1-1-2009

A telepresence system for canine search in an urban search and rescue environment

Jimmy Tran
Ryerson University

A TELEPRESENCE SYSTEM FOR CANINE SEARCH IN AN URBAN SEARCH AND RESCUE ENVIRONMENT

By
Jimmy Tran
Bachelor of Science
in the Program of Computer Science,
Ryerson University 2007

A thesis
presented to Ryerson University
in partial fulfillment of the
requirements for the degree of
Master of Science
in the Program of
Computer Science

Toronto, Ontario, Canada, 2009

I hereby declare that I am the sole author of this thesis.

I authorize Ryerson University to lend this thesis to other institutions or individuals for the purpose of scholarly research.

JIMMY TRAN

I further authorize Ryerson University to reproduce this thesis by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

JIMMY TRAN

ABSTRACT

A TELEPRESENCE SYSTEM FOR CANINE SEARCH IN AN URBAN SEARCH AND RESCUE ENVIRONMENT

Jimmy Tran

MSc, Computer Science, Ryerson University, 2009

Two crucial factors in urban 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. Our research demonstrates that emergency responders can improve their situational awareness in a dangerous disaster situation with the aid of search canines augmented with our telepresence system—Canine Augmentation Technologies (CAT). CAT is a system that integrates a set of technologies: wireless mesh network; wearable computing; sensors; and actuators. The goal of our research is to show that it is possible to impart the sensed, real-time situation of a dog through telepresence to a remote human who can use this information to safely find trapped people in buildings having suffered structural collapses.

ACKNOWLEDMENTS

I would like to thank my mom for all the love and support she had given me all my life. Her encouragement and belief in me allowed me to complete this thesis. I would like to thank my dad for teaching me the importance of education.

I am most grateful for the guidance and support of my supervisor Alex Ferworn. He is everything one can hope for in a teacher and I have learned so much from him. Without his guidance, this thesis would not be possible.

A special thank goes to the Ontario Provincial Police, Provincial Emergency Response Team. I would like to particularly thank Constable Kevin Barnum for all his help and support in this research.

I also would like to express my gratitude to Steve Kanellis for allowing me to soak up all his electronics knowledge and Devin Ostrom for his help in the project.

To everyone that has ever been in the hole, especially Cristina Ribeiro, Vijay Somers, Nhan Tran, thank you for being in there so I can run my experiments.

Lastly, I would like to thank my good friend Richard Lee for helping me through the toughest part of this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABBREVIATIONS

CAT	Canine Augmentation Technology
CRDS	Canine Remote Deployment System
CPE	Canine Pose Estimation
CBF	Canine Brain Function
CWA	Canine Work Apparel
SAR	Search and Rescue
USAR	Urban Search and Rescue
EMS	Emergency Medical Service
FEMA	Federal Emergency Management Agency
DHS	Department of Homeland Security
PSEPC	Public Safety and Emergency Preparedness Canada
NIST	National Institute of Standards and Technology
ASTM	American Society for Testing Material
NCART	Network-Centric Applied Research Team
PERT	Provincial Emergency Response Team
OPP	Ontario Provincial Police
CAN-TF3	Canada Task Force 3
CPS	Computational Public Safety
SA	Situational Awareness
DoF	Degrees of Freedom
RF	Radio Frequency
PDA	Personal Digital Assistant

WiFi	Wireless Fidelity
WLAN	Wireless Local Area Network
WMN	Wireless Mesh Network
COTS	Common off the Shelf
IR	Infrared
LED	Light Emitting Diode
SSH	Secure Shell
SDK	Software Development Kit
CPU	Central Processing Unit
GPS	Global Positioning Systems
AI	Artificial Intelligence

CHAPTER 1 INTRODUCTION

1.1 Introduction

Disasters, being intrinsically unpredictable, predicate a need for well-trained emergency first responders to limit casualties. Resources available to the first responders greatly affect their ability to perform their tasks quickly and efficiently. Thus there is a continual impetus for research to devise and improve techniques and equipment in the field of search and rescue (SAR). This thesis describes one such innovative system in the specific area of urban search and rescue (USAR).

In recent years, major urban disasters are not hard to find, Hurricane Katrina (2005), the World Trade Center collapses (2001) and the China earthquake (2008) all occurred in urban centers. There are many cities in the world and those urban populations are growing at an ever-increasing rate [1]. Because there is a higher concentration of people in cities than rural areas, the threat posed by urban disasters—even if relatively moderate—can have profound effects on an individual government's ability to deal with the aftermath. Therefore, the threat posed by urban disasters makes USAR very important.

In urban disasters, one common characteristic is the tendency for buildings to suffer structural collapse. When a building collapses, "voids" are often created. Voids are pockets of space underneath rubble where live survivors may be found. An USAR operation involves the location of these survivors, their medical stabilization and their extraction to safety for further treatment.

Two crucial factors for emergency managers and first responders in any USAR operation are limited time and the need for rapid data acquisition to help establish an understanding of what is actually happening in the operation. This is commonly called "situation awareness". In a fluid progression, emergency responders, under the guidance of emergency managers, locate casualties, develop rescue plans and implement them rapidly—as faster response usually leads to more saved lives. The main challenge is to rescue casualties quickly without any 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 search team consisting of one or more trained USAR dogs and a human handler. Such teams are highly effective at locating casualties and are the primary means of the initial "search" in USAR. Dogs are used because they can be trained to search for humans trapped in rubble relatively easily using their sense of smell, are extremely fast, and agile and because they are reliable.

However, due to the limits of communication between the handler and dog and the fact that the dog can work in areas that the handler cannot access, information about casualties may be incomplete or inadequate. In other words, the dog may be in a position to sense something about a casualty and their situation and not be able to communicate it to the handler.

Relatively recently, another method capable of providing data about the disaster environment has become available in the form of rescue or "response" robots. These mobile robots are generally teleoperated and can be fitted with a variety of sensors [2-4]. However, some artificial sensors are not as effective as those found in biological systems like dogs and their olfactory system. However, other useful sensor types that can be carried by robots that 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.

We propose that it is possible to have a synthesis between natural and artificial systems that exploits the best features of both [5] to address the problem of improving what can be sensed about survivors trapped in rubble. The direct application is to aid search and rescue workers in gathering data promptly and efficiently using tools with which they are already familiar. This research is in the field of Computational Public Safety (CPS), which involves the application of computational resources, theory and practice in support of safety processes with the goal of improving them.

The goal of this thesis is to prove that it is possible to impart the sensed, real-time situation of a dog—through telepresence—to a remote human who can use this information to help plan a rescue.

1.2 Problem Definition

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 with time.

In order to expedite the rescue effort, better situation awareness is needed. Useful information such as the precise locations of survivors and visual data of internal structures formed by rubble can help improve situation awareness. However, some areas are too dangerous for humans to access and collect this information. These areas must first be stabilized before humans can enter them and this adds delay to the search process when one realizes that many hours can be spent stabilizing an area to be searched even though no humans may be found within.

Ideally, emergency responders would like to gain awareness from 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 and can even determine their numbers. 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.

Response robots can provide video, audio and other sensory data. Their main deficiency is that in their current form they are ineffectual at actually finding people. One reason for this is because they rely mostly on visual cues indicating the presence of survivors that are very sparse when compared with the space that must be searched. This is additionally problematic because often these cues are obstructed or obscured by fallen debris and dust. In addition, robots have difficulty traversing rubble. Often they get stuck and become damaged by the rubble that can be traversed easily by a dog.

1.3 Objectives

The original concept of combining the innate abilities of canines and strengths of robotics into one extensible system to provide a better tool for USAR operations was originally proposed by Dr. Alexander Ferworn of the Computer Science Department of Ryerson University as a solution to the problem defined in section 1.2. The system called Canine Augmentation Technology (CAT) is a wireless video, audio, telemetry and sensing system designed to be worn by a USAR dog while actively searching for survivors in areas where their handler cannot follow [6-8].

The first generation prototype of the system was comprised of a wireless analog video and audio camera that could be worn on a dog's head. The system had some success but eventually encountered severe limitations in effective transmission range, the quality of transmitted data, and, perhaps most importantly, the lack of expandability for additional sensors. In addition, the dog ergonomic needs were not addressed. The last problem coined the term "dogonomics".

The purpose of this thesis is to continue the work on CAT by completing and improving upon the concepts and designs of the original work. The goal is to prove that it is possible to impart the sensed, real-time situation of a dog, through telepresence, to a remote human who can use the information to safely find trapped survivors in a structural collapse and plan for their rescue.

This research involves the design of a new architecture for CAT that provides robust communication, expandability for different types of sensors, digitization of data, and addresses various dogonomic and human usability issues.

Key elements of the new architecture were implemented in a demonstration system. One such key element was the use of the IEEE 802.11 standard commonly known as wireless fidelity (WiFi) [9] for communication. By design, the use of WiFi meant that all data transmitted must be digital. Our main focus was directed toward effective video transmission, since visual information was a practical means for imparting what the dog is experiencing to humans that are not physically present with the dog. Thus, we assume that visual information will provide the best means of imparting situational awareness to humans.

Although the main focus is video data in this implementation, the design of the architecture facilitates the addition of other types of sensors. Further, an algorithm utilizing CAT for canine search operations was developed to demonstrate its utility and assist in it effective application.

In order to confirm that the goals of this thesis have been met, a series of experiments were designed to test the efficacy of CAT in operation.

1.4 Thesis Organization

This chapter serves as an introduction to four additional chapters. Chapter 2 presents an overview of the emergency management field, its strategies and the technologies used in USAR operations. A literature review of related work in augmenting animals with technologies, telepresence and situation awareness is provided.

Chapter 3 describes the current CAT architecture. All prototypes within the current generation leading to the latest are described. The algorithm utilizing CAT in canine assisted USAR operations is explored.

In chapter 4, experimental procedures are explained and the results obtained are presented. This is followed by analysis and discussion of the results.

Finally, chapter 5 presents a summary of this thesis and contains a discussion of future research.

CHAPTER 2 BACKGROUND

This chapter provides background information about the Emergency Management field in general and USAR in particular. Additionally, it describes and reviews the search techniques, strategies, and technologies used in USAR. Furthermore, this chapter is a review of the literature on past and current research in animal augmentation as well as wireless communication standards and technology. Finally, this chapter reviews literatures on two key concepts in this thesis: telepresence and situation awareness.

2.1 Emergency Management

In the filed of Emergency Management, the terms disasters, emergency, and hazards are common and will be used throughout this thesis. These terms may seem to have similar meanings, but there are distinct differences in meaning in the field of emergency management.

In [10-12], the term **disaster** is defined as deadly, destructive, and disruptive events that occur when a hazard or multiple hazards interact with social objects. Disaster refers to events that cause great damage that are beyond the abilities of a community to cope with. Usually the aid of regional or national government agencies is required to deal with a disaster. Disasters cause many human casualties, massive property damage, significant environmental damage, or severe social disruption.

There are two different ways to define **emergency** [10, 12]. The first is a minor event that causes few casualties and a limited amount of property damage. Emergencies affect a few people and can occur more regularly than disasters. Examples of emergencies include, residential fires, vehicle accidents, and medical crises. The second way the term emergency is used is in a broader sense. It refers to an event that will happen in the near future. An example of this might be the report of a hurricane that is predicted to strike within a short period of time.

A **hazard** is a threat or an extreme event that has the potential to cause damage to humans, property, and the natural environment in a given location [12]. Hazards can be natural, technological, or caused by human activity.

When a disaster occurs, professional emergency managers are required to deal with the situation. **Emergency managers** are public servants that have the knowledge, skill and expertise to help reduce liabilities [11] as the emergency unfolds. There are four phases of emergency management: preparedness, response, recovery and mitigation.

Figure 2.1 – Emergency Management Cycle

Mitigation activities try to prevent disasters, and reduce loss in case of a disaster. Preparedness activities refer to the efforts made to increase readiness for a disaster. Response activities are the actions performed immediately after or during the occurrence of an emergency to protect life and property. The term "**first responder**" is derived from this phase of emergency management. First responders are generally made up of fire fighters, police and emergency medical services (EMS) personnel. Recovery activities begin after the situation is stable and efforts are made to return the affected community to a pre-disaster state.

Examples of this cycle working are the tragic incidents which were experienced by Oklahoma City after a domestic terrorist bomb[13], Kobe Japan and [14], Mexico[15] after devastating Earthquakes and the World Trade Center[16] after international terrorist attacks.

2.2 Urban Search and Rescue

USAR is a multi-hazards discipline that is capable of addressing a wide assortment of emergencies and disasters. The model for USAR organization is generally based on the "**task force**" concept. An USAR task force is usually a regional or national organization that is staffed with first responders with special skills and equipped with specialized equipment that would not normally be available to local responders. While most USAR task forces are permanently established, their personnel are mostly volunteers who are regular fire fighters, police, EMS or heavy equipment operators in their regular careers. Task Forces are deployed when the regional or national authority makes a formal declaration of a disaster situation that would require the response of a task force.

In the United States, the national organization responsible for responding to disasters is the Federal Emergency Management Agency (FEMA) of the Department of Homeland Security (DHS). There are 28 USAR Task Force teams spread over the United States. Similar to the United States and DHS, Canada has Public Safety Canada (formerly known as Public Safety and Emergency Preparedness Canada) (PSEPC). The Canadian government currently provides for the funding of 5 USAR Task Forces spread regionally across the country.

Task Forces are responsible for the location, rescue, and initial medical stabilization of survivors trapped in confined spaces. Survivors are also called "patients" by emergency managers. The most common cause of patients becoming trapped in a confined space is the structural collapse of the building they happen to have been in before the collapse occurred, but other causes may be transportation accidents, and the collapse of mines and trenches[1][17].

Members of a USAR task force work in four different specialties:

Search: locate trapped people;

Rescue: safely retrieve patients;

Technical: includes structural specialist who make sure that the site is safe for other rescuers to do their work, heavy equipment operators who are trained in disaster excavation; and

Medical: provide medical care for patients and members of the task force.

[1] Trenches are common in the construction industry where they are dug and reinforced to allow work to occur on subsurface components of a work site.

Each search and rescue operation is unique but typically involves common elements. After arriving at the scene of a disaster involving a structural collapse, structural engineers examine the damaged buildings and other structures and determine the unsafe and safe areas. These will be marked and unsafe areas will be isolated and preclude human search. The search teams are then deployed to locate patients, using all the techniques available to them. These may include technologies such as specialized listening equipment, video cameras, rescue robots[3, 4, 18, 19] and canine search teams.

Practicing a form of triage, patients that can easily be extracted are assisted first. Patients that have been located but whose extraction requires more work are handled next. Often achieving rescue involves the task of digging through tons of concrete, metal, and other building materials to reach the patient. Medical teams standby to stabilize patients as they are extricated from the rubble [20]. Once a patient is stabilized they will be evacuated to medical facilities.

2.2.1 Urban Search and Rescue Canine Team

One of the most effective ways to search for patients buried under rubble is through the use of USAR canine teams. A single canine team consists of one highly trained handler and one or more specially selected and trained canines. Dogs are used for their incredible sense of smell, agility and "dogged determination". Canines primarily use their olfactory sensory system to track and identify items of interest as opposed to their visual sensory system [21]. Their sense of smell can be used to great advantage, as a canine's olfactory system is extremely sensitive—far beyond the ability of any human or human-made instruments. Also, this ability to smell what they are interested in allows dogs to find targets that are not visible—such as patients who are fully covered by rubble. The use of dogs as a scent detecting systems is very common and used in various applications. Some examples of this include detecting explosives [22], drugs [23], and even cancer [24].

USAR dogs are trained to specifically locate live human scent. Unlike "**tracking**" dogs, USAR dogs do not need an article that belongs to the patient to locate a particular individual. In training, the dog learns that any human they find will do as long as they cannot be seen or are lying down. They pick up the scent of a human in the air of the area of interest, and follow the scent plume to where the scent is strongest. This is usually near where the hidden human is located. This process is known as "**air scenting**"[25].

While USAR canines or "**disaster dogs**" or "**sniffer dogs**" are directed and guided by their handlers, they mainly work off-leash. They are trained to be able to work on their own, away from the handler [26-28]. This means that they can enter areas of the disaster site that are too small for a human to fit into, or too dangerous for humans to follow. Disaster dogs are trained for working in unfamiliar, and hazardous environments. Their training and innate agility allow them to safely explore the disaster site.

Despite the many advantages of dogs, there are several challenges to overcome. An obvious issue is the human-animal interaction. Disaster dogs are trained to bark as an indication that they have found a human. This is the only way that a dog can deliberately communicate with the handler. Barking provides very limited information. Richer information such as the visual depiction of the inside of the structure where the dog found the scent source would communicate more information to the search team, more precise location information and an indication of the condition of any live humans would be helpful as well. In addition, the barking does not indicate the number of trapped people that might be present. Another concern is related to the nature of the disaster site. If the dog enters an area where its barking cannot be heard by a distant handler, any trapped people will not be located despite being found by the dog.

