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Wearable Concepts for Gesture-Based Robot Control, Direction Localization, and Communication to a Tactile Belt Display

by Gina A Hartnett, Linda R Elliott, Lisa Baraniecki, Anna Skinner, Kenyan Riddle, and Rodger Pettitt

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Wearable Concepts for Gesture-Based Robot Control, Direction Localization, and Communication to a Tactile Belt Display

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14. ABSTRACT
This report describes development and evaluation of a wearable control and display concept developed through Small Business Innovative Research's Phase 2 funding, as accomplished by AnthroTronix, Inc. Instrumented gloves were adapted for two broad uses. The first involves use of the instrumented glove for robot control (i.e., driving and robotic arm manipulation). Soldiers used the instrumented glove and a handheld controller to navigate around obstacles and manipulate the robotic arm. Results suggested the use of the instrumented glove reduced the time needed to maneuver the manipulator arm as compared with the use of the hand-held controller. The second application demonstrated use of the instrumented glove to generate direction and distance through a pointing gesture. This capability was further explored with regard to the manner in which direction and distance can be communicated to another Soldier. Direction and distance information was conveyed to Soldiers using three conditions that combine speech and tactile cues. Results suggested the mixed condition reduced time needed to accurately determine direction and distance to a threat compared with the all-tactile and all-speech communication conditions. Soldier-based feedback on these concepts was generally positive and will serve to enhance further development toward operational readiness.

15. SUBJECT TERMS
gesture, robot control, haptic, tactile, Soldier navigation, Soldier communication, Army

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1.   Introduction

1.1 Background

A future vision of the use of autonomous and intelligent robots in dismounted military operations has Soldiers interacting with robots as teammates, with an interim goal of having the robot able to execute tactics much like a military working dog (Phillips et al. 2013; Redden et al. 2013). Soldiers would no longer have to continuously micromanage every movement of the robot. Instead, Soldier–robot interactions would be more tactical and bidirectional. One critical goal is to improve capabilities enabling Soldiers and robots to quickly and easily communicate with each other. This report examines the concept of wearable systems having interfaces expected to be easier to learn and use. Instrumented gloves are used to investigate aspects of gesture-based controls compared to a hand-held controller. In addition, a tactile belt interface is compared to more traditional speech communications.

There have been many studies showing usefulness of more naturalistic interfaces for robot control (Goodrich and Schultz 2007). The use of gestures for robot control is progressing rapidly. Gesture-based commands to robots have been used in a variety of settings, such as assisting users with special needs (Jung et al. 2010), assisting in grocery stores (Corradini and Gross 2000), and home assistance (Muto et al. 2009). Examples of gestural commands in these settings include "Follow me", "Go there", or "Hand me that". While there have been attempts to use pointing gestures, they often have to be combined with speech or graphical interfaces to accomplish the communication.

Progress has been made, and demonstrated within this effort, with regard to the effectiveness of a pointing gesture for localization (e.g., communication to a Soldier or robot). In this investigation we focus on how best to display the direction and distance information that is generated.

1.2 Purpose

The current effort seeks to investigate advanced concepts in intuitive interfaces (e.g., instrumented gloves and tactile displays) to reduce cognitive, physical, and temporal demands and enhance dismounted Soldier communications and robot control. Instrumented gloves were adapted for two broad uses.

The first involves controlling the robot with the instrumented glove, driving, and robotic arm manipulation. Soldiers used the instrumented glove or a hand-held controller to navigate around obstacles and manipulate the robotic arm. The two

methods of control were compared on robotic control performance, operator workload, and user experience.

The second application demonstrated using the instrumented glove to generate direction and distance through a pointing gesture. This capability was further explored with regard to the manner in which direction and distance can be communicated to another Soldier. Direction and distance information was communicated to Soldiers using three means: 1) direction and distance through speech communications, 2) direction by tactile belt and distance through speech, and 3) direction and distance through the tactile belt. The following sections discuss progress and issues associated with these capabilities.

1.3 Gestures for Robot Control

Instrumented gloves are the most common instantiation of wearable instrumented systems for robot control (Elliott 2016). The glove concept is congruent for many work situations where operators may already have to wear gloves. Early versions of these gloves were integrated for computer usage, in that the gloves could be used for computer-interface actions such as menu selection. However, the reliance on a visual display was somewhat detrimental to performance (Kenn et al. 2007). For robot control, glove-based approaches do not require a visual display, with the glove sending signals to robotic control software for recognition, interpretation, and translation into computationally understandable and executable robotic behaviors.

Gesture recognition is accomplished through the mathematical interpretation of human body movements by computing devices. Hand and body gestures can be transmitted from a controller mechanism that contains inertial measurement unit (IMU) sensors to sense rotation and acceleration of movement, or in other instances via camera-vision-based technologies. Gesture recognition has been used within a wide variety of domains and applications ranging from robotic control to film and video-game development and is a key component of what developers refer to as a perceptual user interface (PUI). The goal of PUI design is to enhance the efficiency and ease of use for the underlying application design in order to maximize usability. Common gesture-recognition analytical methods include hidden Markov models (HMMs), finite-state machines (Hong et al. 2000), and artificial neural networks (Oz and Leu 2007). Due to the ability to model sequential information using HMMs, this method has been used dominantly throughout the past decade (Ong and Ranganath 2005).

IMU sensor technologies placed on the body provide an alternative, technically feasible, near-term approach to gesture recognition within uncontrolled

environments. AnthroTronix, Inc. (ATinc) has demonstrated IMU-based, hand- and arm-signal gesture-recognition accuracy of 100% (Vice et al. 2001) via a custom instrumented glove interface.

1.3.1 Robot Control

Robot control is traditionally accomplished using hand-held controllers, much like a gamepad or joystick form factor. Use of instrumented gloves to accomplish simple movement commands has been demonstrated across a number of situations (Elliott 2016). A strong advantage to a multiuse instrumented glove to a dismounted Soldier is that sensors can be embedded within a standard Army field glove that Soldiers normally wear, thus eliminating the need to carry a handheld controller and allowing easier access to their weapon.

While it is easy to think of single commands (e.g., stop, move forward, turn left) as simple commands, one should keep in mind it is not the command per se, but the distinguishability and the intuitive nature of the gesture that determines ease of use and recognition. When the gesture set is small, recognition rates have been high across many glove-based approaches.

1.3.2 Remote Manipulation

Ground-based mobile robots are often used for remote manipulation of objects. In combat situations, this capability is often used for bomb disposal (Axe 2008). Several efforts have been reported where gestures have been developed for remote manipulation; some regard the development of service robots designed to assist people in locations such as offices, supermarkets, hospitals, and households. Other efforts focus on assisting users in more dangerous environments such as hazardous areas or space, using telepresence and teleoperation (see Basanez and Suarez [2009] for a review of teleoperation issues).

