Vibrotactile Feedback for Enhanced Control of Urban Search and Rescue Robots

John Sibert, Jeff Cooper, Christopher Covington,
Aleksandar Stefanovski, Darby Thompson
Department of Computer Science
The George Washington University
Washington D.C.20052 USA
{sibert, coryll, mairsil, astefano, darbyt}@gwu.edu

Robert W. Lindeman
Department of Computer Science
Worchester Polytechnic Institute
Worchester, MA 01609 USA
gogo@wpi.edu

Abstract—This paper describes a method of enhancing feedback for Urban Search and Rescue (USAR) robot operators through the use of a wearable vibrotactile display. The display provides vibrotactile feedback corresponding to sensor data collected by the robot. A USAR robot may be equipped with a variety of sensors including proximity, temperature, motion, and many others. The system described here is intended to enable a series of empirical studies aimed at evaluating this use of vibrotactile display.

I. Introduction

Urban Search and Rescue (USAR) robots are equipped with a variety of sensors designed to enable them to search through a post-disaster environment to locate survivors and perform other tasks. Video cameras and proximity sensors are used to find a path through the environment. Audio, heat, and CO_2 sensors are used to both locate survivors and determine their condition. Although it is considered desirable to increase the degree of autonomous operation of these robots, for the near future a relatively high degree of operator control will remain necessary. This means that the operators will need to utilize data from a number of sensors to determine the condition of survivors and to navigate the space successfully.

Currently, robots are controlled by human operators with a visual display (*e.g.*, a laptop), and interaction devices ranging from keyboard and mouse, to joysticks and other types of controllers. Sensor data obtained by the USAR robot is presented visually, typically alongside one or more remote video feeds. The combined camera views and sensor outputs can lead to a complex visual display.

We hypothesize that by distributing some of the load to the haptic channel, we can ease the burden on the visual channel and better use the overall human information bandwidth capacity. Accordingly, we are investigating the use of a torso-mounted vibrotactile display to convey some of the sensor information to the operator. For example, a robot with proximity sensors around its perimeter could have its sensor data mapped to a directional vibrotactile display in order to help the operator avoid obstacles. For a number of reasons, including low cost, portability, relative ease of mounting on the human torso, and modest power requirements, we have been concentrating on the use of the vibrotactile cues.

Other sensors, such as heat sensors, may prove to be better candidates for the use of vibrotactile feedback. For example, a tactile cue could be given in the direction of an anomalous temperature reading. As the operator turns the robot in the direction of the source, the spatial vibrotactile cue will move around the torso until it is centered in front of the operator. This can provide a constant directional vector to help aid the robot operator in seeking out the temperature source.

In recent years, a number of research groups have explored the use of tactile warning signals and information displays within a wearable context [7,8,1,10,11,12,13]. Even though the torso has not been found to be the best body location for high-resolution vibrotactile feedback [14], those parts that are more perceptive to vibrotactile stimuli, such as the hands, are typically involved in other tasks, whereas the surface of the torso is relatively unused. Christy Ho and her group [13] have studied the use of the spatial vibrotactile cues to direct visual attention in driving scenes where subjects performed an demanding visual monitoring task. Their results highlight the potential utility of vibrotactile warning signals in automobile interface design for directing a driver's visual attention to time-critical events or information.

Yano, Ogi, and Hirose [15] developed a suit-type vibrotactile display with 12 tactors attached to the forehead (1), the palms (2), elbows (2), knees (2), thighs (2), abdomen (1), and back (one on the left side and one on the right). They examined the effectiveness of using this vibrotactile display for tasks that required the user to walk around a virtual corridor visually presented in a CAVE-like display. They showed that presentation of tactile cues was effective for imparting collision stimuli to the user's body when colliding with walls.

Aleotti, Caselli, and Reggiani [16] designed and implemented a multimodal user interface for tele-exploration of remote, partially known environments. They incorporated a VR glove which gives the operator proximity feedback through vibrotactile actuators. Initial experiments designed to measure the benefits of this interface when visual feedback was missing, showed promising results.

In the area of robotic teleoperation, the focus of haptic input devices has mainly been on force-feedback joysticks and gloves [16,17]. We have found no previous work or use of sensor feedback applied through a "body-wearable display" in human robot interaction and robot teleoperation for search-and-rescue operations.

