Dog and Snake Marsupial Cooperation for Urban Search and Rescue Deployment

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Abstract**—**One of the many challenges in developing ground response robots for Urban Search and Rescue (USAR) is endowing them with mobility that allows traversal of challenging terrain. In a preliminary study we introduced a new approach to the mobility problem that utilizes USAR dogs to deliver robots close to human victims in rubble. The results indicated that some search dogs are able to carry a small robot to a victim. This paper extends the original work—this time employing a more capable snake robot. Snake robots have much better maneuverability within rubble than wheeled or tracked robots. Unfortunately they are very slow—making timely rubble traversal a moot point. The premise of this work is that our hybrid system exhibits the advantages of rapid canine mobility with the flexibility and sensing capability of a snake robot.

Keywords**:** *Snake robots, USAR, Canine delivery, marsupial robotics*

I. Introduction

Urban Search and Rescue (USAR) environments often contain buildings which may have been reduced to rubble where trapped humans may be hidden. One of the first tasks of USAR search teams is to locate these trapped people.

Using dogs to find people in rubble is common practice. Their keen sense of smell, agility, intelligence and speed make them an ideal means of searching for people in rubble. While USAR dogs can find people, they cannot convey additional information concerning the state of the person and their surroundings nor can they stay in situ with the victim. These additional services would be useful to search teams in order to plan a rescue.

The use of snake robots in USAR environments has been proposed [1]. Snake robots are hyper-redundant (many degrees of freedom) mechanisms consisting of a series of joints which move via internal shape changes like a snake [2]. The narrow minimum cross section of a snake robot and extreme range of motion of its joints allow it to traverse many diverse environments, such as uneven ground, slopes, channels, pipes, poles, and trees as shown in Fig. 1. This makes them suitable for environments common in USAR. Unfortunately, snake robots typically move very slowly and are usually encumbered with a tether. In addition, they must be manually inserted into access points in rubble where victims may be located.

Fig. 1. Snake robot

There has been some initial work done on the use of search dogs as marsupial delivery mechanisms for robots—called the Canine Assisted Robot Delivery (CARD) [3]—CARD allows a small robot to be carried by a USAR dog and includes a release mechanism called the Canine Remote Deployment System (CRDS) [4] that drops the robot near a victim. In one modality of the CRDS, the release of the robot is triggered continuous barking is detected (USAR dogs bark when they

978-1-4799-0165-4/12/$31.00 (c)2012 IEEE

find hidden humans).

This strategy employs a dog's mobility to carry a robot through the majority of any challenging terrain. Once deployed near a victim, the robot can transmit video back to the search team. A small 4-wheeled robot, Drop and EXplore (DEX) was developed to test the CARD system [5]. DEX weighs less than 1 Kg and was easily carried by the search dog. Unfortunately, due to its small size and wheeled design, it had very limited mobility in rubble and its camera was in a fixed location, therefore DEX had only limited utility.

In this paper, we extend our previous work in marsupial robotic cooperation and employ an appropriately equipped USAR dog to deploy a snake robot in rubble. We wished to examine if a larger, more cumbersome and heavier snake robot could be carried by a search dog and if the robot's dexterity could provide better surveillance of interior structure once delivered to a victim.

The work presented in this paper is collaboration between the Institute Robotics at Carnegie Mellon University and the Network-Centric Applied Research Team (N-CART) at Ryerson University. N-CART began the initial study with the CARD systems and developed the CRDS. The modular snake robot was developed by Carnegie Mellon University.

II. EXPERIMENTAL TASK

A. Canine-Deliverable Marsupial Robot

USAR dogs certified by the Federal Emergency Management Agency (FEMA) are highly trained and are extremely effective at their job. However, they are normally trained without wearing any equipment. A series of experiments were conducted to determine if the extra payload would distract the dogs and hinder their ability to perform the search task.

A common means of training USAR dogs is to employ a "bark barrel". A person to be "found" by the dog (called a "quarry") is placed inside a large barrel and hidden from the dog's view. The purpose of the bark barrel is to train a dog to bark when it smells the human in the barrel. The dog is rewarded with a period of play with a toy if it successfully completes the task.

Our first set of experiments repurposed the bark barrel test. A dog would perform the same exercise equipped with the CRDS and a snake robot. Once the dog started to bark, the snake robot would be deployed. These experiments had two purposes. The first was to test for the dog's ability to accept the load (the snake robot weighs almost 3 Kg) and still find people. Our second goal was to determine different ways of attaching the snake robot to a dog. The attachment mechanism had to hold the snake robot firmly while the dog was running but also needed to allow the snake robot to move freely away from the dog once deployed.

B. Visual Acuity

The Intelligent Systems Division of the National Institute of Standards and Technology (NIST) of the U.S. Department of Commerce is investigating means for objectively testing the performance of rescue robots. The main goal of the investigation is to determine how to evaluate the performance of robots in operation in an USAR environment through the use of common metrics. Various metrics in many categories of performance have been suggested through the ASTM standards process [6-8].