2.2.1.1 USAR Training Exercises and the Canine Team

Equipment designed to be used in USAR operations must be tested thoroughly due to the hazardous environments that it will be used in, as well as the critical need for it to not fail. It is ideal to be able to test equipments in the real disaster environment. Opportunities to test equipments in a real disaster in Canada are rare, but USAR training exercises can provide similar environments. In order to provide a better understanding of the field experiments conducted in this research, this section will describe some of the training methods that the USAR canine teams employ in training.

The majority of the time, USAR dogs and their handler train on "**rubble piles**" (or simply, **"piles")** where they can find them. This includes the use of construction sites, demolition areas, and, if they are lucky, specially built piles similar to the one shown below.

Figure 2.2 – Rubble pile at PERT Training Facility

Rubble piles can be of many materials found in buildings. Usually, they are built from construction debris made up of concrete and reinforced concrete[2] and any other materials which are available and would normally be present after a building's collapse. Often a tunnel system is built under the rubble pile to facilitate training in confined spaces.

Typically in a canine search exercise, there will be a volunteer who acts as a survivor in the collapsed structure. In USAR canine terminology, the volunteer is known as the "**quarry**". At the beginning of the exercise, the quarry is given the chew toys of each of the dogs that will be searching, is placed in the rubble pile and covered or hidden so that they cannot be seen.

[2] Generally reinforced with steel rods called "rebar"

A period of time is allowed for the scent plume to build up around the quarry. Following this, canine handlers will bring out their dogs one at a time and direct them to search. The dogs search for the scent plume by moving rapidly across the face of the rubble pile. When they find the plume they follow it until they find the area where there is the highest concentration. Usually, this is where the quarry is buried, At this point a dog will start a continuous series of barks. Other sections of this thesis will refer to this as the "**bark indication**".

When the dog is close enough to the quarry and a sufficient quantity and volume of barking has taken place, the handler will indicate to the quarry that the dog should be rewarded. The quarry will cheer the dog in a high-pitched voice and provide the dog with its chew toy. Sufficient barking is important as it alerts searchers that someone has been found. Staying by the patient allows searchers to locate where someone may be buried. Good dogs will keep barking and stay by the patient for a long period of time until recalled by the handler.

2.2.2 Rescue Robots

In a similar fashion to dogs, rescue robots are employed in disaster environments that are too hazardous or inaccessible for humans to enter. However, disaster environments have proven to be hazardous for the robots as well. Even the most advanced mobile land robots equipped with wheels or tracks can encounter difficulties with rubble, debris, and even obstacles as simple as stairs. There has been recent progress in robot designs that utilize shape-shifting or variable geometry [19,

Figure 2.4 – Kohga Robot

Despite many different schemes for achieving mobility in rubble, the mobility performance of rescue robots is generally quite poor-with robots becoming stuck quite often. One scheme for overcoming the rubble mobility problem is through the use of multiple robots acting in concert. The notion here is that when one fails because of a deficiency in its design, a partner robot may be able to succeed using the progress made by the previous robot to its own advantage. Probably the most common cooperative technique is marsupial operation.

Marsupial operation seeks to take advantage of the fact that different robot designs have different strengths and weaknesses. By combining the strengths of one robot, the weaknesses of another robot can be overcome as multiple robots interact to complete complex tasks. For example, a large robot can scale terrain with big steps while a small robot can enter small openings. If the large robot carries the small robot and places it for entry in a small opening, the large robot is said to be using marsupial delivery when it places the small robot. The concept is explained in details in [30]. In practice, marsupial delivery is not commonly used as emergency task forces typically do not carry compatible robots nor do the robot operators practice this rather complex operational skill.

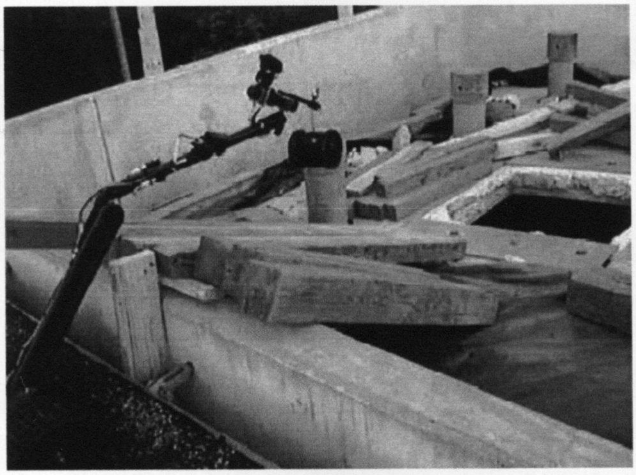

Figure 2.5 – A Large Talon robot delivering a small Toughbot robot (seen in Talon's gripper) into a small opening in a roof. Note that the Talon is unable to cross the concrete threshold shown in front of the robot arm.

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 USAR environment [32] 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 manufacturers 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 [33] through the ASTM standards process, E54 Task Group [33-35].

Figure 2.6 – Participants in the fifth DHS/NIST Response Robot Evaluation Exercise at "Disaster City", College Station, Texas. Participants are drawn from the first responder, academic and manufacturer communities in the U.S. and internationally.

Robots are evaluated on various performance characteristics including mobility, sensing capabilities and overall system performance (durability, communication, power) as well as secondary 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 NIST response robot standard for mobility in rubble.

2.2.3 The Dog as Autonomous Robot Metaphor

Dogs have agility that can be enhanced through training and are thus able to overcome what would be serious barriers to robots. Motor control is intrinsic to the animal, thus navigation can be accomplished 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, we can think of the dog as an autonomous robot where the handler can let the dog do the driving as the dog is equipped with many of the characteristics that robot designers can only hope research in Artificial Intelligence can deliver. In the case of a dog, biological intelligence is used instead of artificial intelligence.

The majority of USAR robots currently in operation are teleoperated through tethered control lines or analog radio frequency (RF) links [33, 36]. Tethered robots typically require two operators to control them effectively—one to drive and another to manage the tether. The problem with a tether is that it can be caught, snagged, or become tangled. Similarly, robots communicating wirelessly often employ multiple operators as the difficulty of controlling the robot distracts the operator from actually looking for signs of trapped people. In addition, Radio signals are susceptible to interference and have difficulty in penetrating concrete and other debris. Since the scene of a disaster incident may be quite large, wireless robots may be susceptible to inadvertent jamming by other operators controlling other robots in the same vicinity. Some of the problems that the robots that were deployed in the World Trade Center terrorist attack in September 11, 2001 experienced are described in [4]. Robots were actually lost in the rubble due to loss of wireless communication. Others were damaged due to the harsh environment. Typical damage and ware to robots are shown in Figure 2.7 and 2.8.

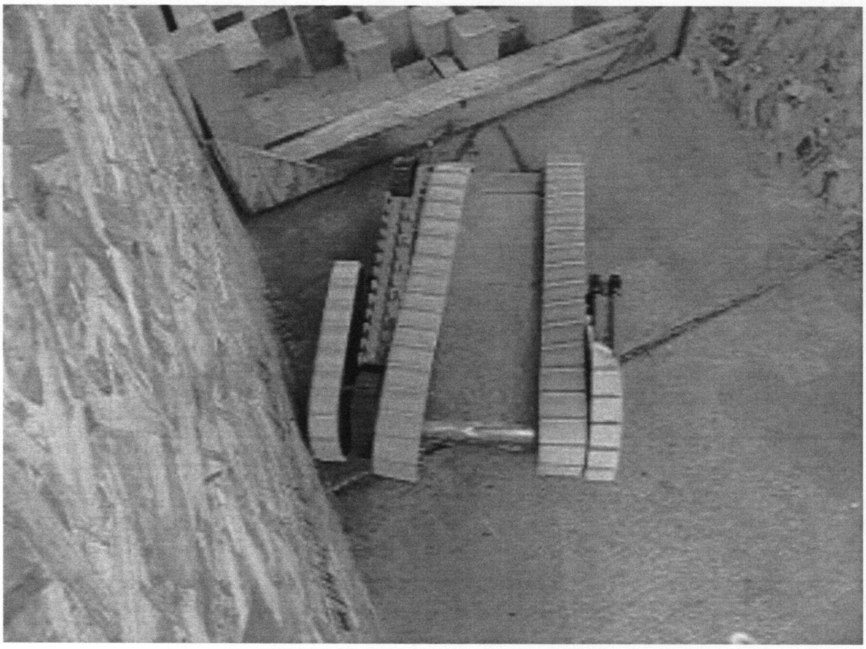

Figure 2.7 – Packbot having undergone track shedding after NIST Response Robot endurance testing

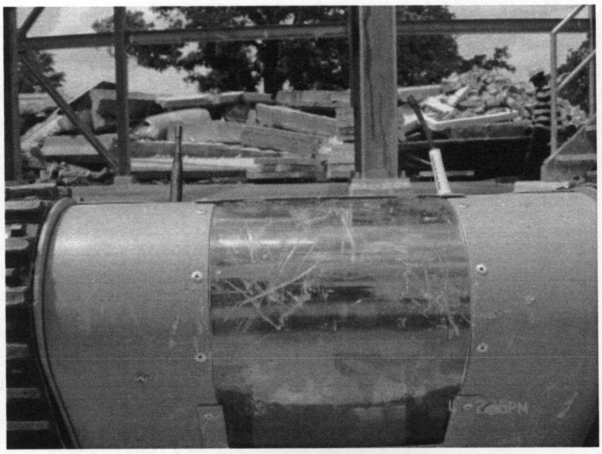

Figure 2.8 – Matilda robot with scratched and abraded armoured front visor. Damage caused by attempting to traverse rubble seen in background

2.2.4 Augmenting Animals

The concept of augmenting animals with technology is not new. The United States Navy use trained bottlenose dolphins equipped with transponder to detect and mark anti-ship mines [37]. Other technology such as camera systems have been attached to sharks for research [38].

Aside from sea creatures, land animals have been equipped with technology as well. One of the most common animals used in this capacity are dogs. At the World Trade Center disaster, USAR dogs had wireless cameras attached to their collars. They were sent into the rubble to search for patients and either transmitted video back or recorded video for later examination [39]. Industrial Television Limited of the United Kingdom has produced a system called the FIDO Police Dog Camera that attaches a wireless camera to a harness worn on a dog's head. The system is used by the UK police in weapons seizure operations [40].

In 1974 [41] a study was conducted whose goal was to develop procedures by which a dog handler could control the direction of off-leash movements of appropriately trained dogs through remote means in an unrestricted environment. The intent was to employ dogs as independent scouts. The study was successful in conditioning several dogs to respond to a transmitted tone that would cause the dog to change direction. It was reported that it was possible to control dogs up to one-half mile or more under the control of terrain stimuli and tone signals.

Canine Augmentation Technology as a system bypassing the need for an artificial mobility system, was first introduced by Dr. Alexander Ferworn of the Network-Centric Applied Research Team (NCART) at Ryerson University [8]. Early prototypes consisted of wireless analog cameras that were attached on top of a dog's head—similar to the FIDO Police Dog Camera system. Later versions of the system attached a wireless camera on a pair of modified dog goggles (goggles for dogs) where the lenses were removed and batteries and other electronics were housed in webbings that was attached to the straps. This prototype also had a wireless audio receiver and earphones to transmit voice command from the canine handler. Unlike FIDO, CAT was designed for USAR dogs that work off leash and had an effective range of 100 meters (line of sight).

Figure 2.9 – USAR canine wearing CAT dog goggles at exercise in Fergus, Ontario 2006

Probably the biggest challenge to early CAT prototypes was dogonomic. The dogs are not comfortable wearing the doggles. It was surmised that the doggles hindered the dog's ability to search—perhaps by interfering by their peripheral vision or by providing discomfort to the dogs. At times when dogs were very exited about searching, they would search effectively for a while. However, after some time passed the dogs would begin to perform unusual maneuvers to remove the goggles.

One of three other technologies developed by NCART is the Canine Remote Deployment System (CRDS). The CRDS was developed to increase patient survival rates during the—often long—intervals between discovery and rescue [42]. The CRDS utilizes the agility and determination of USAR dogs to deliver food, water, medical supplies and communications devices to patients trapped in areas where passage by human workers is difficult or not practically possible. The supplies are stored in a bright orange bag that the dog carries under its belly called the "**underdog**" as shown in Figure 2.10.

Figure 2.10 – CRDS detail. From left to right: Harness, CRDS with Bark Release, underdog.

Figure 2.11 – Under dog wearing CRDS and underdog and barking

Figure 2.12 – USAR Dog left underdog behind

When a USAR dog finds a live patient, it provides a bark indication which continues for some time as the dog remains where it "found" the patient. The handler then uses a remote transmitter to wirelessly release the underdog from the harness.

Another parallel research effort within NCART seeks to determine the "**pose**" or body position of a remote dog. The Canine Pose Estimation (CPE) system [43] project was created to investigate mechanisms which allows handlers to know what their dogs are doing when a dog is out of sight. This is achieved by knowing what pose (sitting, standing, walking etc.) that the dog is in. The research is developing an algorithm that estimates the dog's pose from acceleration data. The data are collected and transmitted wirelessly from accelerometers attached to the dog. This is important as the dog's body position can communicate many things including camera angles for images received from CAT. CPE also increases the potential communication vocabulary between and the dog and handler. For example, cadaver dogs are trained to sit when they discover a dead human. Using the CPE it is possible to detect this sitting pose and show it to the handler.

The fourth canine research project from NCART is Canine Brain Function (CBF) [44]. The research has found that it is possible to sense what an USAR dog is experiencing by measuring its physiology during the activity. The device used in CBF is a multi-channel near infrared brain spectroscope as reported in [45, 46]. This type of sensor is capable of measuring brain oxygenation by illuminating the brain tissue within the skull and detecting the lights reflection.

Many canine handlers believe they will be able to determine the mental state of the USAR canine. This will allow them to determine if the dog is actually working on the problem of finding people. The potential advantages CBF includes is the ability to differentiate various canine states and apply them to the sensing task. For example, explosive detection dogs will indicate the presence of an explosive but perhaps it is possible to determine what explosive is actually present by measuring their physiological response.

In experiments conducted, canine handlers were asked to hold a sensor on their dog's head for several minutes until the dog became familiar with this and became calm. After the calming period, the sensor output was recorded. Another participant would then show the dog its favourite toy. It was possible to detect a change in the blood oxygenation shortly after the toy was presented and before any physical activity was exhibited by the dog.

2.3 Wireless Technology

The wireless technology chosen for this thesis is WiFi. WiFi is a technology used for wireless networking commonly employed in office and residential environments. WiFi technologies are used in a wide variety of electronic products ranging from personal computers, laptops, Personal Digital Assistants (PDA), to mobile phones, and video games. WiFi allows network clients to form a local area network without the connection of physical wires. It follows the various IEEE wireless local area network (WLAN) 802.11 sets of standards, which include 802.11a, 802.11b, 802.11g, 802.11n. Figure 5 is a table comparing the 802.11 technologies. Complete information on the IEEE 802.11 standard can be found in [47].

	Release date	Frequency Band	Data Rate (Typical)	Data Rate (Maximum)	Range
802.11a	October 1999	5.0 Ghz	23 Mbit/s	54 Mbit/s	35m
802.11b	October 1999	2.4 Ghz	4.5 Mbit/s	11 Mbit/s	38m
802.11g	June 2003	2.4 Ghz	19 Mbit/s	54 Mbit/s	38m
802.11n	Pending	5.0 and/or 2.4 Ghz	74 Mbit/s	300 Mbit/s	70m

Table 1 – Comparison between the different 802.11 standards

2.3.1 Wireless Mesh Networks

Due to the limited range of the 802.11 WiFi standard, it is difficult to build a wireless network that can span a large geographic area. Wireless Mesh Network (WMN) technology is a way to overcome this problem. WMNs can be applied to different wireless technologies but the focus in this section is on 802.11. A WMN expands a WLAN by connecting many WLANs together. In a WMN, there are 2 types of nodes, mesh routers and mesh clients. The mesh routers connect together to form a network as well as acting as access points creating an infrastructure/backbone for mesh clients to connect to. After a WMN is formed, a mesh client connected to the network can communicate to any other mesh client seamlessly regardless of which mesh router it is connected to.

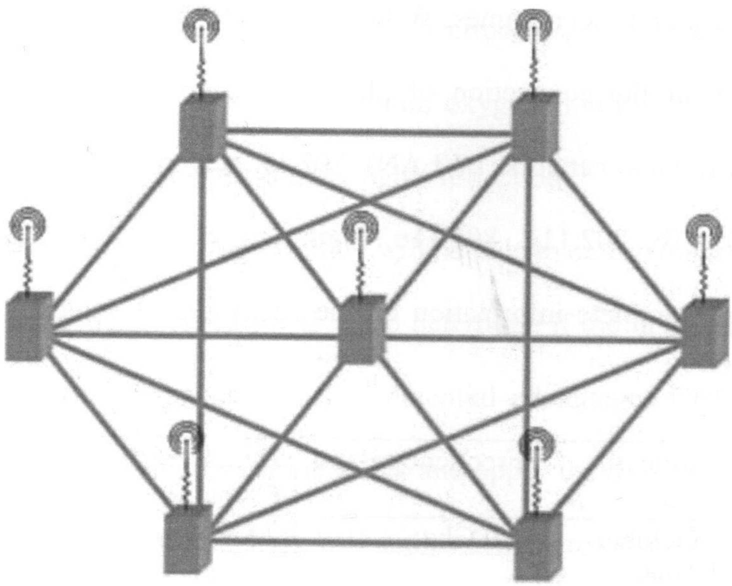

Figure 2.13 – Wireless Mesh Network diagram

The most important characteristics of a WMN are their self-forming, self-configuring, and self-healing capabilities. Self-forming means as each mesh router node goes on-line, it automatically connects to other mesh routers to form a network. Self-configuring is the ability of each mesh router node to configure the shortest path to route the data from one client to another. Self-healing is the ability of the WMN to be aware when a mesh router node is down and to re-route data through a different path [48]. These characteristics allow the WMN to behave as a flexible network, with fault tolerance that makes it a desirable topology for demanding environments such those found in and around collapsed buildings. Because of these , a WMN can WMNs can be deployed with relative ease.