One primary manipulation common to most applications is that of grasping. Grasping consists of several steps: a) perception of object, b) determination of object form, size, orientation, and position, c) planning the grip, d) grasping the object, e) moving the object to a new location, and f) releasing the object. In this study we include use of an instrumented glove to manipulate a robotic arm as part of the robot-control investigation.

1.3.3 Gestures for Soldier Communication

A fundamental form of communication among dismounted warfighters while conducting combat maneuvers is the use of hand and arm signals. Dismounted warfighters in the field often utilize an established set of hand and arm signals in order to communicate with others while maintaining noise discipline (e.g., when approaching an objective) or at times when noise levels exceed what can be heard via voice and radio (e.g., due to the sounds of explosions and weapons firing). These signals, which may include commands, threat identification, and directional cues, can be relayed from one team member to the next, reaching team members not within line of sight of the initial team member issuing the command; however, this takes time and requires visual attention in order to receive signals. Automated electronic capture of hand and arm signals via instrumented glove technologies enables commands to be initiated and instantaneously sent to all team members simultaneously, without requiring line of sight. These electronic signals can be presented to both human and robot team members. The sensors necessary for gesture recognition are small and lightweight and can be unobtrusively integrated into warfighters' current field gloves. Hand movements can thus be used for direct control of robotic assets, and standard hand-signal commands can be presented to human team members via a variety of modalities.

A fundamental task for Soldier coordination and communication and robot control is that of directing movement through a pointing gesture. Pointing gestures have been developed over several years, either to convey direction information or to clarify ambiguous speech-based commands. While the pointing gesture is natural and intuitive, recognition of "where" and "what" by a computing system can be challenging. Areas can be more precisely circumscribed when augmented by use of a map display (e.g., circling the area of interest) (Brooks and Breazeal 2006; Perzanowski et al. 2000a, 2000b). Other approaches have used object recognition as an aid to gesture interpretation (e.g., "Bring me that cup"). However, advancements in instrumented glove technology are enabling determination of azimuth from a point gesture; when combined with a GPS-based wearable device, both direction and distance can be determined through sensors within the glove (Vice 2015). This capability was demonstrated within this effort.

1.3.4 Tactile Interface

While the instrumented glove provides the means for gestural signals out of line of sight, the reception will be accomplished through a torso-mounted belt with vibrating tactors. The tactile modality has proven to be a reliable and covert conduit for the conveyance of critical information during infantry tactical operations. For

example, Van Erp (2005) showed that a localized vibration on a waist belt could easily and accurately be interpreted as a direction in the horizontal plane as it is intuitive to infer direction from the torso, which is relatively stable. Recently, torso-mounted tactile displays have proven very effective for navigation in field evaluations (Pomranky-Hartnett et al. 2015). These interfaces, if integrated with GPS, enable dismounted warfighters to navigate in low-visibility conditions, hands-free (allowing the Soldier to hold his/ her weapon), mind-free (not having to pace count), and eyes-free (allowing focused attention to surroundings rather than a visual display) (Pomranky-Hartnett et al. 2015; Elliott et al. 2011; Elliott and Redden 2013). Torso-mounted interfaces have also proven effective for warfighter communications. However, tactile systems must be integrated with visual and control systems to support optimal display of certain types of complex information and to enable map-based situation awareness and easy input of waypoints. Multi-modal information presentation supports redundancy and enables warfighters to attend to the individual modality or combined information channels of choice in any given situation. Additionally, intelligent wearable computing devices allow warfighters to communicate with each other, obtain information, and control remote devices without impeding their ability to perform tasks in a field environment (Vice et al. 2005).

1.3.5 Summary

In this Soldier-based study our goals were to evaluate the use of an instrumented glove to accomplish robot maneuver and manipulation tasks and to evaluate the use of speech and tactile displays to communicate direction and distance (e.g., localization) information to a user. Evaluations were based on a) performance-based measures to assess these capabilities, b) performance-based measures of more traditional capabilities, and c) Soldier-based feedback with regard to user experience and workload and suggestions for further engineering development.

2. Communication-based Operational Multimodal Automated Navigation Device (COMMAND)

2.1 General Description

The COMMAND integrates an instrumented glove for automated gesture-based communication and control, a tactile display belt, and a GPS-enabled ruggedized handheld computer. The COMMAND technology is designed to support gesture recognition, navigation, wireless communication, robotic control, and multimodal information presentation. The tactile interface received signals from the

instrumented glove (i.e., pointing gestures), enabling Soldier-to-Soldier communications. In addition, the instrumented glove was used for robot control.

2.1.1 Instrumented Glove for Robot Control

Participants used one of two methods at a given time to control the robot. The order of methods was randomized per participant. One of the methods used was a single instrumented glove for robotic maneuvering and manipulation developed by ATinc (Fig. 1). The glove contained 10 nine-axis sensors (three-axis accelerometer, three-axis gyroscope, and three-axis magnetometer), which were sampled at a rate of 100 Hz. The glove was tethered to a smartphone to transmit the wireless command signal to the robot. The single-glove configuration could be switched between driving the robot and manipulating the robotic arm. The IMU outputs from the index finger were converted into quaternion values and mapped to the position of the manipulator arm attached to the robot.

In addition to the instrumented glove, the robot could also be controlled via a traditional gamepad controller commonly used for robotic control and gaming. This gamepad, an Xbox 360 controller (Fig. 2), is familiar to most video gamers and was integrated with a laptop via USB.

For both conditions, video feed was streamed using a "back-up" camera typical of those found on motor vehicles to aid in navigating while in reverse. The camera was fixed to the chassis of the Unmanned Ground Vehicle (UGV) and transmitted wirelessly to a small screen, which was included in the back-up camera as a part of the system. Figure 3 provides an image of the video feed. Figure 4 shows a portion of the path the robot completed.

Fig. 1   Instrumented glove

Fig. 2   Xbox gamepad controller
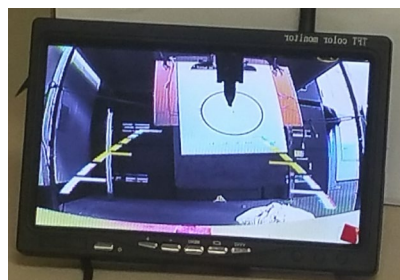
Fig. 3   Tablet for robot's camera view

Fig. 4   Robot's path view

2.1.2   Instrumented Glove for Soldier Communication

The same instrumented glove was used for the dismounted Soldier communications task (Fig. 1). The configuration contained a single glove for gesture recognition via azimuth and hand-signal communication.

2.1.3   Speech and Tactile Communications for Soldier Communication

Gestures from the glove were communicated to a tactile belt worn by Soldiers around the waist. It contained an array of embedded tactors spaced evenly around the waist to be used for combinations of temporal and spatial tactile messages. The location of buzzes (location on the waist) corresponded to the direction of the threat and the number of buzzes corresponded to the number of meters (in multiples of 10) that the threat was away. For example, three buzzes (temporal) on the right side (spatial) of the waistline could indicate a threat to the Soldier's right flank 30 m away. The belt was configured to convey a distinct signal for each of the designated hand signals. Only the lower-frequency tactor was utilized during this study for both the directional and distance cues. This tactile belt was connected by wire to the smartphone for GPS and signal transfer.