One performance metric is visual acuity in which targets must be identified in various situations using the camera systems of a robot being evaluated. We created an analog to this test. We created an end-to-end test where a hidden quarry was placed in a confined space within a tunnel system similar to NIST's testing environments. A snake-robot-equipped USAR dog was sent in to find the quarry. Once deployed, the robot operator was tasked with identifying the quarry, and also a set of visual acuity targets placed in the surrounding area. A score was given for the number of targets identified correctly.

C. Test Environment

Several test environments were used. The experiments were conducted at two USAR training facilities--"Disaster City" on the grounds of Texas A&M University, and the Ohio Task Force 1 Training Center in Dayton, Ohio. These facilities contain purpose—built rubble piles that closely resemble a collapsed structure but are safe to work in. More importantly, under the rubble are tunnel systems ideal for this test.

Fig. 2. Rubble pile at OH-TF1 Training Center

III. THE APPARATUS

A. Snake Robot

The Bio-robotics Lab modular snake robot [9] consists of 16 1-DOF modules serially connected, with each joint rotated 90 degrees from the one before. This gives the robot 8 lateral and 8 dorsal rotary degrees of freedom. The robot moves by undulating its body through coordination motion of all of the joints. The snake robot is connected to the operator control unit (OCU) by a tether containing power, data, and video connections.

The tether contains a Kevlar braid, which combined with the custom connector to the tail of the snake is load tested to 181.44 Kg pulling force. The OCU consists of a DC power supply for the robot, a laptop computer to command the robot, a display for video from the robot, and a game controller for the operator to drive the robot. The OCU is completely contained within a ruggedized case allowing for easy transport and deployment.

TABLE I

SNAKE ROBOT SPECIFICATIONS

Power	36 VDC 1.5A (typical) 8.0A (theoretical max)
Data	RS-485 Serial
Video	Analog NTSC
Sensors (in each module)	3-axis accelerometer 3-axis gyroscope Temperature Voltage Motor Current Joint Angle
Actuator	35V brushed DC motor 1.356 Nm torque (continuous)
Weight	0.159 Kg (1 module) 2.948 Kg (full snake robot)
Dimensions	5.08 cm in diameter x 93.98 cm in length

B. USAR Dogs

Two German Shepherds, Freitag and Anno, were selected to carry the apparatus. Each dog was sufficiently large (weighing in excess of 36.3 Kg) and had shown an eagerness to search even when encumbered with additional weight.

C. CARD

The CARD system is a synthesis of three components: a USAR dog, a robot, and a CRDS. The CRDS is a simple release mechanism, originally designed to deliver emergency supplies (i.e. water, first aid, radio, blankets, etc…) to trapped victims. The main unit is situated on the dog's back and attached to a custom design harness. The payload is placed in a bag called the "underdog underneath the dog's chest.

Through experimentations an underdog design was developed that could accommodate the snake robot and would be tolerated by the dog. In the next section we describes the experiments conducted.

IV. EXPERIMENTS AND RESULTS

A. Bark Barrel Tests

The bark barrel tests were performed at both of our test locations.

At Disaster City, the test was conducted using Freitag. We observed that, although Freitags gait was different due to its front legs hitting the robot as it was running, the Freitag was still able to concentrate on finding the human in the barrel. In other words, the dog was not distracted by the load it was carrying.

Fig. 3. Snake robot worn by Anno

Fig. 4. Snake robot deployed

During these initial tests, the snake robot was attached using a regular underdog. We experimented with different methods of looping the straps around the snake robot to keep it in place with varying degrees of success.

The second set of bark barrel experiments were conducted at the Ohio facility used both Freitag and Anno. Anno is a USAR dog in training and had significantly less experience than Freitag. The second test provided the research team an opportunity to redesign the underdog for use specifically with a snake robot. The underdog was redesigned with a semi-ridged platform. As seen in the figure below, the snake robot would first coil into an 'S' shape around two posts to prevent it from falling. Once deployed the snake would be able to straighten out and free itself from the underdog.

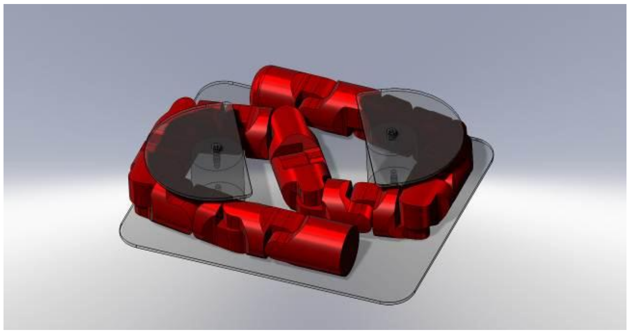

Fig. 5. Underdog design Mark-2

While this new design allowed the robot to free itself from the underdog easily, the 'S' shape configuration made the snake robot quite wide which made it very difficult for the dogs to walk. A field modification was made in which the snake robot would coil t in a horseshoe shape as shown in Fig. 6 below—providing more leg room for the dogs.