One implementation of an 802.11 WMN is a series of products developed by Rajant Corporation of the United States called “Breadcrumb” [49]. Breadcrumbs are wireless mesh routers ranging in size, shape, and wireless radio technologies (802.11b/g). Their intended use is to allow the rapid deployment of wireless networks in any location. They are becoming more commonly used in military operations where geographic topologies are difficult to predict, mining operations where wireless communication is constrained because of the physical characteristics of the environment, and USAR operations where both topological and physical constraints come into play.

2.4 Telepresence

In [50] the authors identify three definitions of telepresence used in the literature: the simple, the cybernetic and the experiential. In the simple definition, telepresence refers to the ability to operate in a computer-mediated environment. For example, telepresence occurs when an operator controls a machine from a remote location.

In the cybernetic definition, telepresence is determined through metrics employed in the measurement of the efficiency of a human-machine interface. Thus cybernetic telepresence refers to the degree of success an operator can achieve in a specific task while using displayed system information (video, audio, etc.) and controls the teleoperated system.

In the experiential definition, telepresence is a mental state in which the user feels physically present within the computer-mediated environment. For example, telepresence is when the user feels or has the illusion of physically being present at a remote site.

It is important to note the distinction between cybernetic and experiential telepresence. As stated in [50], "cybernetic telepresence is the projection of human capability into a computer-mediated environment; experiential telepresence is the projection of human consciousness into a computer-mediated environment." According to the authors of [50], experiential telepresence is the most useful definition to researchers and developers. While quality of the human interface is a determinant of the effectiveness of the experience, experiential telepresence is beyond cybernetic telepresence. They felt that other existing literature were careless in using the term telepresence with the first two definitions. In the remainder of the thesis, when we refer to telepresence we shall mean experiential telepresence.

Telepresence systems are common in our daily lives. Even though the experience is limited when using simple technology such as a telephone or video conferencing system, these still can be considered as telepresence experiences. More advanced implementations of telepresence systems are becoming more common like robots used to perform remote surgery [51, 52]. Teleoperated robots are often used for telepresence especially in areas where human are unable to work or even visit.

Some of those areas include pipeline inspection [53], deep sea work [54] and USAR operations [3, 19, 29].

2.5 Situation Awareness

Situation Awareness (SA) can be defined in simple terms as knowing what is important that is going on around you. SA is often used as an operational term, since a person does not necessarily need to know everything that is going on around them, just the information required to complete whatever task they are trying to accomplish. For example, a bus driver does not need to know the colour of the bus, but he does need to know all the information related to the goal of driving safely.

There are many definitions of SA and these may vary from one domain to another. However a general definition of SA is "the perception of the elements in the environment within a volume of time and space, the understanding of their meaning and the projection of their status in the near future" [55].

In the case of an USAR operation, SA applies differently to the different roles of those participating in the event. A canine handler may only be concerned with the dog that he is directing in a particular search. SA to a structural engineer might be achieved through the visual information of the disaster site. A rescue robot operator's main concern might be the status of the robot (location, orientation, surrounding environment). An emergency manager would need information that allows him to see the overall status of all the resources working at an incident so he can make decision concerning how to deploy resources. This information can be provided by the canine handlers, robot operators, structural engineers and others at the incident.

2.6 Computational Public Safety

CPS involves the application of computational resources, theory and practice in support of safety processes with the goal of improving them. Some examples of systems that fall into the category of computation are CAT, CRDS, CPE, CBF and rescue robots. These systems provide better SA so that optimal decision can be made in rescue efforts.

2.7 Summary

With the intent of providing a clear understanding of the motivation of this thesis, the background information about Emergency Management and USAR operations was present. These materials describe the need for USAR, how operations are carried out, and the challenges likely to be encountered. Literature reviews of other research in robotics and animal augmentation that have similar goals or concepts to this work were also presented. Additionally, this chapter includes a literature review of the wireless technology used in this research. Finally key concepts and definitions of important terms in this work were explained.

CHAPTER 3 MATERIALS AND METHODS

3.1 Architecture of CAT

Prior to the research of this thesis, the CAT project included the development of prototypes consisting of several components including a head mounted analog camera system. During field tests of these initial prototypes it was shown that a video stream from a camera mounted on a search dog can be useful for USAR operations. The work provided valuable experience in understanding the challenges of designing a telepresence system for USAR where lessons learned could influence the design of a better CAT system. However the previous work was done in an ad hoc manner and was not guided by an architecture.

In order to address the need for a long-term vision for what CAT could become, an architecture for an ideal CAT system was designed. This section describes this architecture in detail.

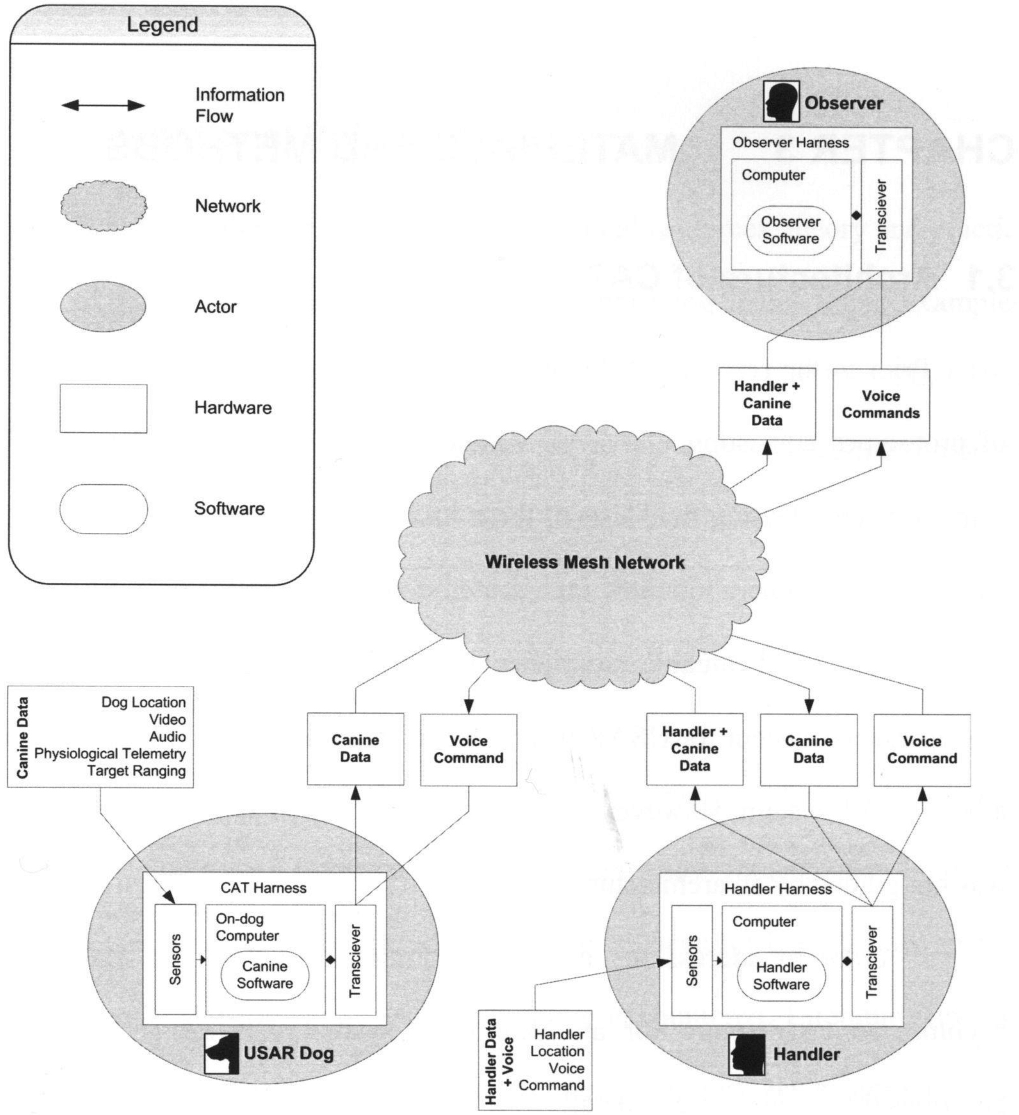

Figure 3.1 – CAT Architecture

The design of the CAT architecture began with the attempt to understand all the actors or entities that are involved in USAR operations. While a single canine team consists of an **USAR dog** and **handler**, there may be a need for the involvement of a third entity called the **observer**. It is known that directing a dog to conduct searches is already a stressful task for a handler. We also know from the response robotic literature that it is often important to have a second person helping to search [18] when the operator is fully engaged in controlling the robot. We assume that this will be the case if a handler is fully engaged in interacting with a remote dog. Therefore handlers should be focused on tasks directly related to guiding the dog in relation to the search process. Data relevant to the handler may include the dog's pose, its physiological responses and video streams. The handler might only use the video stream to help establish the relative position of the dog within the structure if she could not directly see the dog. On the other hand, the **observer** who is situated at a command post vehicle and is not directly involved with the dog could be viewing the same video stream, and be able to extract different information from it, such as clues to the structural integrity of the search area, possibly creating a map of the path the dog has taken and determining the condition of any survivors caught in the video streams. In this way there is a division of tasks such that the handler can focus on controlling the dog while the observer handles the analytical portion of deciphering what the video and other data streams mean.

3.1.1 Telepresence Sense Simulation

The next part of the design required the examination of the digital data required to impart the most appropriate level of telepresence given the realities of collecting the data from a dog carrying equipment. Practically speaking, it is problematic as to how one would go about imparting a truly immersive rendition of what a dog experiences based on providing input to five human senses. Of the five senses, sight and hearing can be simulated through video and audio sensing and transmission from the dog and provide many clues as to what is occurring to the dog. There is no practical purpose or mechanism to simulated taste nor is there a practical means for conveying smell, and arguably unnecessary since the dog smells the hidden humans being searched for and moves to that location on its own. Touch could provide important information about the physical location of the dog. As it moves over rubble it touches the surface it is moving on with its body, legs and feet. Although not impossible to simulate, current technologies are limited and placing sensors on a dog's extremities remains problematic, making touch impractical to implement in our system.

Other relevant data transmitted from the dog are physiological information such as body temperature, heart and breath rates. These data help handlers monitor their dogs' physical condition while the dog is working. Often when a dog is working hard it is fully engaged in the search and ignores its own health condition. At the time of writing, there are several complementary investigations occurring within the NCART lab. One area of investigation has been the estimation of a canine's pose (sitting, standing, etc.) in order to determine how the dog is physically situated.

Figure 3.2 – Collecting Canine Pose Data

Another area of investigation has been the monitoring of Canine Brain Function in which the blood oxygenation levels of the dog are monitored through a near infrared spectroscopic sensor. These data streams may eventually be integrated into the CAT system and our architecture addresses this need.

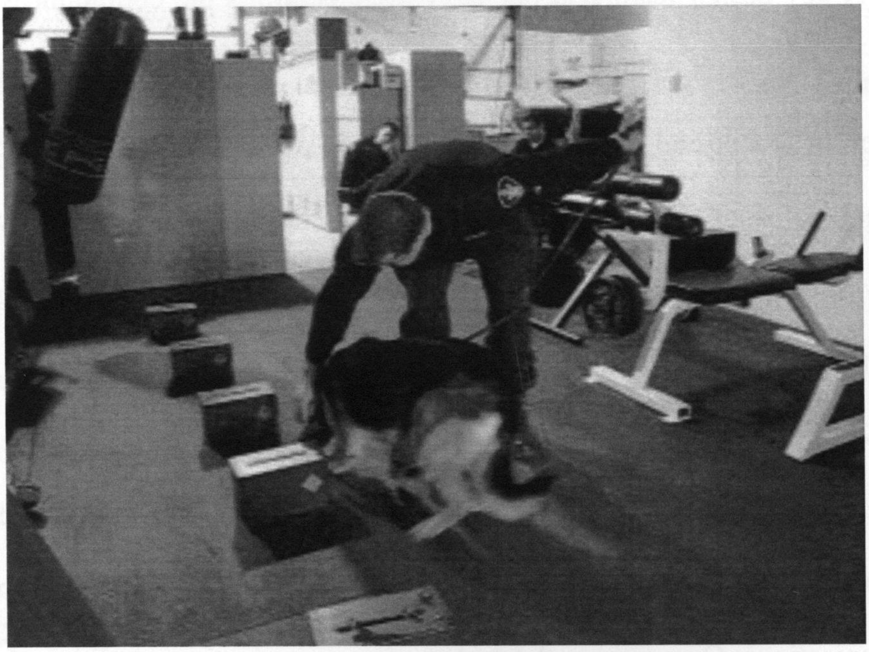

Figure 3.3 – Canine Brain Function Testing with a trained dog searching for a hidden item while wearing a sensor

While there are many potential streams of data being transmitted from the dog, it is also desirable to be able to send data to the dog from the handler or observer. During a search, canine handlers may want to re-call their dogs or redirect them to another area. The ability to send voice commands to the dog may be needed. In 4.3, there is a description of an experiment that was conducted to assess if it is possible to send voice commands to a dog from a remote location. The experiment yielded mixed results, thus more research is required to determine if this is even reliably possible. Even if the dog will not respond to audio commands it is still desirable to send an audio stream, especially if the audio could be heard by a trapped victim.

Other data may be sent to the dog such as a signal to activate the CRDS device described in 2.2.4. This means that communication between the agents (USAR dog, handler, observer) should be bidirectional.

A key design feature in our CAT architecture is the communication method. While a tether on a robot is a practical means for ensuring reliable communication between the robot and its controller, this is not possible on a dog given the agility and speed of dogs. With the many problems associated with tethers it was decided that wireless communication would be necessary to avoid impeding the dog's mobility.

Wireless networking presents a different set of challenges. One being that the most common materials found in buildings are concrete with reinforced steel. This fact makes a collapsed building a problematic environment for wireless communications. Overcoming the reality of communication conditions is one of the most difficult problems in USAR and was a major factor in choosing the wireless technology appropriate for CAT. Another factor that had an affect on choosing the appropriate wireless technology was that transmission of audio and video data requires large amounts of bandwidth. Additionally the size and power requirement of the transceiver modules must be small as the device will be worn by a dog. With the consideration of all these factors, many wireless technologies were reviewed and finally WiFi was selected as the best fit for our system.

While there are many low-power wireless technologies, WiFi is one of the lowest energy schemes with the ability to transmit video. As discussed in 2.3.1, even though WiFi does not have a long transmission range or penetration power, when used to a form of WMN, a WiFi network can easily be expanded with the addition of more wireless mesh nodes.

Our software architecture has been divided into various subsystems. The **Canine Software** is responsible for the collection of sensed data, their encoding, local recording and finally their transmission. Canine Software also receives incoming data and handles its distribution. The **Handler Software** records and filters the canine data and presents it in a way that is useful to the handler. **Observer Software** does the same job as the Handler Software, except it presents the appropriate data to an observer.

3.2 CAT Architecture and Prototypes

The CAT architecture has four critical features. These are

1. capturing the local situation of the dog,
2. integrating this data into a single separable stream of data,
3. providing a means of transmitting this integrated situational information, and
4. the system must be expandable.

These features are discussed below.

We argue that the CAT architecture provides guidance for the delivery of canine-based sensing and feedback systems as well as a means of reasoning about sub-components of such systems. In order to achieve the goals of this thesis and demonstrate a dog-based telepresence system, it is necessary to develop a prototype that successfully integrates the four key components of the CAT architecture.

The ability to capture the local state of what is happening to and around the dog from CAT's sensing capabilities must provide sufficient feedback to a human observer to allow them to decipher the clues that provide the dog's "reality". A pragmatic approach we have taken in our prototypes is that we employ relatively simple video technology in various forms and placements as the primary sensor system.

Another critical feature of the architecture is to provide a means of data transmission that does not fetter the dog. We have selected WiFi as a communication method in order to demonstrate that wireless connectivity is possible for such a system. As WiFi technology is ubiquitous, it is easily tested. However, the selection of WMNs as a network architecture addresses the fault-tolerance necessary in USAR applications in general.

The integration of all the sensed data (starting with video but which can expand to include others) into a single stream is another important architectural feature. The single stream concept addresses two facts, the first is that bandwidth is limited in most urban disaster environments and second that the data being transmitted is related—but specific—to the needs of the end-observer. Different observers will have different uses for components of the single stream—using some and ignoring other components. For example, a search specialist might be looking for visual clues as to where a trapped person might be located, a structural engineer might require visual data related only to the physical components of the wreckage, while the canine handler might be only interested in the body temperature of the dog so that he can recall the dog should overheating become a problem.