The tactile belt used was a commercial off-the-shelf (COTS) wearable vibrotactile array optimized for advanced tactile displays. The stretchable, torso-worn Dual Belt System contains two rows of 8 tactors; the lower row is electromagnetic resonance (EMR) and the top row is C-3 tactors. The Dual Belt connects to an Engineering Acoustics, Inc. (EAI) tactor controller. The combination of tactor types enables a

larger vocabulary of tactile signals to be sent to the operators and enables operators to more easily distinguish multiple tactile signals. Only the lower-frequency tactors were used during this experiment.

EAI's ATA Dual Belt (shown in Fig. 5) represents a state-of-the-art, wearable vibrotactile array, suitable for a wide variety of military, biomedical, research, and commercial applications. The EMR tactor (Fig. 5) is a miniature vibrotactile transducer that has been optimized to create a strong localized sensation on the body. This tactor uses an eccentric motor in a proprietary and patented configuration to provide low-frequency, high-displacement contactor vibration. The C-3 tactor (Fig. 5) is a miniature vibrotactile transducer that has been optimized to create a strong localized sensation on the body. A body-referenced arrangement of tactors activated individually, sequentially, or in groups can provide intuitive "tactile" instruction to a user.

Fig. 5   EAI's Dual Belt (left) uses rows of EMR (middle) and C-3 tactors (right)

Figure 6 shows the technical specifications for the EMR tactor and C-3 tactor.

Physical Description:	0.8" (20.3 mm) diameter by 0.25" (6.35 mm) high	Physical Description:	1.2" diameter by 0.35" high
Weight:	8 grams	Weight:	5 grams
Exposed Material:	Anodized aluminum, polyurethane	Exposed Material:	Polycarbonate and ABS
Electrical Wiring:	Flexible, insulated, #24 AWG.	Electrical Wiring:	Flexible, insulated, #24 AWG
Skin Contactor:	0.3" (7.62 mm) diameter, pre-loaded on skin.	Skin Contactor:	0.5" diameter, pre-loaded on skin.
Tactile Pulse Characteristics:	180-280 Hz, <2 ms rise time	Electrical Characteristics:	DC motor, 0.2W typ. (ON)
Electrical Characteristics:	11.0 ohms nominal with lead.	Tactile Pulse Characteristics:	120 Hz, 12 ms rise time
Insulation Resistance:	50 megaohm minimum at 25 VDC, leads to housing	Insulation Resistance:	50 megaohm minimum at 25 VDC, leads to housing
Transducer Linearity:	+/- 1 dB from sensory threshold to 0.02"(0.5 mm) peak displacement.	Maximum Drive:	Max 10% duty cycle, max on time 500 ms (at max gain)

Fig. 6   Technical specifications for (left) EMR tactor and (right) C-3 tactor

A GPS-enabled smartphone was used for data processing and signal communication (Fig. 7). This was performed on a Samsung Galaxy S4 device. The smartphone included a touchscreen and visual display, an Android operating system, custom gesture-recognition software, and tactor-controller software, as well as embedded GPS and wireless communication capabilities. The operators did not interact directly with the smartphone.

Fig. 7   Smartphone with GPS

2.2 Robot

The robot used for this evaluation was a Jaguar V2 Robot implemented with a 3 degrees-of-freedom (DOF) manipulator arm (Fig. 8), which is a COTS mobile robotic platform. It is rugged, lightweight (< 25 kg), and compact, as well as weather and water resistant. It has a chassis with two flippers for completing mobility tasks and a manipulator arm with a gripper for completing manipulation tasks.

Fig. 8   Robotic platform and manipulator arm

3.   Method

Two experiments were conducted: 1) Soldier communication and 2) robot control. Each will be described separately.

3.1 Participants

Twenty-four Soldiers participated in this study and completed both the Soldier-communication task and the robot-control task. They were recruited from the Officer Candidate School at Fort Benning, Georgia. All of the Soldier-participants had a bachelor's degree or higher—two had doctorates. Ages ranged from 22 to 32 (average = 26.04). Twelve were female. Three Soldier-participants were left-handed. Uniform size ranged from XS to L. (Further details from investigators' interactions with Soldier-participants are found in Appendixes A–I.)

3.2 Soldier Communication

3.2.1 Soldier Communication Procedures

Soldier-participants were briefed on the purpose of the Soldier-communication experiment. They were told they would be trained on information received through speech and/or tactile displays. After training, they participated in all three communication conditions, with each condition providing information on 10 targets. The order of participation in each condition followed a counterbalanced William's square design (Williams 1949). Performance data were collected through trained observers. After all performance sessions were complete, the Soldiers filled out a questionnaire pertaining to each condition.

3.2.2 Soldier Communication Training

Soldiers were first trained on the signals for the commands they would receive. For example, the number of vibrations would indicate the distance, in 10s of meters, away. Additionally, the direction of the threat would be indicated by the location of the vibration on the belt. Likewise, in the speech condition, the distance would be conveyed by voice over the "radio" (smartphone speaker). Once in place, the Soldier faced north. Soldiers were told that another Soldier spotted a threat and would be communicating that threat either by "radio" or by tactile belt. Soldiers were trained until proficient in each condition.

3.2.3 Soldier Communication's Task Demands

After training, each Soldier responded to incoming information. To interpret and measure accuracy of their response, Soldiers were placed within a direction ring that had random letters placed around the ring that corresponded to the four cardinal directions (north, south, east, and west) and four intermediate directions (northwest, northeast, southwest, and southeast), as depicted in Fig. 9. These randomly chosen letters were used in the same positions for every trial and for every Soldier. The