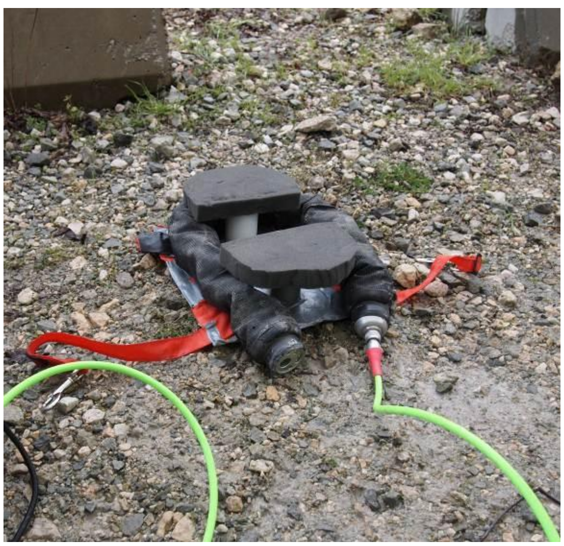

Fig. 6. Underdog design Mark-3

B. Visual Acuity Tests

The tunnel system under the rubble in Ohio lent itself well for visual acuity tests. Fig. 7 depicts a top view of the tunnel system. There is one circular chamber (1.2 m radius) with two concrete tubes connected to it. The concrete tube has a diameter of 0.8m which is just large enough for human and large dog to go through. One small concrete tube connecting from the side was the hiding place for the quarry and a second tube provided a path way into the chamber. A total of 12 visual acuity targets were placed on the walls and ceiling of the chamber.

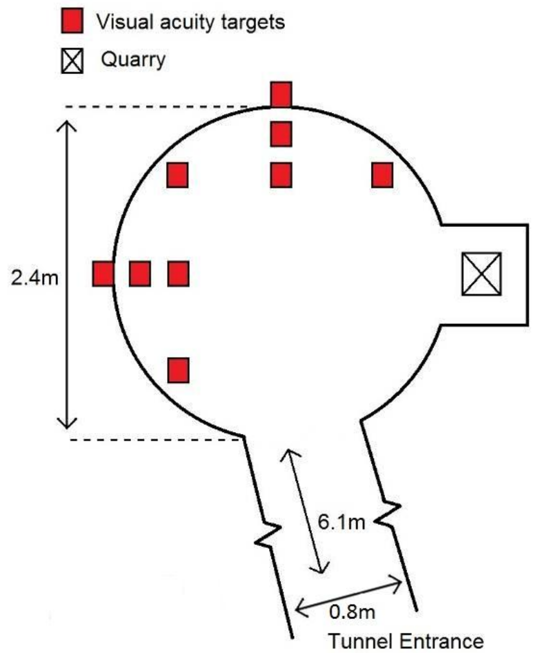

Fig. 7. Top view diagram of tunnel in Ohio

Fig. 8. Visual acuity target placements

Testing consisted of a succession of trials where snake-robot-equipped dogs were sent into the tunnels to find the quarry. Once deployed, the operator of the snake robot was tasked with finding and identifying visual targets through the control unit display. There were three separate trials performed in this experiment. In the first two trails there were two different robot operators who attempted to spot the targets. In the last trial, a canine handler was asked to do the same. The canine handler would verbally communicate with the robot operator to direct where they wanted the snake robot camera to point. The results from the trails are displayed in the table below.

TABLE II

VISUAL ACUITY RESULTS

Spotter	#Targets Acquired
Operator 1	11/12
Operator 2	12/12
Canine handler	11/12

The results indicate that using the snake robot, most targets were easily spotted. During the first trail, a score of 11 was assigned even though the location of the 12th target was known but, due to the glare from the sun, the operator could not properly identify the target.

V. DISCUSSION

In this set of experiments we have demonstrated the feasibility of using snake robots combined with dogs to form a rapid delivery system for USAR operations in rubble. In addition, we demonstrated that it is possible for USAR dogs to travel safely for short distances “tethered”. We have provided some evidence that this hybrid system is both feasible and has utility. We modified the visual acuity test method suggested by NIST in order to highlight the need to associated mobility with the acuity task. As many first responders have pointed out to us, just because you have an expensive camera does not mean that you will see anything if you cannot get to the target. In our system, we see the target because we can get to it.

VI. FUTURE WORK

Our work is far from complete. There are many systemic difficulties including a tendency for the CARD release mechanism to fire early as it undergoes violent shaking and rubbing against concrete because of the rapid movement of the dog. This will require some redesign as dogs have no interest in the equipment they are carrying and tend to damage it quickly. While we have demonstrated a tethered version of our system, it would be advantageous to have a snake robot that did not require one. The team has discussed various strategies to achieve this goal. We will continue to collaborate to make our system smaller, more durable and dogonomic.

ACKNOWLEDGEMENT

This research was supported by a number of USAR responders: canine handlers Tom Haus and Athena Haus from California Task Force 2, Connie Armbruster from Ohio Task Force 1. The responders provided access to USAR dogs and their expertise on USAR training procedures and operations.

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