The need for expansion of a CAT system is important as CAT is a work-in-progress. By no means are there any defined rules for what can be placed on a dog, nor is it clear that "more is better" but the ability to easily integrate other components undergoing investigation such as the CRDS, CPE, and CBF or other sensors such as those that measure the physiology of the dog is a potential reality and must be addressed.

The following sub-sections describe the progression of prototypes that have formed the CAT project. The progression is presented because each prototype family presented a learning opportunity that improved the next prototypes and lead to the current system architecture.

3.2.1 CAT 1 and 1.5

As reviewed in section 2.2, the head mounted camera version of CAT (CAT 1) had some severe limitations, both technologically as well as dogonomically. Through numerous trials of observing dogs performing searches wearing CAT, it was apparent that it was uncomfortable for them to wear and hindered their ability to search. We received numerous comments and complaints from handlers who observed that the dogs appeared uncomfortable wearing the apparatus and they believed our system was distracting the dogs from the search task. This was problematic for the obvious reason that the apparatus slowed or stopped the dog's search progress. Another, more subtle, problem was that the handlers could blame the equipment for a dog's failure to find a "quarry". This was a problem because search training involves the careful reflection of what happened during any search[3] and why a dog did what it did. If CAT leads to unquantifiable but tangible distractions for the dog, the handlers would eventually discard CAT.

Figure 3.4 – USAR Dog Dare attempting to remove the doggles of CAT 1.5 by physically rubbing them off on a piece of concrete

An interesting and unforeseen problem was related to how dogs perceive their world. Dogs search by following a scent trail detected through their complex olfactory system—not their eyes. This means that most of the time they have their noses to the ground and consequently our videos showed mostly scenes of the ground in front of the dog or around the dog. It was theorized that some form of pan and tilt camera system would solve this problem—allowing an operator to manually move where the camera was pointed, however it was not feasible to have such a large system attached

[3] All OPP canine handlers are required to keep a log book of searches conducted by their dogs including very detailed information about the weather conditions. In our experience we have observed that most canine handlers we encountered did the same.

to a dog's head given their intolerance of the existing smaller system. In addition, the reason the camera was attached to the dog's head was because of the assumption that the dog actually looked at interesting things. This simple observation led to the realization that there was no benefit in attaching video capture technology to a dog's head.

The next generation of CAT would require the dog to carry a lot more electronics and batteries to implement the necessary camera controls. Before developing the second generation of CAT, there was a need to explore other methods of attaching electronics and cameras to a dog. This lead to the work in CAT 1.5 which was not the next generation of CAT but was a necessary next step.

When interviewed, canine handlers surmised that they would want to see a 360 degrees view around the dog while it was searching. This could be achieved on top of a dog's head but practically nowhere else. A pan and tilt camera on a dog's back might work but we reasoned that the forward view would be obstructed by the dog's head and neck. Raising the camera on some kind of pole or strut would cause the dog to be hindered by the pole as the dog attempted to move through low or small openings, or would result in the pole being ripped off. After some experimentation with different attachment points,

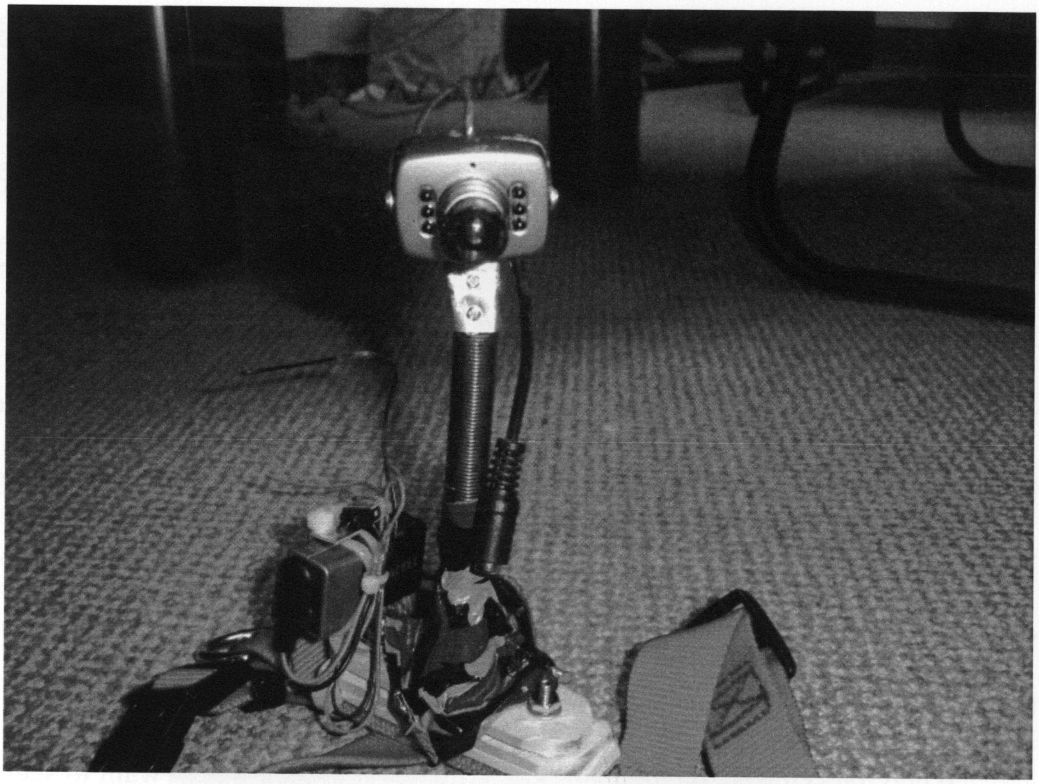

Figure 3.5 – Camera on spring mast to be worn on dog's back was a complete failure as the mast extension caused too much motion in the video stream and the dog knocked the camera off very quickly.

a workable solution was discovered but had the disadvantage of necessitating the placement of a pan and tilt camera on either side of the dog's body. The combined views of both cameras could almost cover 360 degrees around the dog. Some of the front view was still obstructed by the dog's head especially when it swayed from side to side but this location was superior to other camera attachment points.

When it was finally constructed, CAT 1.5 consisted of two wireless analog cameras. Each camera was attached to a panning mechanism and to a tilt mechanism actuated by servo motors and housed in a clear plastic dome with a dome placed on each side of the dog's harness. The cameras were operated by a joy-stick system carried by a search assistant. The canine handlers would not carry the equipment as it was seen as too cumbersome.

Figure 3.6 – USAR Dog wearing CAT 1.5 with the side mounted camera domes

The camera domes were attached to a commonly available[4] dog body harness as seen in Figure 3.6. All of our early prototypes were constructed using improvised technology[5].

Since both of the cameras were analog and wireless, they were on the same channel, causing interference with each other when they were both on. This necessitated creating the ability to switch between cameras. A main control unit was constructed that consisted of a serial Bluetooth module, an ATMega8 microcontroller and relay switching circuit. The microcontroller received commands through the serial Bluetooth radio and either actuated the servos or switched the relay

---

[4] All of our early harnesses were common off the shelf harnesses typically purchased several at a time from a wide variety of retailers.

[5] Typically constructed from duct tape, tie wraps, twine, wire and lozenge boxes.

circuit to select which camera to be powered. The main on-dog controller unit received commands from a custom-built remote controller that was also equipped with a serial Bluetooth radio and an ATMega8 microcontroller. The microcontroller on the remote unit was connected to a series of buttons. It listened to each button action and relayed the appropriate command to the serial Bluetooth radio.

Our test rig provided a very short-range connection between the cameras on the dog and the controller unit. With this rig, we were able to experiment with moving the cameras around, selecting cameras and conducting a preliminary investigation on the effectiveness of a manual pan and tilt system being placed on a highly unstable, mobile dog.

3.2.2 CAT 2.0

With the experience gained from our CAT 1.5 prototypes, we constructed our first CAT 2.0 systems that incorporated the twin cameras, domes and body harness designs similar to the previous prototypes with various substantive improvements based on our experience. The camera domes were redesigned and constructed of high-quality acrylics as it became clear fairly quickly that the protective dome housings would be subject to considerable amounts of abrasion and repeated collisions. Inside each dome, a new pan and tilt mechanism, actuated by miniature servos, was also designed and constructed to minimize the amount of space used and to simplify the placement of the cameras. CAT 2.0 marked the first time that the four key architectural components were incorporated in a working system.

CAT 2.0 required a reexamination of core functionality with respect to the use of common off the shelf (COTS) components that could meet the requirements for CAT 2.0. There were numerous WiFi cameras available. Most were too bulky, especially the ones with pan and tilt capability. All of these cameras lacked the capability of integration with other sensors. CAT 2.0 could not be constructed of two WiFi cameras simply attached to a harness, as the apparatus would have been far too bulky and fragile for the envisaged work environment. Fortunately, through research, we discovered that there were two devices that had the required capabilities.

An IP Video Server with two Universal Serial Bus (USB) ports to interface with USB web cameras and an Ethernet port was employed. Some desired characteristics of this device were that it could broadcast two camera feeds and the web cameras that it connected with were small and equipped with infrared (IR) Light Emitting Diodes (LED) attached to them for both day and low-light operation. The server itself was small, measuring in at only 6.3 x 4.8 x 2.1 cm. The device required a 5 volts input and, perhaps most importantly, would consume a maximum of 1 amp, making its total power consumption 5 watts. The device's capability to stream two video feeds over a network and its small size were a good fit for CAT 2.0. When integrated with the second device, they made up the main sensing and computing hardware of CAT 2.0.

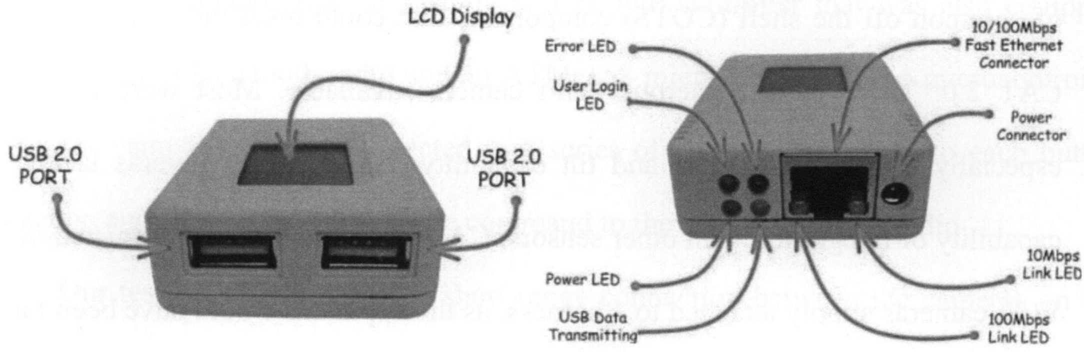

Figure 3.7 – IP Video Server

The second device was a WiFi router whose specifications are provided in appendix A.

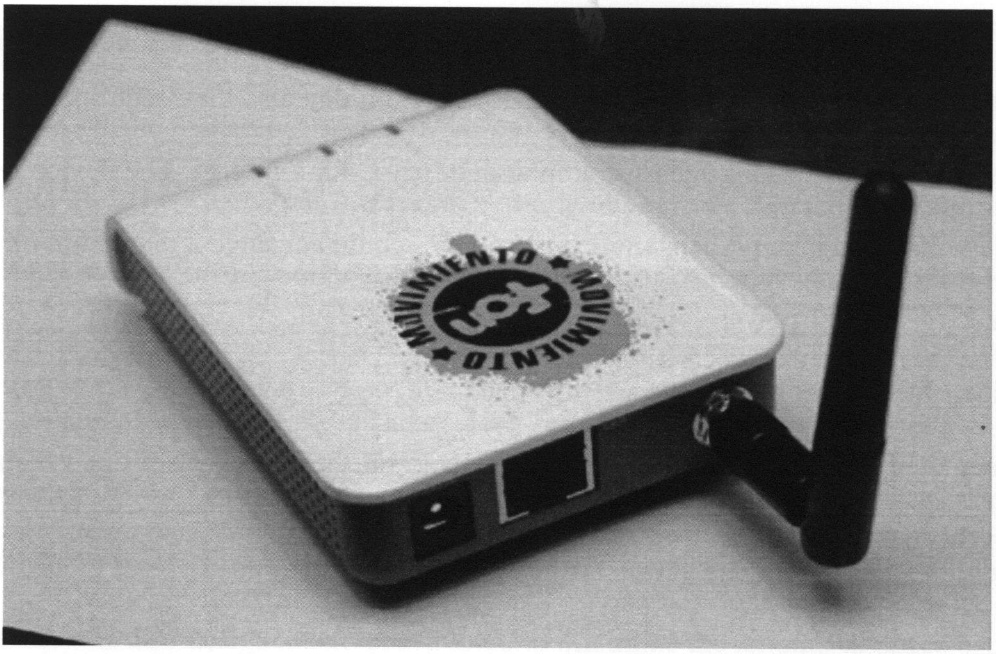

Figure 3.8 – La Fonera Router

The router came preloaded with custom firmware based on an OpenWRT. OpenWRT is a Linux based firmware program for embedded devices that includes but is not limited to wireless routers.

We replaced the routers firmware with DD-WRT, a Linux based firmware for wireless routers. Amongst many features of the DD-WRT firmware was the ability to change the router's functionality from a WiFi access point to a WiFi Ethernet adapter. When a connection was created between La Fonera and IP Video Server through their Ethernet ports, the video server became a wireless video server capable of broadcasting two video streams and thus doing exactly what was required.

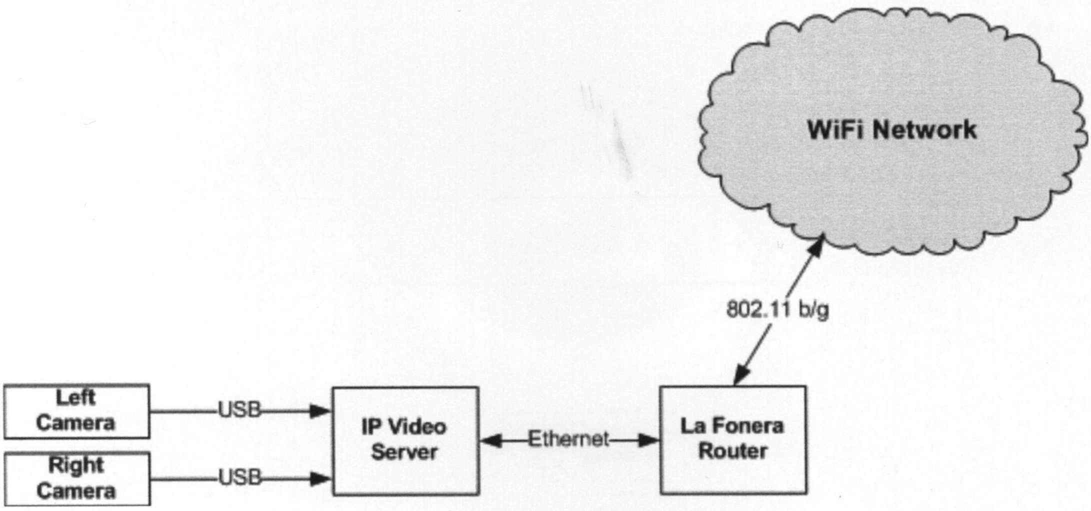

Figure 3.9 – Block diagram of video server + router

Another feature that assisted us was support for the Secure Shell (SSH) network protocol. Functionally, the La Fonera router became an embedded computer running a limited version of Linux after its augmentation with the DD-WRT firmware.

Another benefit of employing this device was that it had a serial port. The serial port is a common communication interface amongst embedded devices. This

The IP Video Server interfaced with 2 web cameras through the USB ports and transmitted the video through Ethernet. The Ethernet port of the La Fonera Router connected with the Ethernet port of the IP Video Server. The serial port of the router interfaced with the serial port of a Pololu Servo Controller. Four servos were connected to the servo controller to control pan and tilt on two cameras.

Figure 3.11 – Camera Dome

Initially, The entire system drew power from four 1.5V Alkaline AA batteries placed in series. However, the AA batteries proved to be a bad idea as they were quickly drained. The router and video server drew a maximum at 1A each and with the addition of the servo controller and four servos (2 per camera dome). The entire system consumed a total of 2.2A at 5V. This works out to be 12W. See appendix C for details.

Different temperature conditions affected the performance of the system batteries. Nominally, the batteries were able to sustain half an hour of operation before needing to be replaced. To improve the operating time, a new battery system was used. Custom lithium ion battery packs were created. A single battery pack consisted of two 3.7V lithium ion cells placed in series, with the capacity of 2.2Ah. CAT 2.0 was powered from two of these packs with a combined power of 7.4V at 4.4Ah. The appropriate voltage was provided through twin voltage regulators. With the lithium ion batteries, CAT 2.0 was able to operate for 1.5 hours.