II. BACKGROUND

A. USAR Robot Arenas

To enable the development and application of performance metrics for rescue robots, researchers at The US National Institute of Standards and Technology (NIST) have developed several test arenas with varying degrees of navigational difficulty [2]. Virtual versions of the arenas [9] are available which run on the commercial Unreal Tournament game engine (Figure 1).

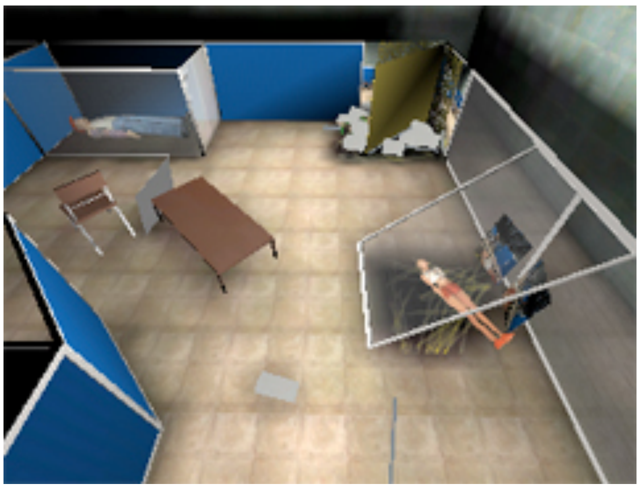

Fig. 1. Virtual USAR Arena

The Unreal game engine provides a three-dimensional environment complete with realistic physics interaction and the ability to add "avatars" which, in this case, represent the various USAR robots. Unreal also uses a client/server architecture, with the server responsible for maintaining the simulation environment. The clients, which possibly run on different computers, provide views of the simulated environment from the robots' perspective.

The virtual arenas provide a functional environment that can simulate any number of situations. These situations mimic the environments in which a USAR robot might be deployed. Figure 1 shows one such environment, which has elements similar to what could be found in an office environment after an earthquake or other catastrophe. Additionally, the system supports the use of different robots and sensor configurations. Multiple environments and situations may be tested rapidly and easily by changing a few simulation parameters.

B. The TactaBelt

To demonstrate the feasibility of a wearable haptic display as part of a human-robot interface, we have combined a TactaBelt [3] with a simplified graphical user interface (GUI), which provides a USAR interface for the operator. The TactaBelt, shown in Figure 2, consists of a modified sports wrap and vibrating tactors encased in plastic. Each tactor contains the same type of vibrating electric motor found in a cell phone. The belt can be firmly attached around the torso with the tactors equally spaced about the center of the torso.

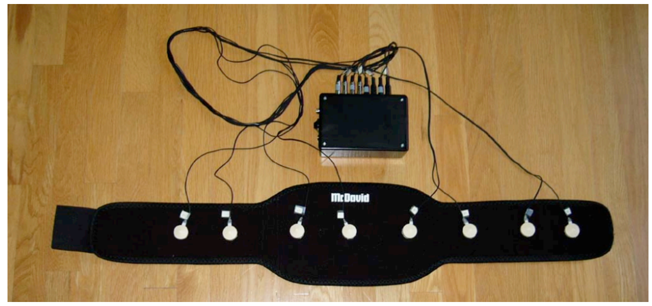

Fig. 2. TactaBelt

In previous work by ourselves, and by others [1,5,7,8], directional vibrotactile cuing has proven to be effective in a variety of domains. Recently, we found that vibrotactile cuing using the TactaBelt significantly improved performance in a searching task [4]. In this case, the TactBelt alerted the participant to search areas that were overlooked.

III. THE TEST ENVIRONMENT

In order to effectively test the impact of a wearable haptic device on a USAR robot task, it is important to pay particular attention to the different elements that make up the testing environment.

A. Visual Interface Issues

Our visual interface endeavors to simulate an actual interface that would be used by a USAR robot operator. To do so, there are two problems that must be resolved. First, the placement and representation of the controls and sensory feedback need to be consistent with current USAR robot control schemes. Due to the different layouts for various robots, our GUI incorporates a generic layout comparable to existing controls.