letter R was always placed facing north and the Soldier would begin each trial by facing north (the letter R), as illustrated in Fig. 10. The Soldier responded to incoming information by facing the letter corresponding to the incoming direction, stating the letter representing that direction, and stating the distance information. After each response, the Soldier turned to face north again and prepare for the next signal. This was true in all conditions.
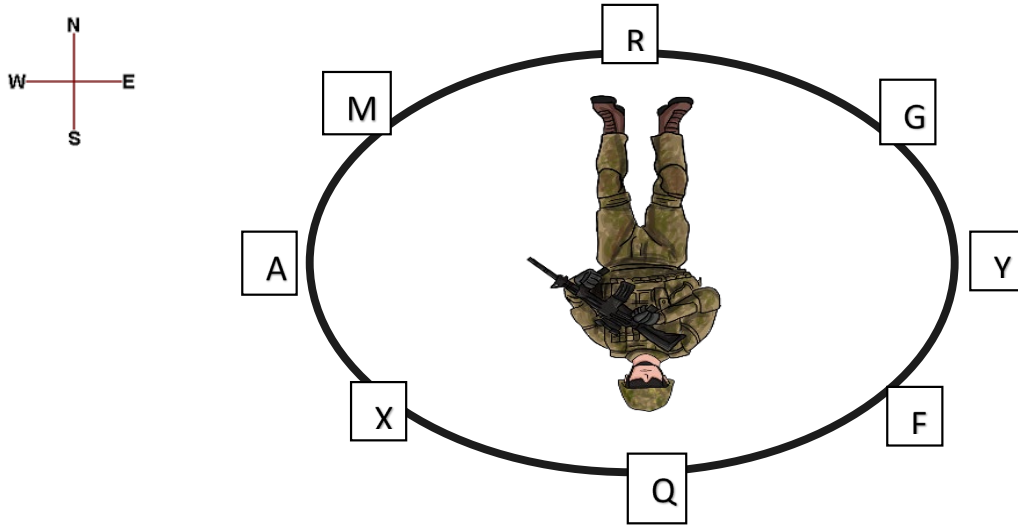
Fig. 9   Direction ring

Fig. 10   Soldier preparing for cue facing north (R)

For the all-speech condition, the distance and direction were received by speech over the "radio". Note that in the speech condition the Soldier was required to know that he or she was facing north and to determine which direction they needed to

turn to. For example, the Soldier would hear "30 meters west". Given that prompt, the Soldier's correct response would be to turn and face the direction indicated and verbalize the corresponding letter found at that location on the direction ring along with the distance ("A 30 meters"). See Fig. 11.

Fig. 11   Soldier moving in the direction of threat (A)

In the all-tactile condition, the Soldier received a vibration on the belt that corresponded to the location of the threat. The EMR or lower-frequency tactor was used for both direction (location of the vibration on the belt) and distance (number of vibrations). The number of vibration taps felt would indicate the distance (in 10s of meters) away from the threat. Upon feeling each cue, the Soldiers would turn their bodies to face the direction they felt on their torso. This direction corresponded to a letter on the direction ring (Fig. 9). For example, if the Soldier received two vibrations at his 3 o'clock, the correct response should be "Y 20 meters".

Finally, in the mixed condition (direction via tactile belt and distance via speech), the Soldier received a low-frequency (EMR) vibration on the belt that corresponded to the location of the threat and an auditory cue that indicated the distance away from the threat. For example, if the Soldier received a vibration at his 6 o'clock and heard via the "radio", 40 m, the correct response should be "Q 40 meters".

3.2.4 Soldier Communication's Performance Measures

Communication performance regarding direction/range comprised

- Speed of Soldier response to incoming information (i.e., number of seconds, logged by the data observer).

- Accuracy of direction response. If the response is correct, it was logged as a "0" error. Any error was measured by counting how many letters were between the correct and actual response. For example, if the correct response was Q but the response was X, that would be an error of 1 (as per Fig. 9); if the response was R, it would be an error of 4.

3.2.5 Soldier Communication's Subjective Measures (Feedback)

Subjective measures included the "Soldier Communication" questionnaire's responses and comments.

3.2.5.1 Soldier Communication Questionnaire

Soldier-participants were asked to provide open feedback on the following aspects of the overall system and experiment:

- Ease of training regarding the tactile signals

- Comfort/fit of the tactile belt

- Any problems experienced with the belt or speech

- Which condition was preferred (all-speech, all-tactile, or mixed)

- Overall tactile-belt-communication concept

- Ways to improve the signals and tactile belt

3.3 Robot Control

3.3.1 Robot Control's Procedures

Soldier-participants were briefed on the purpose of the robot control experiment. They were told they would be trained on two controllers (i.e., gamepad and instrumented glove). After training, each Soldier accomplished robot navigation and manipulation two times, once with each controller. Order of participation was counterbalanced, such that half of the participants performed with the gamepad first and the other half with the glove first. Performance data were collected through trained observers. After each performance session, each Soldier filled out a NASA Task Load Index (TLX) self-report of workload. After both performance sessions were complete, they filled out a questionnaire pertaining to each controller.

3.3.2 Robot Control's Training

Soldier-participants were trained on the different controllers prior to completing the task. The trainers described the general task demands throughout the robot control course and explained that the goal was to teleoperate the robot through the course while avoiding all obstacles and staying within the barriers. Soldier-participants were then shown the robot that they would be operating, including the chassis and 3-DOF arm. They were told to navigate using only the camera for visual feedback, and for the task they must drive the chassis through the course and touch the target using the arm. They were told they would be using two different control methods to operate the robot.

For the handheld-controller condition, Soldier-participants were shown the layout of the joystick and button controls. They were told to regard the arm as they would a human finger, given that it had the same number of joints and segments. They were shown how to use the handheld-controller buttons to move the joints of the arm. For the layout, the right thumb stick was used for up/down and left/right (for drive) and the buttons were used to switch between modes. The top button was used for controlling the top joint of the manipulator arm, the right button was used for the middle joint, the bottom button was used for the base joint, and the left button was used to toggle to drive. The Soldiers were also shown how to control robot maneuvers and movements via the camera feedback. They then completed a test run once all of their questions had been addressed.

For the glove condition, Soldier-participants were shown the Android interface that was used in conjunction with the glove to operate the robot. The app interface consisted of "Drive", "Arm", and "Lock" buttons. This was used to toggle between driving (Drive) mode and manipulation (Arm) mode, as well as the option to completely stop operation of the robot (Lock). Participants were only able to control "Drive" or "Arm" at a given time. To drive the robot, the user made a fist with the pointer and middle fingers extended and parallel to the ground. To turn, the user controlled the up and down movement of their pointer (left) or middle (right) finger depending on which direction they chose to go, thus changing the yaw of the vehicle. As in the controller condition, Soldier-participants were encouraged to regard the manipulator arm as they would the human finger. Movement of the arm mapped directly to the index finger on the glove. Soldier-participants were then shown how to use the glove to control the chassis drive. They were asked if they had any questions and, if none, asked to complete a test run.

3.3.3 Robot Control's Route and Task Demands

There were two options for robot control setup: single-glove control in which control was switched from the chassis to the manipulator arm and gamepad control in which one joystick controlled the chassis and the button pad was used to control the manipulator arm. A marker was attached to the end of the robotic arm to indicate where the participant planted the target. A camera was attached to the robot chassis for video feedback during teleoperation.