Figure 3.12 – USAR Dog Dare wearing CAT 2.0 prototype

From a dogonomic perspective CAT 2.0 allowed us to identify a serious design challenge. The heat generated by the CAT system would need to be dissipated. Dogs have no means of shedding excess heat except through panting. Any heat generated by our system might prove disastrous if it were to add to the heat burden of the dog and this could be extremely dangerous for a hard-working dog in an already hot environment.

3.2.3 CAT 3.0

CAT 2.0 incorporated all four of the relevant architectural features of the desired CAT system. However, it lacked robustness, 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.

The first problems encountered were with the camera domes. In order to minimize the size of the dome, the pan and tilt units were constructed using the smallest available servos. The disadvantage of the servos was their fragility and it became clear that fragile servos are no match for a working dog.

Dogs have a tendency to shake violently when they attempt to dislodge something on their body, or they are irritated by something, or they simply feel the urge to shake. Combined with the need to run and jump through and around rubble with complete disregard for the equipment, one is faced with another serious design issue—tolerance to shaking. Often, the servos would stop working after a search was conducted and other components would fail as wires became dislodged or simply broke.

Another important issue related to the dog's behaviour was discovered when designing the protective domes. Dogs naturally move close to walls and other objects. Like other animals, they have a set of whiskers that allow them to detect edges easily and have a high tolerance for body contact with surfaces. In an urban disaster characterized by rubble fields, there are a lot of surfaces.

Within the first two minutes of the first test of CAT 2.0 on a dog in a rubble environment, one of the domes was cracked and punctured. The camera was still functional but the field of view was slightly compromised. After 4 or 5 trials, the dome was so severely scratched and lacerated that the cameras could only detect white blurs.

We also observed challenges with the web cameras and low-light conditions. Even with the IR LEDs for low light conditions, most of the time the dogs would work in pitch dark or extremely low light. When tested in a real USAR environment the camera could not pick up any images in the environment.

Perhaps the most significant challenge was identified by the observation that it was useless to try to pan and tilt the camera while the dog was moving as the operator of the controls could not predict which way the dog would move and could not position the cameras to face a given target (except by chance).

Additionally CAT 2.0 hardware consumed too much power and although expansion of the system was possible, it was not practical. Since the La Fonera Router was a commercial product, there was no Software Development Kit (SDK) available to easily develop software for it. As stated above, CAT 2.0 consumed *approximately 15W of power at peak use. By optimizing the power consumption, there could be a reduction in battery usage which would translate to a reduction in* overall size and reduced heat.

Amongst the problems discovered with CAT 2.0, there were also components that worked well. The lithium ion battery pack performed very well, along with the highly efficient switching voltage regulators. Another component that worked well in concept was the use of USB webcams. The particular ones employed for CAT 2.0 were not high-quality but the idea was important for future CAT systems since many high-quality cameras were available.

With the experiences accumulated from developing CAT 2.0, the development of CAT 3.0 began. The new design for CAT 3.0 started with the concept of a main computer unit. The main computer would interface with other devices through the USB interface or serial interface. The challenge was to find a single board computer that was compact, equipped with a USB host interface and extremely power efficient. Many different single board computers were examined. Finally the computer board that best fit all the criteria was the FOX Board LX832 made by Acme Systems. Please see appendix B for details.

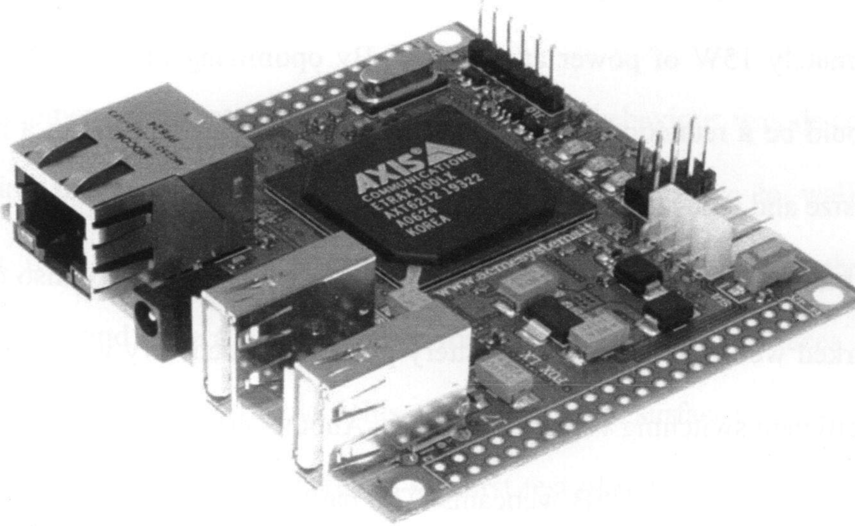

Figure 3.13 – FOX Board LX832

Two features of the FOX Board that stood out were its small footprint and power requirements of only 1W. Another attractive features was that there was an open source SDK available from the manufacturer's website. The SDK allowed users to easily develop software for the FOX Board. Furthermore, a community of developers already existed and there have been drivers created for USB cameras, USB WiFi adapters and even video streaming software. The drivers only support certain chipsets, thus only a small selection of hardware was compatible. The hardware chosen for CAT 3.0 was the Logitech Quickcam for Notebook Deluxe and the DWL-G122 Wireless USB adapter made by D-Link.

Figure 3.14 – Logitech Quickcam for Notebook Deluxe

Figure 3.15 – D-Link DWL-G122 Wireless USB adapter

The FOX Board met almost all specification of CAT 3.0. The limitation of the FOX Board was its Central Processing Unit (CPU). Although the Axis CPU was optimized for Linux and performed very well in streaming video through WiFi, it was only able to handle one video stream. Fortunately the FOX Board was so compact and power efficient, it was possible to have two boards in the system. A single FOX Board running on its own required 1W of power and with the addition of the USB camera and WiFi adapter, it consumed 2W. CAT 3.0 consumed a total of 4W (Appendix D). This was still less than 34 percent of CAT 2.0's power consumption. A positive side affect of this design was that CAT 3.0 became more robust and reliable due to the redundancy of the hardware.

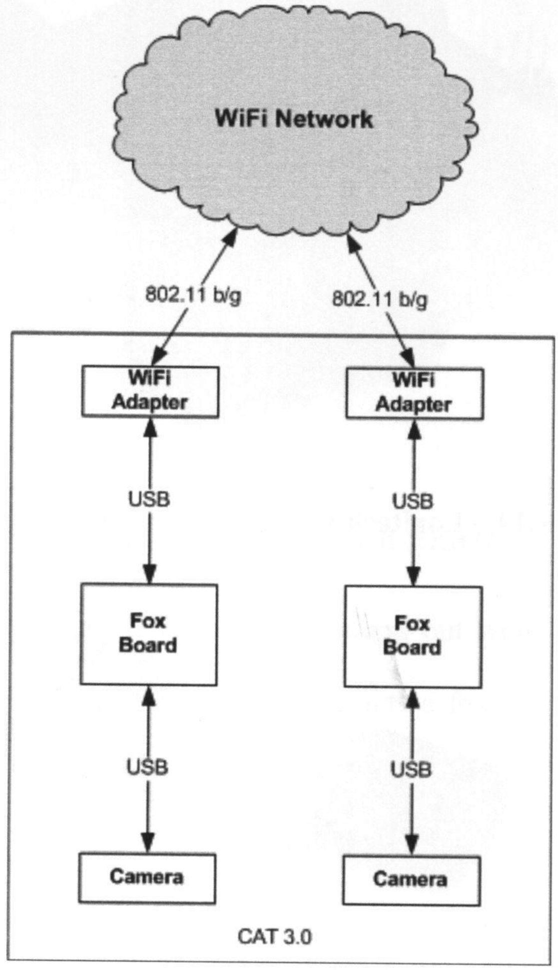

Figure 3.16 – Block Diagram of CAT 3.0

At this point in the development process, CAT 3.0 had demonstrated improvements in expandability and ease of software development—all limitations that CAT 2.0 had. It also improved on power consumption which led to the change in the battery pack design—reducing the weight of the system that needed to be carried by the dog. The new battery pack consisted of four identical flat 3.7V lithium ion cells, each with the capacity of 1.1Ah. The battery pack was configured so that two cells were connected in parallel to double the capacity and those two cells were connected to another set of two cells. Figure 3.17 illustrates the battery configuration.

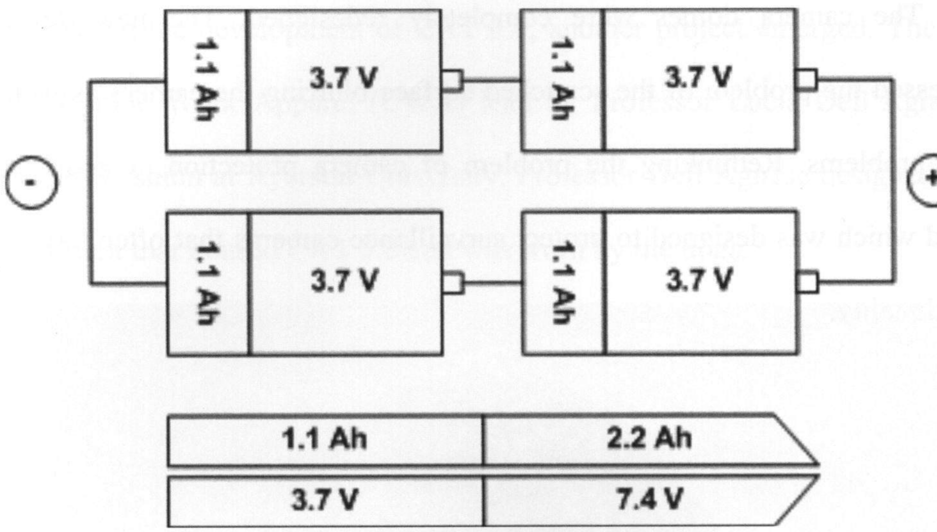

Figure 3.17 – Battery configuration

The battery pack provided a total of 7.4V with the capacity of 2.2Ah. The new battery pack was not only more compact and lighter than the one used in CAT 2.0, but also allowed CAT 3.0 to operate for over 2 hours of continuous operation.

The next component of CAT 2.0 that needed improvement was the pan and tilt servos within the camera domes. Since panning around while the dog moved was ineffective, this feature would be removed and replaced with two 160-degree wide-angle lenses. The lenses allowed the camera to have a wider field of view around the dog—eliminating the need for a pan and tilt unit. The resolution of the image was slightly reduced and was a bit warped. However the distortion was minimal and the software to reprocess the image to flatten it can easily be integrated into a software architecture. CAT 3.0 gave us the insight to infer that it should be possible to take the video streams coming from the dog, record them and potentially algorithmically mark them up so that potential areas of interest could be indicated to human search specialists who could review the video, slow it down and isolate frames of interest.

The camera domes were completely redesigned. The new dome design addressed the problem of the scratched surface blurring the camera as well as low-light problems. Rethinking the problem of camera protection, a good dome was found which was designed to protect surveillance cameras that often have low-light functionality.

Figure 3.18 – Surveillance Camera Dome with IR LEDs

Figure 3.18 is a common camera dome design used for surveillance. The fragile glass surface over the camera is small compare to the entire dome. The shape of the dome protects the glass. For further protection a thin layer of film used to protect cellular phone surfaces was placed over the glass such that only the film would get scratched and could be easily replaced. The dome also had an array of 24 IR LEDs that would light up in the dark. The IR LEDs could illuminate an area of 10m in front of the camera—more than sufficient for the envisioned working environment.

During the development of CAT 3.0, another project emerged. The project is called Canine Work Apparel (CWA) lead by Professor Lucia Dell'Agnese of the school of Fashion at Ryerson University. Professor Dell'Agnese designed and made the garment that housed CAT 3.0 and was worn by the dogs.

Figure 3.19 – CAT 3.0 worn by CA-TF1[6] USAR Dog Freitag

The garment was designed to use principles of human fashion design that would address the features of dogonomics that we could identify (including heat dissipation, size, flexibility and endurance) and had a breakaway safety feature for the dog's safety. This last feature was required by virtually every handler we spoke with. Normally, USAR dogs search "in the nude". This is to avoid the perils of the dog becoming trapped by a collar that is hooked into a piece of debris where the handler cannot assist the dog. The garment designed for CAT 3.0 was designed to fall apart when it became snagged so that the dog could escape.

---

[6] FEMA designation meaning "California Task Force 1".

3.3 3-Dog Protocol

In some situation, it may be useful to use the CRDS in combination with CAT to perform a search. An algorithm was developed that dictates how to do this efficiently. This algorithm is called the "3-dog protocol" or 3DP for short.

As the name suggests, the 3DP algorithm uses three dogs to perform a search, specifically in an area where the handler cannot see the dog searching. The first step is to allow the first dog to do an initial search without wearing any equipment. The dog is referred to as search "nude". This step may seem redundant but dogs perform their best when they are "nude". It is important that the handlers know that there is actually someone to find in the rubble before they commit to sending in equipment. It is critical that the first dog does not miss a patient and this step ensures that the dog is working without distraction.

If the first dog gives a bark indication that someone is in the search area, it will be recalled and the second step in the algorithm implemented. The second dog is sent in wearing the CRDS unit with an underdog usually containing a radio for communicating with the patient. The first and second dog can be the same dog but, in practice, the handlers we have worked with prefer to send in different dogs. When the second dog gives the bark indication, the CRDS will be activated, releasing the underdog in the vicinity of the patient's scent plume. We have determined that the underdog is normally dropped within two feet of the maximum scent plume coming from the patient. Getting the underdog close to the patient is important for a number of reasons. If the bag drops close enough, it is possible that the patient can use the radio to communicate with the first responders. In addition, the underdog acts as a marker indicating the likely location of the patient should they not be visible when they finally make their way in.

When first responders attempt to talk to the patient through the radio and no response is heard, the third step in the algorithm is executed. This involves sending another dog wearing CAT to again "re-find" the patient. The third step relies on the second step as someone viewing the CAT video feed can use the underdog dropped in step two as a reference point within the video to spot the likely location of the patient. Usually, deep inside a disaster site where the search is being performed, there is usually very little or no light. When a patient is hidden underneath rubble, it makes the task of spotting them on video very difficult or impossible. The presence of a bright orange underdog can give searchers a good indication of where the patient may be by providing cues for them to slow down the video or pausing it at certain points when carefully reviewing it. An example of this is shown in Figure 3.20. A picture of a patient hidden between the drywall and concrete block is shown. The orange underdog can be seen at the top right corner.

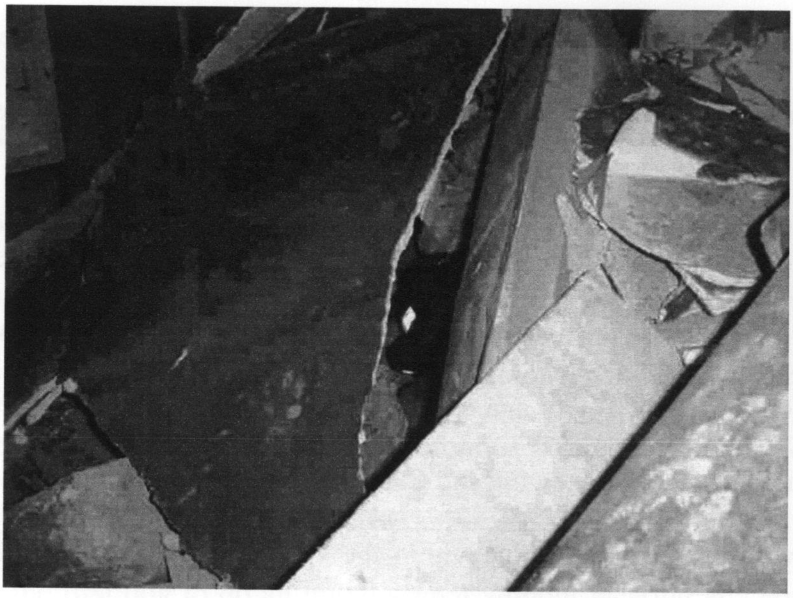

Figure 3.20 – Simulated patient can be seen below and to the left of the orange underdog at the top right of the image

The 3DP algorithm, along with the CAT architecture, and CAT prototypes 2.0/3.0 are the contributions of this research. The next chapter presents the experiments that test the theories of these developments. The results of those experiments will show that these contributions satisfy the requirements to achieve the goal of this thesis.

CHAPTER 4 EXPERIMENTS AND RESULTS

Complementary to Chapter 3, where the designs of each prototype were described, this chapter describes the experiments and results obtained from each of the stages of CAT's evolutionary development. At each stage, new knowledge and experience was accumulated which then guided the next design step. The stages can be classified into the following sections in the chronological order in which they were performed:

- WiFi Repeater Experiments
- CAT 1.5 Experiments
- Remote Audio Command Experiments
- CAT 2.0 Experiments
- CAT 3.0 Experiments
- Deployment Testing

In a final section we will discuss how the video captured through the various CAT systems demonstrated the ability of the system to enhance the situational awareness of an observer.

4.1 WiFi Repeater Experiments

Before the decision to select WiFi as a method of communication was finalized experiments were conducted to test the performance of WiFi in an USAR environment. The experiments were conducted by Alexander Ferworn, Jimmy Tran and Nhan Tran of the N-CART lab [9]. They were performed in two stages. The first stage was a comparison between WiFi and analog RF. The second stage measured the effects of the deployment of WiFi repeater. Surprisingly, The literature is silent concerning similar experiments conducted by others.

