions. This duration is sufficient since canine searches typically do not last longer than 30 minutes.

As the dog traverses a harsh and challenging environment during its search, the CAT equipment worn by the dog must withstand frequent physical shocks. The dog is not cognizant of the delicacy of the equipment it carries. The dog is working to receive a reward and has no interest in anything else. In order to duplicate the unpredictable nature of canine carriage, tests for shock resistance were conducted by vigorous shaking in the lab. A heuristic has been developed that has yielded good results. If a component can withstand 5 minutes of continuous violent shaking it will be suitable for CAT. However, field experience has also shown that CAT equipment must also be well shielded, as the dog often brushes and rubs against objects as it traverses the disaster site potentially damaging CAT components.

4.2. Communication Reliability

One measure of the effectiveness of a system such as CAT in a USAR environment is its tolerance to communication loss. Like most wireless mesh communication systems, two situations arise where CAT experiences communication loss. When CAT moves out of range of the network or when CAT drops one mesh node to connect to another. Repeated tests indicate that the average time CAT takes to reconnect to the network is 10 to 15 seconds. This is true for, going out of range and re-entering network range as well as for network handoff. While this is not ideal, the dog continues to search and operates autonomously throughout. If the dog finds a live patient and indicates their presence, the time delay for network reacquisition is less than the time the dog will spend giving a bark indication.

Each disaster site's physical configuration is unique and determines the network performance. Factors that contribute to interference include wall thickness, material type and number of physical barriers between nodes. Concrete and steel rebar, as common building materials, have been found to cause the most interference. Due to the unpredictability of the USAR environment, replicating it in a controlled lab environment is impossible.

5. Recent Field Deployments

In June 2007, Canada Task Force 3 (Toronto Heavy Urban Search and Rescue) held a simulated structural collapse exercise. CAT was initially deployed at approximately 0845 on June 6th at an abandoned hotel in Toronto that was used as a simulated disaster site. The USAR dog named Dare was fitted with the latest CAT prototype. Under the guidance of canine handler Provincial Constable Kevin Barnum, Dare crossed into the disaster "hot" zone of the hotel's covered driveway that had undergone a partial collapse.

During the test, it was not believed that Dare had not found any casualties as the dog did not bark to provide an indication of trapped people. On later examination of the video recorded from one side of the CAT system, an image of an upright, hunched-over human figure (shown in Figure 6) can be discerned.

Figure 6 Faint image of a casualty recorded by CAT

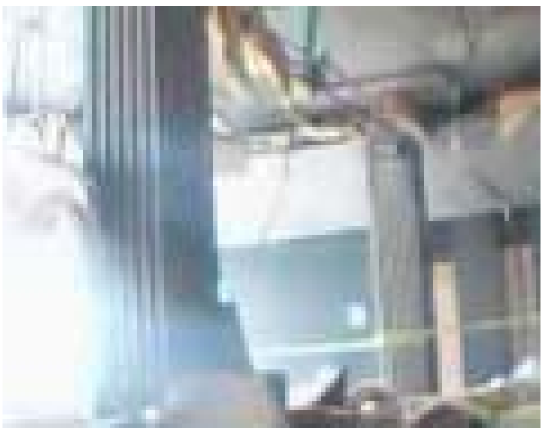

Figure 7 Image of structure supports recorded by CAT

Dare is not trained to provide an indication for people that are standing. Dare's training conditioned him to find people lying down and hidden. Since the person was standing up the "casualty" was missed. CAT detected this situation. Other valuable pieces of information obtained through CAT are the images (Figure 7) of the structure that could have been used by structural engineers to help evaluate the structural stability of the building. Perhaps coincidentally, the final path chosen by the structural engineer to achieve a breach in a wall at the disaster site was the same path that Dare took in the initial search which was recorded by CAT.

6 Conclusions and Future Work

From the exercise held in June 2007, CAT has demonstrated that it can provide valuable information to emergency responders through a video feed from a trained USAR dog. Future plans for CAT include interfacing additional sensor types to provide a more comprehensive understanding of the site.

Of particular importance is the dog's location within an enclosed structure where line of sight is lost. Video images are usually insufficient to determine position unless a video observer is familiar with the interior. Thus, research into tracking the canine's location through triangulation using WiFi signal strength is currently being explored.

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