The second problem is to simulate the volatile nature of the video provided from the robot. USAR robots are used within an urban environment that may contain collapsed buildings, electrical interference, and low visibility. Additionally, the robots typically use wireless methods of video transmission. All of these combine to degrade the video transmission in some way. For analog signals, common video problems include the classical "snow" phenomenon and distortion. Digital broadcast signals also have problems such as: pixilation, frame-rate lags, and signal dropouts.

We have attempted to incorporate these signal problems in our interface to make it as realistic as possible (Figure 3). A properly degraded video signal, combined with the virtual arenas mentioned previously, provides an interactive approximation of a real emergency situation. A setup such as this is more realistic and allows the operator to focus on the task rather than on how effective the simulation is.

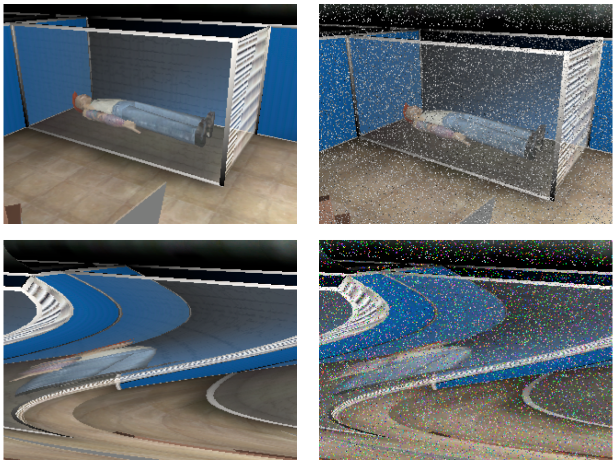

Fig. 3. Video degradation examples. from upper left: a) Detail from Figure 1. b) With "snow" added. c) Sinusoidal magnetic distortion. d) Sinusoidal distortion with snow.

B. Operational Environment

USAR robots usually perform in a disaster environment. This kind of environment is chaotic and difficult to work in. Background noise from sirens and emergency equipment, as well as between emergency personnel, can make auditory feedback difficult to hear or understand. Visual feedback can also be negatively influenced by flashing emergency lights, smoke or even movements by the operator and other emergency personnel. Haptic feedback has the advantage of being relatively uninterruptible since the operator is in direct physical contact with the tactile device.

Another issue is the appropriate mapping of sensor data to display feedback. Humans tend to process spatial information (geometry, pictures) differently from linguistic information (algebra, text). For example, both proximity information and directional signals are spatial information. By mapping this information to a belt surrounding the midsection, we maintain the correct spatial (directional) correspondence between the sensor and the tactor. In contrast, a turn right, turn left signal, perhaps applied to the right wrist vs. left wrist, is linguistic rather than spatial feedback.

It is also important that the robot's operator be able to move around freely and unburdened in such an environment. Large or immobile devices would serve as a hindrance to this mobility. The size and design of the TactaBelt provides the additional vibrotactile feedback with little impact on mobility.

IV. Conclusion

With the ever-increasing sensor capabilities of typical USAR robots, operators are expected to process more and more sensor information. By redirecting existing visual sensor information to the haptic channel, a more appropriate form of feedback for certain sensors may be accomplished. Complementary visual and haptic output may also provide faster recognition of, and responses to, sensor events.

Our immediate goal is to perform informal experiments using the virtual USAR arenas to determine the optimal configuration and use of the TactaBelt and its accompanying interface. We want to determine the most effective mappings for various sensors as well as the best sensor data to display in haptic form.

We are also concerned with the method of signaling. The intensity of the tactor vibration can be varied with the vibration getting stronger as the target gets closer. However, pulsing the tactors instead of using a continuous vibration signal may prove to be a more-effective signaling approach. Pulsing at different frequencies may also allow multiple items to provide simultaneous vibrotactile feedback.

So far, we have used eight tactors affixed to the TactaBelt at the four cardinal directions and their intermediates. This configuration has worked well, but further testing needs to be done to determine whether this is an optimal configuration. If it is not, then the optimal number of tactors and their placement needs to be determined through testing. By extending the body coverage of the vibrotactile cues to include more of the body, three-dimensional information could be presented.

Our plan is to use informal experimentation to frame formal hypotheses, which we will be able to test empirically. Our first empirical studies will use the virtual arena simulations described above. For final validation, we plan to extend the studies to incorporate using real robots in the actual physical USAR arenas.

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