4.1.1 Test Facility

With the collaboration of the Ontario Provincial Emergency Response Team (PERT) of the Ontario Provincial Police (OPP), a purpose-built "**confined space**" training and testing facility used as a simulated disaster site was made available for the experiments. In USAR parlance, confined spaces are those that restrict access to trapped people and make their rescue more difficult as the physical space available for the rescue effort is extremely limited.

The facility is constructed of steel-reinforced concrete sewer pipes meant to simulate structures and materials often found in urban areas and typically at disaster sites. The facility is composed of a series of interconnecting pipes forming a rectangle shape 13.45 meters by 11.4 meters, depicted in Figure 4.1 and 4.2. The facility was repurposed to provide a suitable location for analog and digital RF testing.

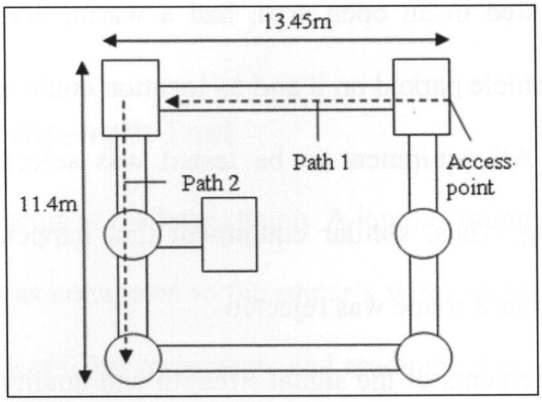

Figure 4.1 – Top view of confined space facility

Figure 4.2 – Actual facility shown during construction[7]

4.1.2 Test Setup

The confined space was completely sealed with 1.5 cm thick steel doors, except for the access point. A master communication point was set up 15 meters directly in front of the access point indicated (Figure 4.1). This acted as a base where all communication would be received. This point was selected because it was

[7] The current facility is buried under several hundred tons of rubble.

conveniently located in an open area, had a warm, dry and electrically equipped command post vehicle parked on it and its location could be marked so all tests could be reproduced[8]. All equipment to be tested was selected for its potential to be attached to a dog. Thus, similar equipment that happened to be the wrong size, weight or an awkward shape was rejected.

The measurements of the signal strength and quality were made starting at the access point to the facility. The signal quality was recorded at 50 cm increments. The analog RF signal testing was accomplished using 2.4Ghz analog transmitter/receiver pair transmitting the signal from an infrared camera. For the WiFi signal tests (with repeater) commercial routers and repeaters were employed. The D-Link DI-624 router was used as the access point at base station. A repeater "puck" was constructed using a D-Link DWL-2100AP WiFi repeater modified to be powered by batteries. Two laptops with IEEE 802.11b capability were used to transmit video.

4.1.3 RF Signal Test

For the RF signal tests, a small analog RF wireless camera system was used. The wireless camera transmitted video signals via RF to a receiver that output the video to a monitor. The video receiver and monitor were located at the base station. The wireless camera was moved through Path 1 (see Figure 4.1) until the video signal was completely lost. The position where the signal loss occurred was recorded.

[8] This is, in fact, no longer the case as the entire testing site has been covered over with a layer of rubble and debris to improve the facility for disaster training.

4.1.4 WiFi Signal Strength Test

The router was setup at the base station. A laptop equipped with signal strength measuring software was connected to the router's wireless network. The laptop was moved through Path 1 at 0.5m increments and readings of the signal strengths were recorded until the signal was lost. The position of the signal loss was recorded.

4.1.5 WiFi Video Test

This test examined video transmission through WiFi transmission. For this test, the router and two laptops were used. Laptop 1 and the router were at the base station. Laptop 2, equipped with a webcam, was moving through the structure along Path 1. Both laptops were connected on the same network through the router. Laptop 2 was broadcasting the video feed to Laptop 1. When Laptop 1 could not receive the video signal from Laptop 2—indicating the network connection between Laptop 1 and Laptop 2 was lost—the position of Laptop 2 was recorded.

4.1.6 Trial Results

Tests reviewed how disruptive reinforced concrete can be to analog RF communications. Consistent results showed reception for a clear video signal at 1.0m inside the structure and a very weak signal at 1.5 m. The signal was completely lost at 2.0m.

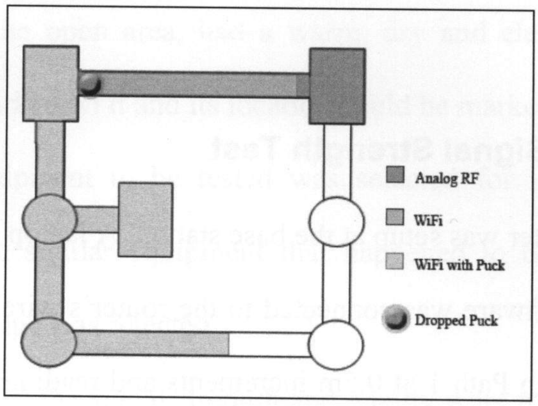

Figure 4.3 – Signal Penetration

While the WiFi network also communicated at 2.4ghz, it did considerably better than the analog system. We were able to broadcast from inside the structure along Path 1 (Figure 4.1) up to the 12.0 m point. At 12.5 meters, the connection to the network was dropped and the video feed stopped.

The third set of tests with the puck repeater demonstrated that while the signal was still lost at 12.0 m, communication could be reestablished with the puck dropped (depicted by a red circle in Figure 4.3) and activated. We were able to cover path 2 completely and extend 7 meters into the third side of the structure.

4.1.6.1 Conclusions from WiFi Experiments

This set of tests demonstrated that it would be fruitless to continue using analog radio technology for the given environment. This conclusion actually runs contrary to the radio communication apparatus of the majority of deployed response robots in the world [2-4]. This may be because response robots often have the option of using a tether to send and receive information—not the case in our application.

In addition, our tests indicated that the use of WiFi was at least feasible and we would not be limited to line-of-sight network configurations. This is important because we cannot guarantee that the dog will always travel within range of a single wireless network node, therefore the ability to extend a network "underground" using multiple nodes that provide predictable performance is essential.

4.2 CAT 1.5 Experiments

CAT 1.5 was designed with the theory that pan and tilt cameras attached to the sides of a search dog could provide enough visual information for users to be aware of the dog's surrounding and that they would not hinder the dog's ability to conduct searches. Experiments were conducted to test this theory.

4.2.1 Test Setup

With the help of a Canadian and US FEMA OPP certified canine teams[9], two experiments were conducted. For the first experiment, the canine "Dare" wore CAT 1.5 while Const. Kevin Barnum, his handler, walked him around PERT headquarters. The video feed from CAT 1.5 was recorded. At the same time, the pan and tilt features were used to obtain more visual information. In this experiment we wished to employ the cameras in an area where we already understood what we were likely to see and to determine if the cameras could be employed to focus on familiar objects and spaces within the building.

[9] Provincial Constable Kevin Barnum and the Black Labrador Retriever "Dare"

The second experiment took Dare outside to a rubble pile that simulated a collapsed structure. Dare's task was to locate an OPP constable acting as a quarry hidden somewhere in the rubble. Again, Dare wore CAT 1.5 and the video feed was recorded.

This test was would give us a good idea if the pan and tilt system could be used to focus on a scene of interest. Given that most rubble piles have few memorable features, the presence of a human figure in the video stream would indicate success since successful active control of the camera would have to be employed.

4.2.2 Experiments Results

The video recorded from the first experiment confirmed the theory that the body-mounted cameras were better than the head mounted version. The pan and tilt feature enhanced the view by allowing a user to control the direction where the camera was pointed. A series of stills extracted from the video shown in Figure 4.4 demonstrated that the user first encountered an image of someone's feet and then tilted the camera up to get a better picture of the that person. It must be stressed that Dare was on a leash—restricting his movements—and was walking at the pace of the handler.

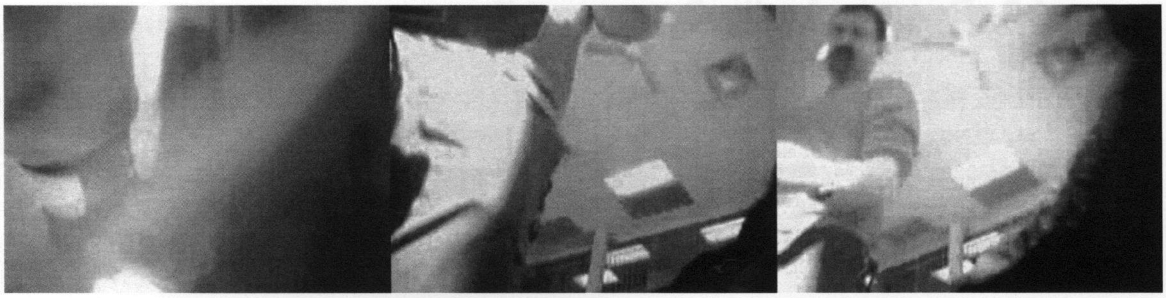

Figure 4.4 – 3 consecutive images recorded from CAT 1.5 demonstrating tilt function

The second experiment was conducted on a February[10] day at a construction rubble pile several miles from PERT headquarters. Within the first 2 seconds of being released to do the search, Dare was out of the range of the wireless camera when he leapt on the rubble piled and ran to the opposite side. This confirmed the ineffectiveness of wireless analog RF technology and also that the cameras on the body harness did not interfere with Dare's motion. Clearly the test also confirmed that extended network range is necessary, as humans cannot keep up with dogs.

In the final stages of the search when Dare was very close to the quarry, to our disappointment, we discovered that the pan and tilt camera system was effectively useless. As the dog moved about in great excitement barking, it was rare that any image could be extracted that actually contained useful information about the quarry. This was our first indication that the pan and tilt methodology for acquiring images might need to be abandoned.

[10] Recorded outside temperature -35 degrees Celsius in icy conditions.

4.3 Remote Audio Command Experiment

Inspired by the work in [41] explained in 2.2.4, we wished to learn if USAR dogs can be directed through voice commands remotely. If this was possible then a dog can be controlled like a biological robot with its own biological intelligence system to navigate through rough terrain without getting stuck. Two trials were conducted to test this hypothesis.

The first trial was a simple setup where a USAR dog was equipped with a hand radio strapped to its collar. The dog was sent down a hallway by itself while the handler gave voice commands over the radio. Another person followed the dog and observed if it was obeying the commands. After a short while it was clear that the dog did not respond to any commands.

It was hypothesized that a possible reason for the first trial's failure was that the voice quality over the hand radio was too low fidelity and the dog did not recognize the handler's voice. In the second trial, a pair of extremely high-quality stereo headphones[11] modified to fit on a dog were connected to a higher quality wireless audio system and placed on a trained dog's head. The experiment started in a lab where the handler and the dog were both present and the handler began giving the dog basic commands. The dog obeyed every command. The handler then left the room and went to another room far enough away such that the dog could not hear the handler's voice. The handler gave commands over the wireless audio system, could observe the dog through a window but could not be seen or heard by the dog directly.

---

[11] We gratefully acknowledge the participation of Sennheiser Canada and their assistance in this (http://www.sennheiser.ca)

The dog showed signs of recognizing the handler's voice. Every time the handler gave a command over the speaker the dog would stop what it was doing and pay attention to it. However it showed signs of being confused and stressed. It went back and forth from sniffing the speaker to looking at the door that the handler left through. After a while it lost interest and did not respond any more.

Although the experiments were unsuccessful, the concept of remotely controlling the dog over wireless audio may still be possible. Perhaps some training is required, or instead of voice commands, certain tones could be played to the dog's individual ears directing it left and right. More research is required to explore these ideas which are beyond the scope of this thesis.

4.4 CAT 2.0 Experiments

To ensure that CAT 2.0 could be confidently deployed under expected operational conditions, field tests were performed to determine durability, and communication reliability. The experiments on CAT 2.0 conducted by Jimmy Tran and Alexander Ferworn can be found in [5]. Durability was tested with the endurance test that measures CAT 2.0's operation time and its ability to resist shock. Since CAT 2.0 has a WiFi adapter, it has the ability to connect to a WMN as intended by the CAT architecture design presented in 3.1. The communication reliability test was designed to ensure that CAT 2.0 equipment performs adequately under this type of network.

4.4.1 Endurance Test

CAT 2.0 is comprised of various electronic components. It is known that WiFi devices consume a significant amount of power, as do servo motors. Each component's power consumption of CAT 2.0 was measured.

With the power supply described in 3.2.2, CAT 2.0 could run continuously for 1.5 hours depending on usage conditions. This duration is sufficient since canine searches typically do not last longer than 30 minutes and typically last less than 10 minutes. When test rigs were provided to handlers, they reported continuous operation of over one hour.

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 nor does it care about anything except being rewarded for finding a hidden human.

Figure 4.5 – CAT equipment eviscerated after being worn by a dog

In order to duplicate the unpredictable nature of canine carriage, tests for shock resistance were conducted by vigorously shaking and pounding any dog-wearable electronic components 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 systems which experience several periods of intense and damaging activity by the dog carrying the system during almost every search.

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. In the field experiment described in 4.3.3, the right camera dome was punctured within the first 2 minutes of testing.

4.4.2 Communication Reliability

One measure of the effectiveness of a system such as CAT in a USAR environment is its tolerance to communication loss. As a client roaming through a WMN, two situations arise where CAT experiences communication loss; when a CAT system 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 has proven impossible but simulations within our lab [56] have shown that the expected network performance is acceptable even for multi-hop network configurations where the signal from the dog must be transmitted through four or five nodes.

4.5 CAT 3.0 Experiments

As described in 3.2.3 CAT 3.0 was a complete redesign from version 2.0. Along with the more efficient and powerful hardware, CAT 3.0 also had a far superior camera system with night vision capability. Below is the description of how the new camera system was tested.

4.5.1 The Tube Test

Based on the research conducted by the NIST, the American Society for Testing Material (ASTM) [33, 34] has created a standard test method for visual acuity and field of vision for response robots with onboard video system. The intent of this standard is to provide key metrics for the onboard video systems used for robot guidance within a disaster setting.

Although CAT operates in the same environment and situations as the response robots the visual acuity standard set by ASTM is not directly applicable to it. Unlike robots or other similar transport mechanisms, dogs are rarely still. They are constantly looking about, shaking, licking, scratching or otherwise moving in ways that make testing video systems difficult unless motion is taken into account and controlled. A more suitable test method was developed to measure the visual acuity and field of vision of CAT's or any camera system mounted on dogs or similar rapid transport mechanisms. This is called the "Tube Test".

A long tube, made out of plastic sewer piping, is cut into two or more pieces. These pieces are connected with boxes that form orthogonal joints. In its simplest form, there is a single box and two tubes.

Canine handlers commonly use this arrangement of tubes to get their dogs used to moving through confined spaces when they do not know what is ahead of them. These tubes have the benefit of confining the motion of the dog to a straight line but still allowing the dog to move forward. In our test, standardized targets are placed within the tube at predetermined intervals placed at predetermined angles. Dogs are "dressed" with the necessary equipment and sent through one of the entrances to the tube. As the dog moves rapidly through the tube, the targets are naturally presented to any camera system on the dog and, more importantly, do not interfere with the dog's motion. Essentially, the confined space of the tube ensures that the canine will be presented with the targets. The dog is rewarded with a period of play or is praised at the end of the tube.

The tube test is a compelling mechanism for determining the efficacy of a canine video system for a number of reasons. Confined spaces such as conduits and tunnels are common features of many structural collapses and are common means of gaining access to deep areas within rubble.

Because the test takes place within a pipe it happens in the dark. This means that any system being tested must either cope with extremely low light or produce its own light. In either case, the test takes place in an environment that is common within damaged urban areas. An added challenge is added if the pipes happen to be concrete sewer pipes as these pipes are reinforced with rebar and provide a significant transmission challenge for any test-system as any signal must be transmitted to be useful.

The confined space of the pipe restricts the motion of the dog and forces it to move within a channel. This is important because the test will ensure the equal presentation of all targets to any system being tested and will likely not be effected by the random motion of the dog carrying the system.

Perhaps most importantly, the test can be scored quickly, simply and objectively and the results can be easily reproduced.

4.5.2 Tube Test with CAT 3.0

The tube test was devised by the 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 several FEMA teams and the two teams from the

OPP. All USAR 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 4.5 shows 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 was a hollow allowing a path going 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 canine wearing CAT 3.0 was sent through the path from one end as in Figure 4.5 to the other end as in Figure 4.6. The video feeds from CAT3.0 were recorded and monitored to determine if targets could be spotted.

Figure 4.6 – Handler getting ready to direct dog into the tube

Figure 4.7 – Canine wearing CAT III exiting pipe

There were 2 types of targets used, a human patient and a "paper" target. The preliminary test was conducted with 2 different people in the wooden box acting as patients and 3 different types of "paper" targets. The types of "paper" targets are shown in Figure 4.7 – 4.9. There are many possible targets that can be employed. We selected target shooting targets that can be easily found and reproduced as well as television test patterns.