Obstacle locations were systematically varied for the three performance conditions (e.g., training, glove, and gamepad) to minimize practice effects and conditions were also randomized. Participants were trained for each condition prior to its respective trial. To begin each trial, the robot is placed at the start point. The operator maneuvered the robot along the path, taking care to avoid obstacles and stay within line boundaries. At the end of the route, they deployed the manipulator arm and made contact with a target on the door. The target was clearly visible via the robot's camera. Figure 12 shows photos of the robot system on the actual path. Figure 13 shows the robot system along with the simulated path. Soldiers were given 25 min to complete the building-clearing task. Each condition took approximately 1 h to train, perform, and provide feedback. Each Soldier-participant completed one training run and one official run for each control method for a total of four runs per Soldier-participant (two practice runs and two official runs).
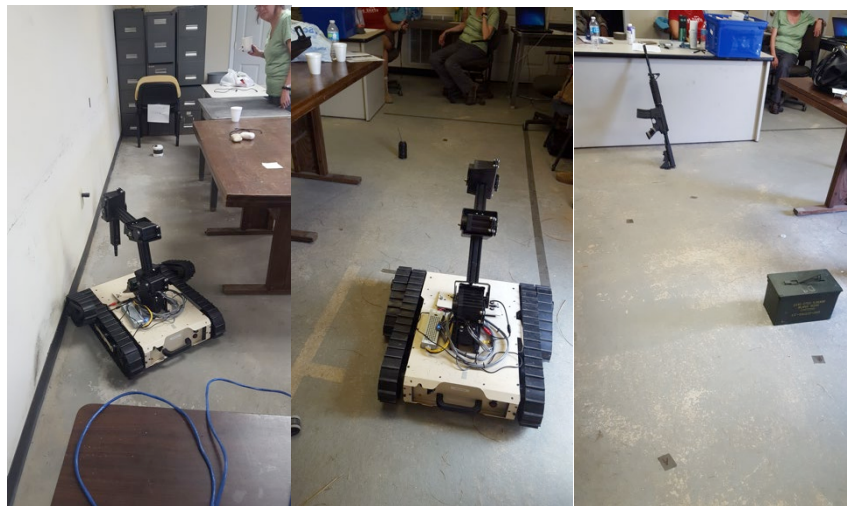
Fig. 12   Robot on parts of the course
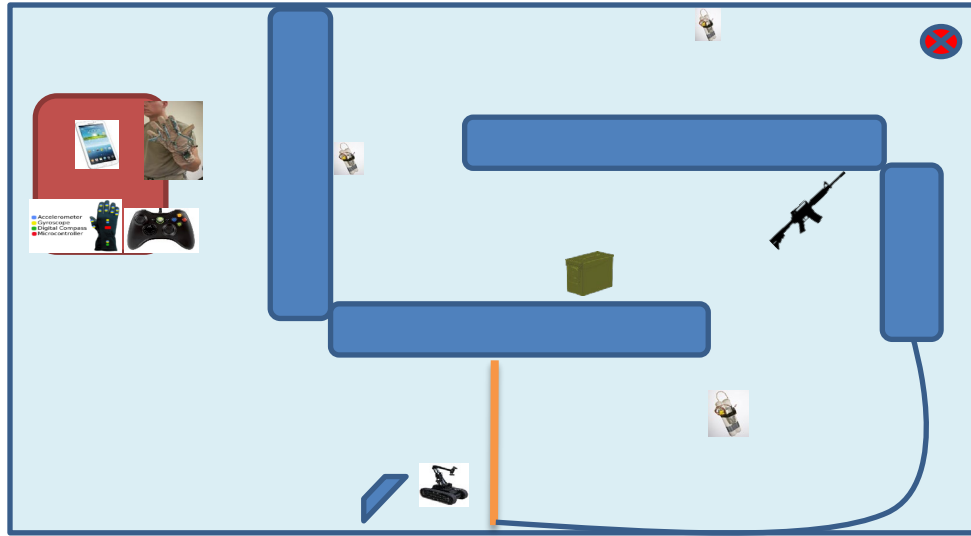
Fig. 13   Robot's path with obstacles

3.3.4   Robot Control's Performance Measures

For each of the conditions, drive time was collected as the total recorded time to complete navigation of the robot from the starting position to the intended target. This included the task time to drive the robot chassis and did not include the time to manipulate the robot arm. Touch time was also recorded and was the total time that Soldier-participants spent within the manipulation mode to manipulate the robot arm to the placed target. Distance in inches of the final mark made by the operator from the intended target was noted as well as the number of times the robot hit or crossed one of three aspects of the course: boundary lines, boundary posts (a table), or a simulated improvised explosive device (IED) obstacle.

3.3.5   Mechanical Failures

Due to power-draw issues, the UGV used for the experiment sporadically dropped wireless connectivity. During these failures, time was stopped. Depending on length of failure, the trial either continued or was restarted upon resolution of failure. During one of the Soldier-participants' runs, the robot struck one of the barriers, causing a gear to snap. The motor was switched out for a spare motor. These issues delayed a few experimental runs but were quickly resolved and the trials were restarted as were trial times.

3.3.6   Robot Control's Subjective Measures (Workload and Feedback)

Subjective measures included the NASA TLX and the robot control survey, described in the following sections.

3.3.6.1 NASA TLX

The NASA TLX is a multidimensional rating scale for operators to report their mental workload. It uses six dimensions of workload, shown in Appendix C, to provide diagnostic information about the nature and relative contribution of each dimension in influencing overall operator workload. Operators rate the contribution made by each of six dimensions of workload to identify the intensity of the perceived workload (Hart and Staveland 1988). Unweighted scores for each dimension were used in analyses.

3.3.6.2 Robot Control Survey

Soldier-participants were asked to provide open feedback on the following aspects of the overall system and experiment:

- Ease of training with the two controllers
- Comfort/fit of the glove
- Any problems experienced with the glove
- Control scheme of the gamepad controller
- Any problems experienced with the controller
- Which controller was preferred
- Overall glove controller concept
- Ways to improve the glove system

4. Results

The results section will first present results from the multisensory Soldier Communication task in Section 4.1. Section 4.2 will address results from the use of the instrumented glove for robot control.

4.1 Soldier Communication

This section describes results of multisensory displays of direction and distance. (Experimental procedures are described in Section 3.2.1.) After training, each Soldier participated in all three communication conditions, with each condition providing information on 10 targets. Conditions had been counterbalanced using a William's square design (Williams 1949). Training was efficient and effective; Soldiers had no problem learning the task. Overall mean ratings of training

effectiveness ranged from 5.40 (on a 7-point scale ranging from 1 = extremely ineffective to 7 = extremely effective) for the speech condition to 6.50 for the mixed condition. Overall mean rating for hands-on training was 6.05.

Data were averaged across each target presentation to represent the mean performance for each person, for each condition. Three main variables reflected performance in the Soldier Communication task. Direction indicates the degree to which the direction indicated by the Soldier was correct. Distance indicates the degree to which the distance indicated by the Soldier was correct. Time reflects the time taken for Soldier response.

4.1.1 Direction

In the tactile condition, direction was indicated by a tactile direction cue. The tactile cue was presented in the direction of interest—the Soldier need only turn to that direction and state the letter indicating that direction. In the Speech condition, direction was indicated by a speech cue indicating a direction (north, south, southeast, northwest, etc.). To respond to the speech cue, the Soldier, who always started facing north (a given advantage for this condition), would turn to the spoken direction and indicate the letter representing that direction. In the mixed condition, the direction was indicated by a tactile direction cue.