Figure 4.8 – Centre-fire Shooting Target

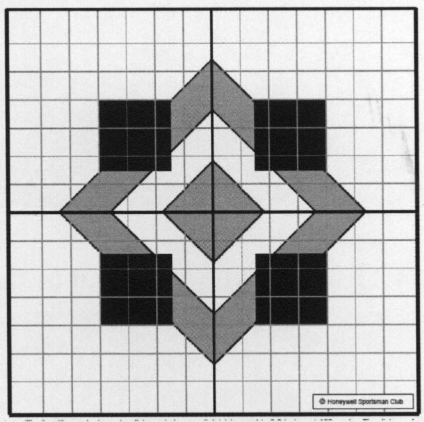

Figure 4.9 – Dot-mil Confidence Target

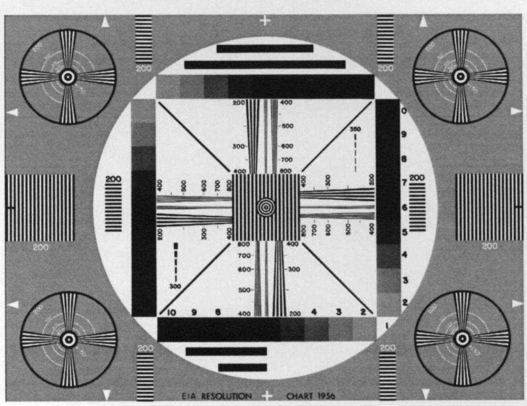

Figure 4.10 IEA – Resolution Chart 1956

It quickly became apparent that the dogs were not effected by the equipment being worn and dogs that had never worn the equipment before performed the tube traversal task very quickly.

Figure 4.11 – Dog with CAT 3.0 in the tube

Figure 4.12 – Video received from CAT 3.0

4.5.3 Results of Tube Test

Our results were better than expected given the extremely high speed of the dogs. CAT 3.0 performed very well in this test. Figure 4.12-4.13 show 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 in the future.

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

Figure 4.13 – First human target spotted

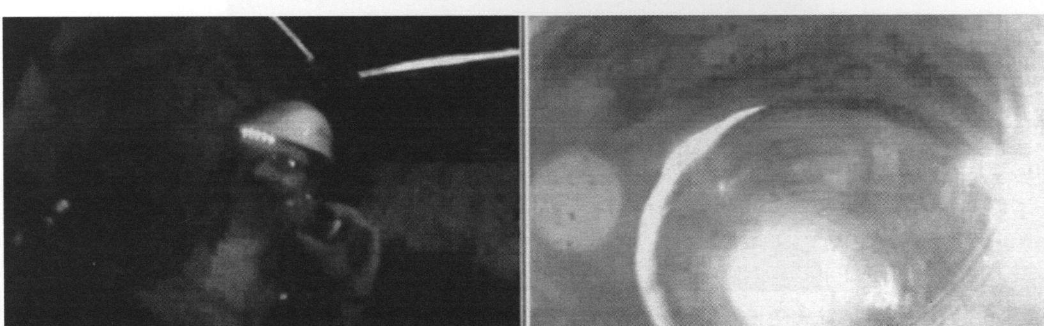

Figure 4.14 – Second human target spotted

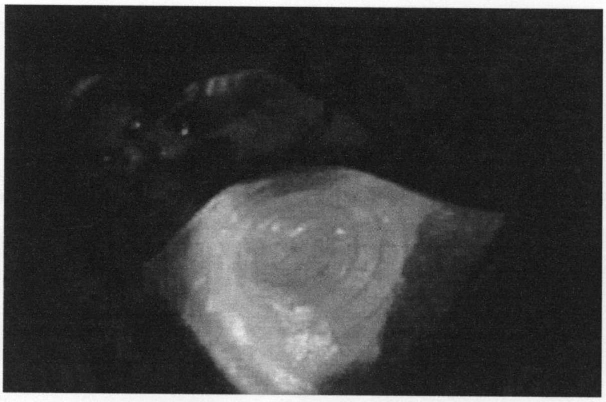

Figure 4.15 – Centre Fire Shooting Target spotted

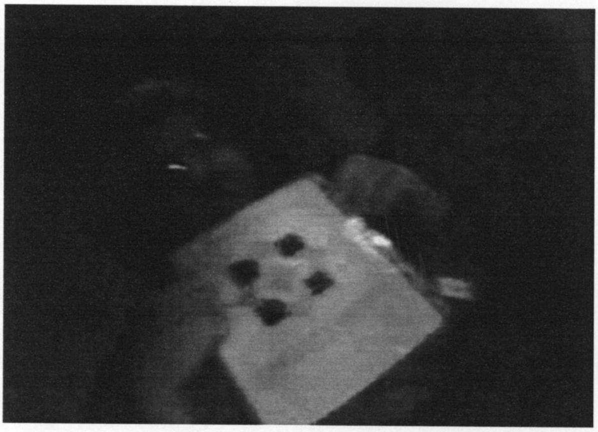

Figure 4.16 – Dot-mil Confidence Target spotted

Figure 4.17 – IEA Resolution Chart 1956 Target spotted

4.6 Field Deployments

In June 2007, Canada Task Force 3 (Toronto Heavy Urban Search and Rescue) (CAN-TF3) held a simulated structural collapse exercise at the old Constellation Hotel on Dixon Road in Toronto. The site was prepared by members of Toronto Fire Services. All entry to the site was denied until the morning of the exercise. The first unit to respond to the disaster was the PERT team who attended the scene at approximately 0700 on June 6th. PERT cordoned off the site from the public and began initial search operations. Initial reconnaissance indicated that the likely cause of the collapse was some form of explosive device (later confirmed to be a car bomb). Because the damaged structure had not been cleared by structural engineers for human entry, only peripheral searches could be conducted around the edge of the parking structure. Since the structure was very large, the interior could not be seen. Members of the NCART lab had been warned to expect this and arrived at the scene at about 0830.

A CAT 2.0 unit carried by Dare was deployed at approximately 0845 into the parking structure under the guidance of Const. Barnum.

Several searches were conducted but Dare never gave an indication. One of the judging staff who was observing the search indicated that this was unexpected as he had personally placed a fire fighter in the garage to simulate a patient. Dare and our equipment were withdrawn from the operation and the canine "Moose" under the guidance of Const. Mike Dallaire was sent in. Moose found the patient and gave a bark indication.

It was initially assumed that our equipment had failed and that Dare had been distracted by wearing it. This was a problem for several reasons. By not finding the patient Dare was seen to have failed in the task which meant that an investigation by Kevin would need to be undertaken to determine why this had happened. This would inevitably involve blaming CAT. In addition, canine handlers are very competitive and the fact that Dare missed a target that Moose found was also a problem.

The video recording was scrubbed by members of NCART and some interesting details were discovered. On one side of the CAT system, a single frame of an upright, hunched-over human figure (shown in Figure 4.17) could be seen wearing what appears to be a fire fighter uniform with a reflective stripe on the right arm.

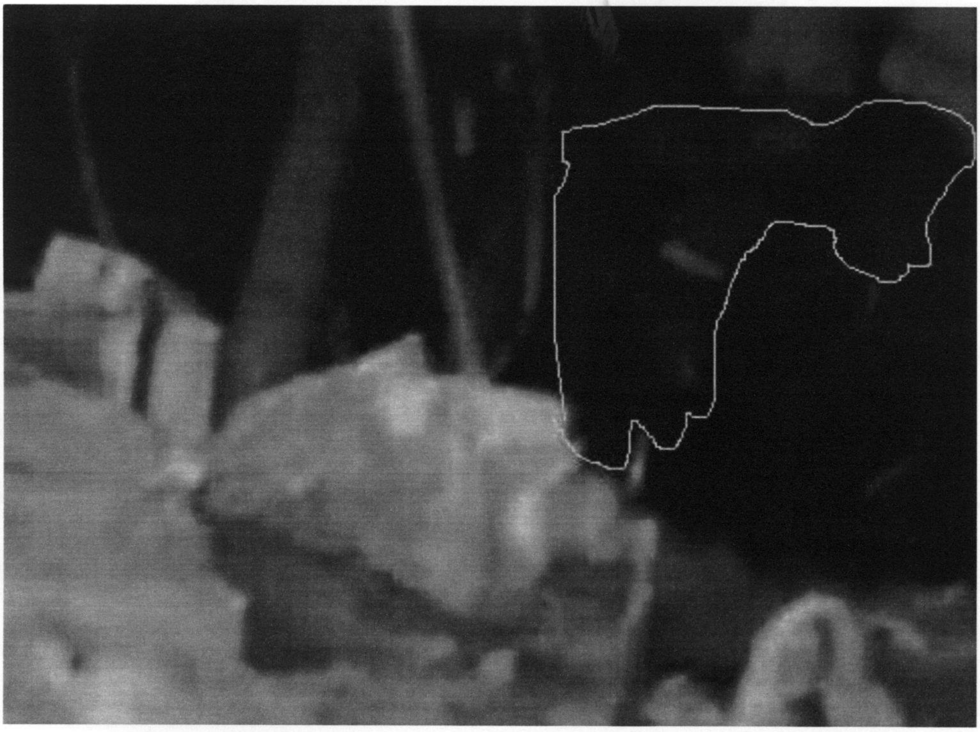

Figure 4.18 – Faint image of a casualty recorded by CAT 2.0

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 this would not lead to a reward for barking and Dare was not interested even though he had seen the fire fighter acting as the patient.

What was a failure became quite a sensation as the image was available to the PERT headquarters staff within 15 minutes of the search having been conducted and marked the first operational success of CAT.

Other valuable pieces of information obtained through CAT 2.0 were the images (Figure 4.18 – 4.20) 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.

Figure 4.19 – Image of structural supports and pillars recorded by CAT 2.0

Figure 4.20 – Debris in search zone from CAT 2.0 video feed

Figure 4.21 – Pillar (Later determined to required shoring) from CAT 2.0 video feed

At follow on USAR exercise CAT 3.0 was deployed at the same hotel. CAT was able to capture images of a quarry "tagged" with the orange underdog. Figure

4.21 shows an image of a quarry with the orange underdog on the left camera and a Figure 4.22 is an image taken with in seconds after showing the underdog on the right side camera. As the dog circled the quarry, the underdog was easily spotted.

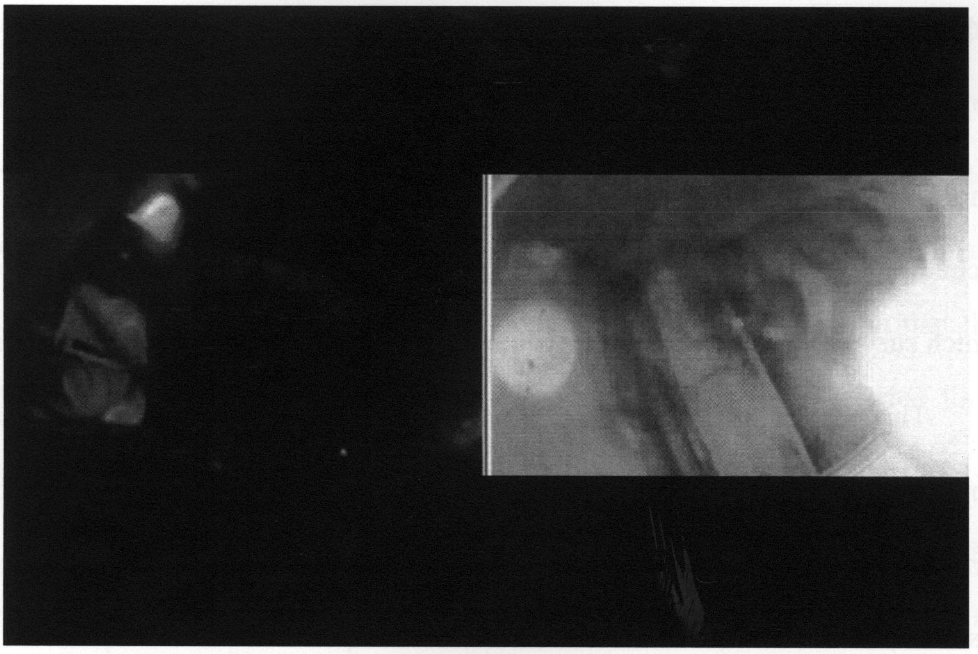

Figure 4.22 – Underdog spotted on CAT 3.0's left camera

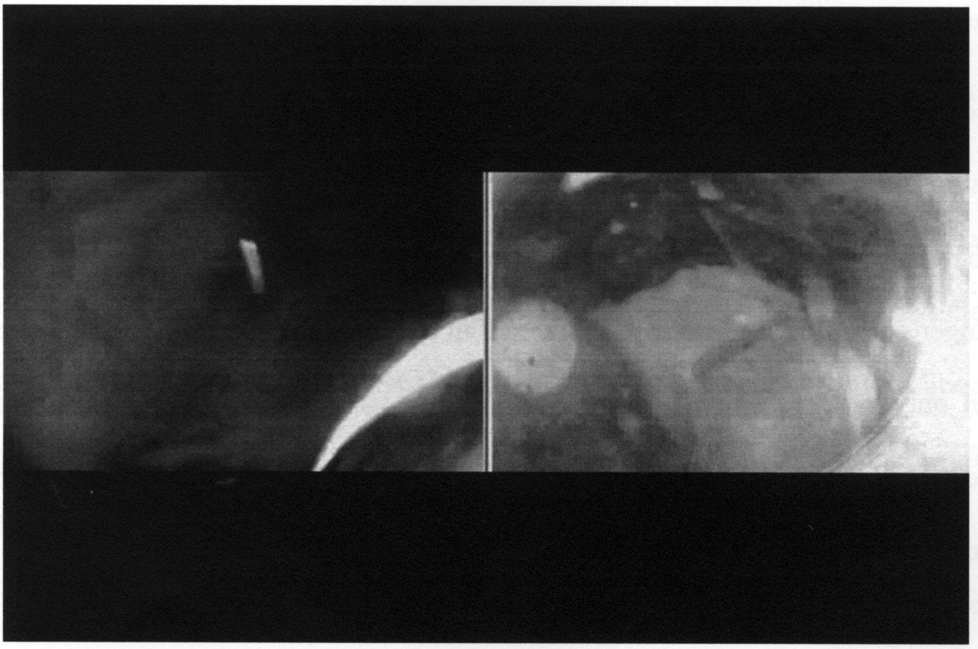

Figure 4.23 – Underdog spotted on CAT 3.0's right camera

CHAPTER 5 CONCLUSION AND FUTURE WORK

5.1 Summary of Findings and Conclusion

The motivation of our work is to investigate a methodology for the improvement of Urban Search and Rescue by providing first responders with technological adjuncts to the basic search dog in order to improve the speed with which survivors of urban disasters can be found resulting in more lives being saved.

The goal of this thesis is to prove that it is possible, through telepresence to impart the sensed, real-time situation of a dog searching for survivor in a collapsed structure to a remote human. This chapter provides a summary of the findings of this research, conclusions drawn from them and presents some topics for future investigation.

When a disaster strikes an urban area, structural collapses are common occurrences. The problem in finding survivors is that after the obvious ones are found, the remaining human survivors may be located deep inside the disaster site where it is potentially dangerous and difficult for humans searchers to enter.. The danger comes from unstable structures that may collapse further. Because the search can only proceed when a path is safe, many valuable time and resources may be spent stabilizing a section of wreckage which may lead to no more survivors being found, while other survivors continue to wait to be found.

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 were explained in details in Chapter 2 but two main concerns are their inability to traverse rubble and their reliance on video systems alone to find survivors. A person cannot be found by a robot if they are 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.

One of the tenets of Computer Science as a discipline are the application of heuristics and algorithms to solve problems. Our approach has been to apply a pragmatic heuristic approach that does not try and replace a working search system but assumes that the dog will be correct most of the time. Instead of creating an Artificial Intelligent (AI) system, a biological intelligent (BI) system is used. Evidence indicates that dogs are efficient at searching through their BI. To compensate for the lack of communication with them, a telepresence system can be designed for them to wear. It is our claim that we have demonstrated how technological systems can be employed to potentially improve the information that is available from a searching dog to human rescuers by imparting a form of telepresence.

We further claim that the CAT architecture, described in section 3.1, provides a workable means for the design of working telepresence systems using dogs as a means of carriage. Our architecture addresses the types of data that might be transmitted and who might be receiving this data. We have suggested that the communication structure should be a WMN—our particular implementation used the IEEE 802.11 b/g standards (WiFi). The advantages of WMNs described in 2.3.1 and within an urban disaster include their ability to be rapidly deployed and expanded, allowing the network to cover areas that would be inaccessible using more traditional means.

Experiments were conducted to confirm that the described communication methods would be appropriate. The results of the WiFi Repeater experiments described in section 4.1 demonstrated that a WiFi network performed far better than an analog RF network and, more importantly, it was shown that it is feasible to use repeater nodes to extend the WiFi network in conditions commonly found in buildings that have collapsed. This confirms that WMNs have the capability of supporting communication from outside a disaster site to deep inside it.