Errors were measured by the number of directional increments the response was off from the correct answer. A zero was given if the Soldier indicated the direction correctly, 1 if he or she was one increment to the left or right, 2 if two increments to the left or right, and so on. Table 1 provides the mean intensity of mistakes as measured in this fashion, by condition. First, means were calculated for each Soldier, to create the mean of means for each condition. These overall means were analyzed using within-subjects Analysis of Variance (ANOVA). While the mean error was lower in the mixed condition, the difference among the conditions was not statistically significant ($F_{(2, 38)} = 1.035$, $p = 0.365$, $\eta\rho^2 = 0.05$). Given the expectation that performance would be better for the mixed condition and the tactile, compared to speech, an a priori t-test was performed for specific comparisons. While the difference in means was greater for the mixed versus speech condition, it was not significant ($t = 1.17$, $p = 0.25$) due to the high variance in the speech condition. The comparison of mixed versus tactile was significant ($t = 2.03$, $p = 0.05$).

It should be noted that errors in the tactile and mixed conditions were typically one off (error = 1), whereas errors of greater magnitude were made in the speech condition (Fig. 14). This is reflected in the larger standard deviation (SD) for the speech condition—two Soldiers had particular problems with the speech

communication of direction and made errors that had them facing the opposite direction. The practical implication of these results is that the tactile direction cue is particularly helpful for those Soldiers who need it the most.

Table 1   Mean error in direction commands

	Mean error	SD
Tactile	0.11	0.11
Mixed	0.06	0.10
Speech	0.12	0.20

Fig. 14   Mean error in direction by condition

4.1.2 Distance

In the tactile condition, distance was indicated by a rapid succession of tactile cues that had to be counted. In the speech condition, distance was indicated by a speech cue (i.e., voice recording) stating the distance (i.e., 20 m), such that the Soldier need only repeat the information correctly. In the mixed condition, the distance was indicated by the voice recording.

Errors were measured by the number of distance increments that the Soldier-participant was off, defined in multiples of 10 m. A zero was given if the Soldier-participant indicated the direction correctly, 1 if he or she was one off, 2 if two off, and so on. Table 2 provides the mean error by condition. Repeated measures ANOVA was significant ($F_{(2, 38)} = 6.037$, $p = 0.005$, $\eta\rho^2 = 0.24$) for the mixed condition when compared to the tactile condition. Means are displayed in

Fig. 15. It was expected the speech conditions (speech and mixed) would be more accurate than the tactile. A priori comparisons using paired t-tests showed that the mixed condition was significantly more accurate than the tactile (t = 3.34, p = 0.003). It is interesting that significance was not found for the tactile–speech comparison (t = 1.45, p = 0.16). It is possible that, in the mixed condition, workload was easier due to tactile portrayal of direction, allowing the user to pay more attention to the speech description of distance.

Table 2   Mean error in distance by condition

	Mean	SD	Number of participants (N)
Tactile	0.08	0.11	20
Mixed	0.00	0.00	20
Speech	0.04	0.89	20
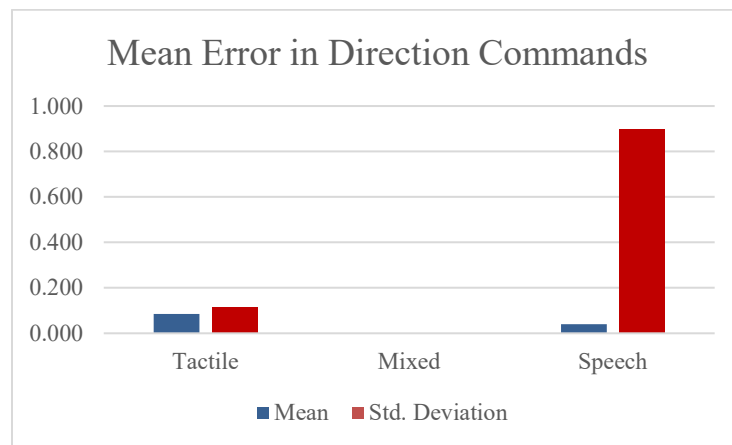
Fig. 15   Mean error and SD in distance by condition

4.1.3 Time

A stopwatch was used to record the number of seconds for the Soldier to respond for each target in each condition. Table 3 shows mean time for each condition, as portrayed in Fig. 16. Total time for the speech condition can be seen to be much higher than the other two conditions. Mean time for the speech condition was much higher. Times were significantly different (F (2, 38) = 183.40, p = 0.00, $\eta\rho^2 = 0.90$). It was expected the mixed condition would be faster. A priori tests using paired-t tests indicate the comparison of mixed with tactile was significant (t = 8.84, p < 0.000) as was the comparison of mixed to the speech condition (t = 16.95, p < 0.00).

Table 3   Mean response time (in seconds) by condition

	Mean	SD	N
Tactile	3.63	0.46	20
Mixed	2.96	0.32	20
Speech	5.19	0.60	20
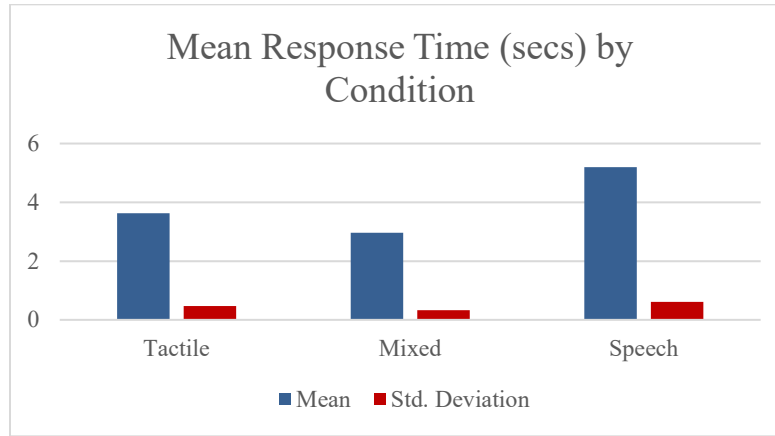
Fig. 16   Mean response time (in seconds) by condition

4.1.4 Soldier Survey

On training, Soldiers rated aspects of it (Table 4) using a 7-point scale ranging from 1 = extremely ineffective to 7 = extremely effective. Mean ratings indicated high levels of satisfaction with training and particularly high ratings of confidence in the mixed system.

Table 4   Soldiers rate training on 7-point scale

Training (N = 20)	Mean	SD
Overall effectiveness of training for tactile belt alone	5.95	0.82
Overall effectiveness of training for audio alone	5.40	1.42
Overall effectiveness of training for tactile and audio together	6.50	0.68
Hands-on training	6.05	0.68
How confident were you for using the tactile belt alone	5.40	0.94
How confident were you for using audio alone	5.30	1.53
How confident were you for using both tactile and audio	6.45	0.89

On comfort, Soldiers used a 7-point scale to rate aspects of the tactile system (Table 5), ranging from 1 = extremely negative to 7 = extremely positive. While ratings were high for comfort, results also indicate the system could be improved with regard to fit and adjustability. Mean ratings regarding ease of perception of tactile cues were moderately high.

Table 5   Soldiers rate equipment comfort using 7-point scale

Comfort / fit (N = 20)		
	Mean	**SD**
Comfort of tactile belt	5.95	0.94
Adjustability of tactile belt	4.30	1.81
Fit of tactile belt	4.80	1.79
Ease of feeling tactors		
	Mean	**SD**
Ease of recognizing direction	5.90	1.12
Ease of recognizing distance	5.45	0.89
Ease of determining the location of the target	5.89	0.87

Soldiers used 7-point Likert scales to indicate degree of agreement with the following statements (Table 6), ranging from 1 = disagree completely to 7 = agree completely. Overall, Soldiers thought the tactile signals were easy to feel, recognize, and understand. They also thought the signals would be beneficial for silent communication in covert operations.

Table 6   Soldiers agree or disagree with statements about tactile system

Disagree—Agree

	Mean	SD
"It was easy to feel each tactile signal in general"	6.25	0.85
"The tactile signal should be stronger"	5.10	1.38
"The tactile signal was annoying"	1.35	0.81
"The tactile signal felt ticklish"	1.65	1.39
"It was easy to understand what each signal meant"	5.30	1.66
"I recognized each signal immediately"	5.30	1.59
"The tactile cues are a good means of silent communication"	6.50	0.69
"The tactile cues are too noisy for regular patrols"	2.50	1.39
"The tactile cues are too noisy for covert missions"	2.94	1.99
"The tactile cues are a good substitute when radios cannot be used"	6.05	1.05
"The tactile cues help keep my attention on my surroundings"	5.40	1.39
"The tactile cues are a useful way for Soldiers to communicate"	5.90	0.96
The tactile system should warn me with a tactile signal before I receive a communication	6.00	0.85
The tactile system should repeat the message until I have acknowledged that I have received it	4.05	2.06
The tactile system should repeat a message upon command	5.60	1.79
The tactile system should be used for critical information that represents imminent danger	5.50	1.36
The tactile system should convey a sense of urgency of the communication	5.15	1.49

Soldiers used a 7-point scale to rate ease of hearing via the audio system (Table 7). Results indicate high levels for ease of perception and understanding of the audio and somewhat lower level of interpreting the correct location from the audio communications.

Table 7   Soldiers rate ease of hearing via audio system using 7-point system

Ease of hearing

	Mean	SD
I was able to hear all the communications	6.25	1.07
I could easily recognize the direction spoken	6.15	0.98
I could easily recognize the distance spoken	6.25	1.02
The volume was too low	3.10	1.89
The volume was too high	1.90	1.29
Ease of knowing the location of the target	5.00	1.30

Soldiers rated the overall effectiveness of the mixed condition higher than both the all-tactile and the all-speech conditions as shown in Table 8. Additionally, the Soldiers rated the overall ease of use high in the mixed condition as opposed to both the all-tactile and all-speech conditions. Paired comparison t-tests indicated the tactile and mixed conditions were rated significantly higher than the speech for effectiveness and the mixed condition was significantly higher than speech or tactile for ease of use.

Table 8   Mean ratings for Soldier survey

	Mean	SD	t (sign) Tactile	t (sign) Speech	t (sign) Mixed
Tactile effectiveness overall	5.85	1.04	…	3.44 (0.003)	0.44 (0.66)
Speech effectiveness overall	4.7	1.63	…	…	2.93 (0.009)
Mixed effectiveness overall	6.05	1.61	…	…	…
Tactile ease of use	5.55	1.05	…	…	2.16 (0.044)
Speech ease of use	5.00	1.59	…	1.37 (0.19)	3.27 (0.004)
Mixed ease of use	6.3	1.03	…	…	…

4.2 Robot Control

4.2.1 Drive Time

Drive time is the amount of time the operator spent driving the platform. Drive times for the Xbox and glove-control conditions are indicated in Table 9. A paired-comparison t-test indicates the glove condition was associated with higher time to

drive (t (18 = 2.368, p = 0.029). Figure 17 shows overall mean drive time in seconds.

Table 9   **Mean drive time (in seconds) for robot control**

	Mean	N	SD	Standard error—mean
Xbox	76.68	19	29.64	6.8
Glove	96.68	19	39.59	9.084
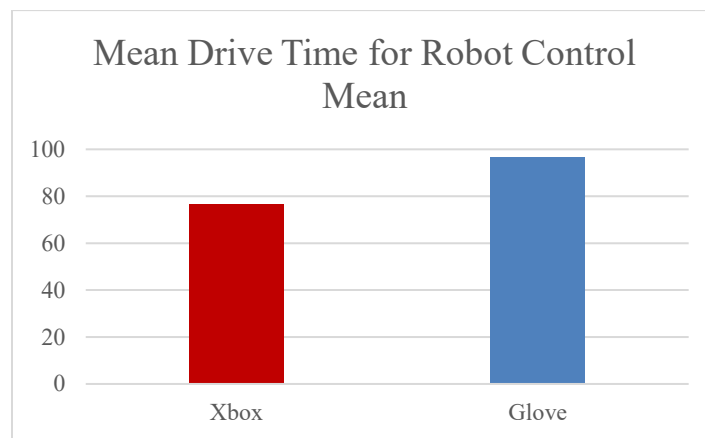
Fig. 17   **Soldier-participants' overall mean drive time in seconds**

4.2.2 Touch Time

Touch time is the time, in seconds, it took to manipulate the robotic arm. Table 10 shows results from a paired-comparison t-test, indicating the glove was associated with significantly lower touch time (t (18) = 2.048, p = 0.05). Figure 18 shows the mean touch time in seconds or the average amount of time spent manipulating the robotic arm.