We also claim that we have shown that placement of cameras and other sensors successfully involves the complex interaction of what the sensors must sense and the needs of the dog—dogonomics. We have achieved, through this research, a more dogonomic design. CAT 1.5, described in 3.2.1, was the first working system that adopted twin cameras mounted on the sides of the dog's body. It is not possible to describe the comfort or discomfort a dog experiences while wearing a canine garment. However, our equipment design was shown to be more practical for a dog to wear by the experiments described in 4.2, 4.4 and 4.5. Every time that a dog wore the CAT equipment, it was able to move quickly, without interference from the equipment and to perform its search without any indication of discomfort.

In 3.2.2 CAT 2.0 prototype was described as the first design that implemented all four key elements of the CAT architecture. It adopted the twin body mounted camera domes design, had a video server streaming two video signals through WiFi and a pan and tilt control system was integrated. The field experiment described in 4.3 showed that CAT 2.0 provided valuable information to rescue workers. It was able to clarify a unique situation at a USAR training exercise where there was a survivor missed by a search dog that was actually indicated by our CAT system. Images of the patient were recorded by CAT 2.0. Furthermore video recorded by CAT provided images of the collapsed structures that could help a structural engineer make decisions about the building's post-disaster stability.

The CAT 3.0 prototype described in section 3.2.3 was a refinement of the 2.0 prototype. CAT 3.0's redesigned system that provided reduced energy consumption, introduced a computational system that made integration of other systems and sensors easier as well as a robust camera dome design. The results of the "tube test" described in section 4.5 demonstrated CAT's ability to operate in realistic environments in confined space and almost complete darkness.

Finally, our introduction of the 3DP algorithm provides a method in which ever-improving versions of CAT can be employed reliably and with a higher chance of transmitting data that is directly related to the situation of a patient in rubble. When working in a dark, unfamiliar and chaotic environment, having a point of reference can be very useful. The orange "underdog" acts as a reference point that can be easily seen in the CAT video stream and can guide searchers to view parts of the video that may contain evidence of survivors.

The purpose of this research was not to provide an ideal telepresence experience. The work of this research has produced a workable CAT architecture demonstrated through functioning prototypes and has provided a workable means of deploying these systems through the 3DP algorithm development. The results of the experiments conducted in this research showed that the goal of providing a useful telepresence system carried by USAR dogs has been achieved. Specifically, the results from the field deployments presented in 4.6 showed that the information obtained from the images in that section would not have been available without the use of CAT.

5.2 Future Research

While CAT 3.0 is the most robust and reliable prototype to date, CAT is still in the prototype stages and is far from being deployable to a disaster. There are many areas where improvements can be made and further research is required.

Although CAT 3.0's redundancy design provides some advantages in reliability, a single board computer with a powerful enough processor to handle two video streams is more desirable. A more powerful processor can allow onboard video processing or computer vision software to run. The ability to record the videos directly on a flash drive located onboard can fill the gaps where communication may be lost. How this recorded and transmitted information might be employed by first responders, is an open question. Our experience to date has been that technologies like CAT will be adopted slowly and only when they can be deeply integrated into the way disaster response resources work. What we mean by this is that a rescuer will not use CAT, or any other system, that has not shown utility in actually rescuing someone.

An area that requires considerable work is the design of CAT components for durability. For example, the current camera domes on CAT 3.0 work well but the domes themselves are only made of plastic and are subject to considerable abrasion. The whole notion of canine work apparel is beyond the scope of this thesis but must be investigated in order to provide guidance for the design of systems similar to CAT.

Aside from the mechanical and electrical components that the dog wears, the issue of user interface still needs to be addressed. The user interface for the handler and observer need to be designed. The handler's interface must have special hardware and software that accommodates their situation. The observer's interface is different and these differences have to be studied. Given the parallels we have drawn between dogs and response robots, while there have been many interfaces for response robots there has been little work in determining what actual first responders need in an interface. To make matters worse, canine handlers are averse to any form of interface that might jeopardize their interaction with their dog. We have observed that even the introduction of a simple button like that on the CRDS is problematic.

The ability to track the dog's precise location in the collapsed structure is a highly desirable function to the canine handlers. This could provide the possibility of providing rescue workers with a map showing the dog's path to a survivor. Since

Global Positioning Systems (GPS) do not work indoors—much less under rubble—this is an open area in research where a lot of work needs to be done.

A similar function is the ability to map the environment. This technology exists in rescue robots. Some systems are able to create a 3D map of the environment as it is traversed. However robots traverse areas very slowly, sometimes stopping to process data. This is problematic when using a dog as transportation.

5.3 Concluding remarks

The intent of this thesis is to create a solid foundation of work related to the notion of augmenting search dogs with technological components to create useful telepresence for remote viewers. We intend our foundation to be solid so that others might continue the work in the future. While disasters are a natural fact of life and cannot be predicted, we can be prepared to respond to them. Being the first line of defense when disaster strikes, search and rescue workers who risk their lives to save others need the best available tools to support them in their task. Our hope is that this research continues to progress to the point where working CAT-like systems can be deployed and used operationally—resulting in more saved lives.

BIBLIOGRAPHY

[1] "World Urbanization Prospects: The 2007 Revision Population Database," United Nations Population Division, 2007.

[2] J. Casper and R. R. Murphy, "Human-robot interactions during the robot-assisted urban search and rescue response at the world trade center," *IEEE Transactions on Systems, Man, and Cybernetics, Part B,* vol. 33, pp. 367-385, 2003.

[3] R. R. Murphy, "Rescue Robots at the WTC," *Journal of Japan Society of Mechanical Engineers,* vol. 106, pp. 794-802, 2003.

[4] R. R. Murphy, "Trial by fire [rescue robots]," *Robotics & Automation Magazine, IEEE,* vol. 11, pp. 50-61, 2004.

[5] J. Tran, A. Ferworn, C. Ribeiro, and M. Denko, "Enhancing canine disaster search," in *IEEE International Conference of Systems of Systems (SoSE'08),* Monterey, CA, USA, 2008, pp. 1-5.

[6] A. Ferworn, A. Sadeghian, K. Barnum, D. Ostrom, H. Rahnama, and I. Woungang, "Canine as Robot in Directed Search," in *IEEE International Conference of Systems of Systems (SoSE'07)*, San Antonio, TX, USA, 2007, pp. 1-5.

[7] A. Ferworn, A. Sadeghian, K. Barnum, D. Ostrom, H. Rahnama, and I. Woungang, "Rubble Search with Canine Augmentation Technology," in *IEEE International Conference of Systems of Systems (SoSE'07)*, San Antonio, TX, USA, 2007, pp. 1-6.

[8] A. Ferworn, A. Sadeghian, K. Barnum, H. Rahnama, H. Pham, C. Erickson, D. Ostrom, and L. Dell'Agnese, "Urban search and rescue with canine augmentation technology," in *IEEE International Conference of Systems of Systems (SoSE'06)* Los Angeles, CA, USA, 2006, p. 5.

[9] A. Ferworn, N. Tran, J. Tran, G. Zarnett, and F. Sharifi, "WiFi repeater deployment for improved communication in confined-space urban disaster search," in *IEEE International Conference of Systems of Systems (SoSE'07)* San Antonio, TX, USA, 2007.

[10] R. W. Perry and M. K. Lindell, *Emergency planning*: Wiley, 2007.

[11] D. A. McEntire, *Disaster Response and Recovery*: Hoboken, New Jersey: John Wiley & Sons, 2007.

[12] M. K. Lindell, C. Prater, and R. W. Perry, *Introduction to emergency management*: Wiley, 2007.

[13] P. Tucker, B. Pfefferbaum, R. Vincent, S. D. Boehler, and S. J. Nixon, "Oklahoma City: disaster challenges mental health and medical administrators," *The Journal of Behavioural Health Services and Research,* vol. 25, pp. 93-99, 1998.

[14] K. J. Tierney and J. D. Goltz, "Emergency response: lessons learned from the Kobe earthquake," 1997.

[15] E. K. Noji, "The nature of disaster: general characteristics and public health effects," *The public health consequences of disasters,* p. 3ñ20, 1997.

[16] R. Simon and S. Teperman, "The World Trade Center attack: lessons for disaster management," *Critical Care,* vol. 5, p. 318, 2001.

[17] J. A. Barbera and M. Lozano Jr, "Urban search and rescue medical teams: FEMA Task Force System," *Prehospital and disaster medicine: the official journal of the National Association of EMS Physicians and the World Association for Emergency and Disaster Medicine in association with the Acute Care Foundation,* vol. 8, p. 349.

[18] J. L. Burke and R. R. Murphy, "Human-robot interaction in USAR technical search: Two heads are better than one," 2004, pp. 307-312.

[19] R. R. Murphy, "Marsupial and shape-shifting robots for urban search and rescue," *Intelligent Systems and Their Applications, IEEE [see also IEEE Intelligent Systems],* vol. 15, pp. 14-19, 2000.

[20] FEMA, "National Urban Search and Rescue Response System: Field Operation Guide," U. S. D. o. H. Security, Ed., 2003.

[21] M. E. Cablk, J. C. Sagebiel, J. S. Heaton, and C. Valentin, "Olfaction-based Detection Distance: A Quantitative Analysis of How Far Away Dogs Recognize Tortoise Odor and Follow It to Source," *Sensors,* vol. 8, pp. 2208-2222, 2008.

[22] A. R. Ford and S. W. Reeve, "Sensing and characterization of explosive vapors near 700 cm," in *SPIE - International Society for Optical Engineering*, 2007, p. 65400Y.

[23] V. D. Acree and U. S. D. o. Justice, "Customs tailored enforcement techniques: trouble for federal lawbreakers," *FBI Law Enforcement Bulletin,* vol. 45, p. 5, 1976.

[24] D. Pickel, G. P. Manucy, D. B. Walker, S. B. Hall, and J. C. Walker, "Evidence for canine olfactory detection of melanoma," *Applied Animal Behaviour Science,* vol. 89, pp. 107-116, 2004.

[25] A. Ferworn, "Canine Augmentation Technology for Urban Search and Rescue," in *Canine Ergonomics: The Science of Working Dogs*, 2009, p. 205.

[26] FEMA, "Disaster Search Canine Readiness Evaluation Process," U. S. D. o. H. Security, Ed., 2003.

[27] FEMA, "Section II - Type II Disaster Search Canine Readiness Evaluation Process," U. S. D. o. H. Security, Ed., 2003.

[28] FEMA, "Section III - Type I Disaster Search Canine Readiness Evaluation Process," U. S. D. o. H. Security, Ed., 2003.

[29] E. Magid, K. Ozawa, T. Tsubouchi, E. Koyanagi, and T. Yoshida, "Rescue Robot Navigation: Static Stability Estimation in Random Step Environment," 2008,.pp. 305-316.

[30] A. Ferworn, G. Hough, R. Manca, B. Antonishek, J. Scholtz, and A. Jacoff, "Expedients for Marsupial Operations of USAR Robots," in *IEEE International Workshop on Safety, Security and Rescue Robotics (SSRR06)* Gaithersburg, MD, USA, 2006.

[31] T. Kamegawa, T. Yamasaki, H. Igarashi, and F. Matsuno, "Development of the snake-like rescue robot," in *Robotics and Automation, 2004. Proceedings. ICRA '04. 2004 IEEE International Conference on*, 2004.

[32] A. Jacoff, E. Messina, and J. Evans, "A standard test course for urban search and rescue robots," *Proceedings of the Performance Metrics for Intelligent Systems Workshop,* 2000.

[33] E. Messina and A. Jacoff, "Performance standards for urban search and rescue robots," *Proceedings of SPIE,* vol. 6230, pp. 639-650, 2006.
[34] E. Messina, J. M. E. Llc, and K. T. Consulting, "Standards for Visual Acuity."
[35] E. R. Messina and A. S. Jacoff, "Measuring the performance of urban search and rescue robots," 2007, pp. 28-33.
[36] H. G. Nguyen, H. R. Everett, N. Manouk, A. Verma, Space, and C. A. Naval Warfare Systems Center San Diego, *Autonomous Mobile Communication Relays*: Defense Technical Information Center, 2002.
[37] J. Pickrell, "Dolphins Deployed as Undersea Agents in Iraq," in *National Geographic News*, March 28, 2003.
[38] M. R. Heithaus, G. J. Marshall, B. M. Buhleier, and L. M. Dill, "Employing Crittercam to study habitat use and behaviour of large sharks," *Marine Ecology Progress Series,* vol. 209, pp. 307-310, 2001.
[39] J. German, "Sandia explores k-9 collar camera kits for hostage rescue, emergency response," *Sandia National Laboratories*.
[40] I. Thomson, "Police unleash dogcam crime busters," vnunetwork, 2005.
[41] J. J. Romba, "Remote Control of War Dogs (Remotely Controlled Scout Dog)," ARMY LAND WARFARE LAB ABERDEEN PROVINGGROUND MD, 1974.
[42] A. Ferworn, D. Ostrom, K. Barnum, M. Dallaire, D. Harkness, and M. Dolderman, "Canine Remote Deployment System for Urban Search and Rescue," *Journal of Homeland Security and Emergency Management,* vol. 5, p. 9, 2008.
[43] C. Ribeiro, A. Ferworn, M. Denko, J. Tran, and C. Mawson, "Wireless estimation of canine pose for search and rescue," in *IEEE International Conference of Systems of Systems (SoSE'08)*, Monterey, CA, USA, 2008, pp. 1-6.
[44] S. Sharieh, "FULLY MOBILE FUNCTIONAL BRAIN SPECTROSCOPY USING NEAR-INFRARED LIGHT AND WIRELESS NETWORKS," in *Computer Science*. vol. Master of Science Toronto: Ryerson University, 2008.
[45] M. J. Herrmann, E. Woidich, T. Schreppel, P. Pauli, and A. J. Fallgatter, "Brain activation for alertness measured with functional near infrared spectroscopy (fNIRS)," *Psychophysiology,* vol. 45, pp. 480-486, 2008.
[46] M. Boecker, M. M. Buecheler, M. L. Schroeter, and S. Gauggel, "Prefrontal brain activation during stop-signal response inhibition: An event-related functional near-infrared spectroscopy study," *Behavioural brain research,* vol. 176, pp. 259-266, 2007.
[47] "IEEE 802.11 Standard Group Web Site."
[48] I. F. Akyildiz, X. Wang, and W. Wang, "Wireless mesh networks: a survey," *Computer Networks,* vol. 47, pp. 445-487, 2005.
[49] "Rajant Corp. Products Page."
[50] J. V. Draper, D. B. Kaber, and J. M. Usher, "Telepresence," *Human Factors,* vol. 40, pp. 354-375, 1998.
[51] G. H. Ballantyne, "Robotic surgery, telerobotic surgery, telepresence, and telementoring," *Surgical Endoscopy,* vol. 16, pp. 1389-1402, 2002.
[52] M. Anvari, "Robot-assisted remote telepresence surgery," *Surgical Innovation,* vol. 11, p. 123, 2004.
[53] C. Zhu, "In-pipe robot for inspection and sampling tasks," *Industrial Robot: An International Journal,* vol. 34, pp. 39-45, 2007.

[54] C. R. Stoker, D. R. Barch, B. P. Hine Iii, and J. Barry, "Antarctic undersea exploration using a robotic submarine with a telepresence user interface," *IEEE EXPERT,* pp. 14-23, 1995.

[55] M. Endsley, "Design and evaluation for situation awareness enhancement," in *Human Factor Society 32nd Anual Meeting*, Anaheim, CA, 1988, pp. 97-101.

[56] C. Ribeiro, A. Ferworn, and J. Tran, "An Assessment of a Wireless Mesh Network Performance for Urban Search and Rescue Task," in *IEEE Toronto International Conference – Science and Technology for Humanity TIC-STH 2009* Toronto, ON, Canada, 2009, pp. 1-6.

APPENDICES

A. La Fonera Router Specification

Manufacturer	Accton
Operating system	OpenWRT
Power consumption	5V at 1A (peak)
CPU	183 Mhz MIPS
Memory	16MB RAM, 8MB Flash
Wireless Standard	802.11b / 802.11g
Antenna	Omnidirectional 1.5 dBi
Dimension	9.35 x 2.55 x 7.0 (cm)

B. FOX Board LX832 Specification

Manufacturer	Acme Systems
Operating system	Linux kernel 2.6.19
Power consumption	5V at 280mA (1W)
CPU	100MIPS Axis ETRAX 100LX 32 bit, RISC, 100MHz
Memory	32MB RAM, 8MB Flash
Ports	1 Ethernet (10/100 Mb/s) 2 USB 1.1 1 serial console port
Extension	2 extension sockets with IDE, SCSI, 2 serial lines, parallel ports, I/O lines, I2C bus interface
Dimension	6.6 x 7.2 (cm)

C. CAT 2.0 Power consumption break down

Component	Current Draw (A)	Voltage	Power Consumption (W)
La Fonera Router	1.0	5	5
IP Video Server	0.6	5	3
Serial Servo Controller	0.4	5	2
Servo (4)	0.1 x 4 = 0.4	5	2
Total	2.2	5	12

D. CAT 3.0 Power consumption break down

	Current Draw (A)	Voltage	Power Consumption (W)
Single FOX Board	0.28	5	1
Single FOX Board + USB camera + WiFi Adapter	0.40	5	2
Complete CAT 3.0 Hardware	0.80	5	4