Table 10   **Mean touch time in seconds**

	Mean	N	SD	Standard error—mean
Xbox	55	19	23.83	5.47
Glove	41.26	19	20.66	4.74
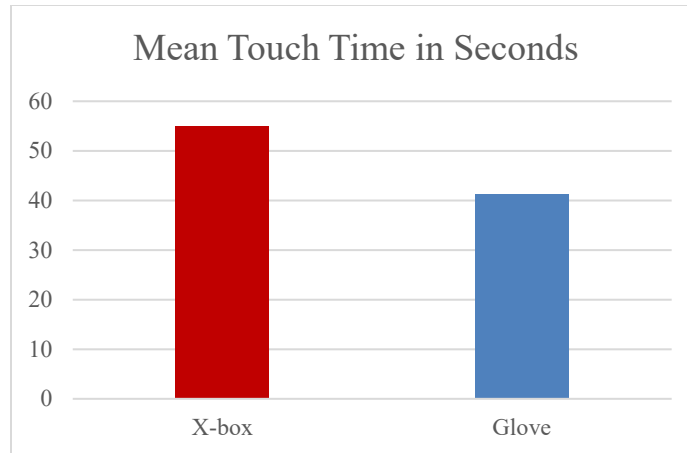
Fig. 18   Mean seconds spent manipulating robotic arm

4.2.3 Touch Error

Touch error is the measurement, in inches, the mark of the pen was from the center of the target. Table 11 shows paired-comparison t-test of this difference, indicating that the glove controller was associated with significantly larger error (t (18) = 2.843, p = 0.01). Figure 19 shows the mean distance in inches that the mark was from center of target.

Table 11   Mean distance of touch error

	Mean	N	S D	Standard error—mean
Xbox	1.35	19	0.99	0.23
Glove	2.50	19	1.57	0.36
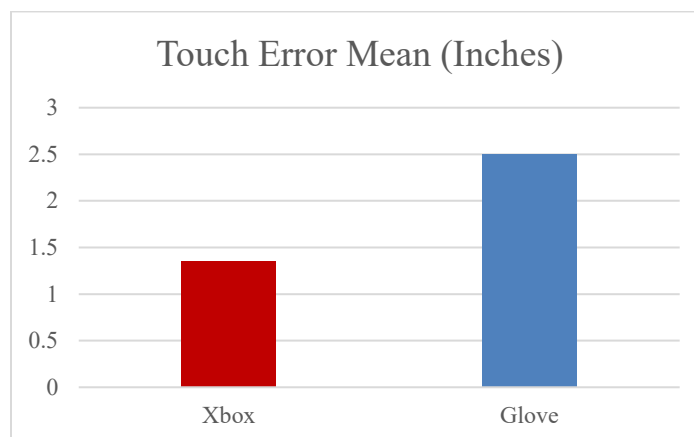
Fig. 19   Mean error (in inches) from center of target

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4.2.4 Line Error

A line error is whenever the robotic platform crossed a line. Table 12 shows the paired-comparison t-test of this difference was not significant (t (18) = 0.547, p = 0.59).

Table 12   Mean line error

	Mean	N	SD	Standard error—mean
Xbox	0.37	19	0.96	0.22
Glove	0.21	19	0.71	0.16

4.2.5 Table Error

A table error is whenever the robotic platform hit a table obstacle. Table 13 shows the paired-comparison t-test of this difference was not significant (t = 0.50, df = 18, p = 0.63).

Table 13   Mean table error

	Mean	N	SD	Standard error—mean
Xbox	1.68	19	1.38	0.32
Glove	1.53	19	1.12	0.26

4.2.6 IED Errors

An IED error is whenever the robotic platform hit a notional IED obstacle. Table 14 shows the paired-comparison t-test of this difference was not significant (t = 0.96, df = 18, p = 0.35).

Table 14   Mean IED error

	Mean	N	SD	Standard error—mean
Xbox	1.42	19	0.9	0.21
Glove	1.68	19	1.06	0.24

4.2.7 TLX

The NASA TLX was used to determine workload. Table 15 shows the workload means. There was no significant difference except in perception of performance, which was higher with the Xbox controller.

Table 15   NASA TLX workload means

Workload categories by condition						
	Mean	N	SD	Standard error—mean	t	Significance
Glove mental	6.02	18	2.76	0.65	…	…
Xbox mental	5.36	18	2.88	0.67	1.59	0.129
Glove physical	2.94	18	2.41	0.57	…	…
Xbox physical	2.02	18	2.48	0.58	1.42	0.171
Glove temporal	4.38	18	2.48	0.58	…	…
Xbox temporal	4.22	18	2.76	0.65	0.30	0.764
Glove performance	4.44	18	2.65	0.62	…	…
Xbox performance	6.58	18	2.23	0.52	–3.65	0.002[a]
Glove effort	5.72	18	2.6	0.62	…	…
Xbox effort	4.55	18	2.77	0.65	1.54	0.14
Glove frustration	3.86	18	2.80	0.66	…	…
Xbox frustration	3.44	18	2.56	0.60	0.79	0.439

[a] Indicates $p < 0.05$

4.2.8 Soldier Survey

After completion of the robotic control task, Soldier-participants were asked to provide feedback of the training, glove, gamepad controller, system preference, and glove controller as a concept and suggestions to improve the system. Overall, the gamepad controller had greater positive feedback, mostly due to Soldiers' familiarity with the system in commercial applications (i.e., home video-gaming). However, the glove was viewed as an intuitive interface for maneuver, but less for arm manipulation. Negative feedback relating to either system corresponded mostly to how the controller (glove or gamepad) was implemented with the robot. When asked which system Soldier-participants preferred, nine responded that they prefer the gamepad controller, mainly due to their familiarity with the system. Of the remaining nine Soldier-participants whose responses were recorded, eight preferred

the glove and reported it as easier to use and quicker to learn. One participant responded that they did not have a preference of system. Other comments on the overall system included ones regarding the camera for feedback.

4.2.8.1   Training

As shown in Table 16, the Soldier-participants rated the Xbox training higher than the glove training for both verbal training and hands on. Additionally, the Soldier-participants felt more prepared with the Xbox training than with the glove and they felt as though the Xbox was easier to learn than the glove.

Table 16   Training means

Training	Mean
Glove training	5.00
Xbox training	5.58
Glove hands on	5.42
Xbox hands on	5.74
Prepared glove	4.32
Prepared Xbox	5.37
Easy-to-learn glove	5.05
Easy-to-learn Xbox	5.74

4.2.8.2   Glove Fit and Comfort

Soldier-participants rated the comfort and fit of the glove about average as seen in Table 17. This is likely because not all sizes were available for the study.

Table 17   Glove's fit and comfort means

	Mean
Glove comfort	5.53
Glove fit	4.84

4.2.8.3   Survey Ratings

Soldier-participants rated the control of the robot between 4 and 7 on a 7-point semantic differential scale as shown in Table 18. Soldier-participants rated the Xbox gamepad higher than the glove for every ease of use question. Nine Soldier-participants listed that they preferred using the gamepad to control the robot as

opposed to eight Soldier-participants who said they preferred using the glove to control the robot.

Table 18   Robot control means

Ease of Use	Control	Mean
Start robot moving	Glove	5.58
Move robot straight	Glove	5
Stop robot	Glove	5.32
Adjust robot left or right	Glove	4.32
General control of robot	Glove	4.95
Buttons' ease of use	Xbox	6.16
General ease of use	Xbox	5.79
Start robot moving	Xbox	6.158
Move robot straight	Xbox	5.105
Stop robot	Xbox	6.158
Adjust robot left or right	Xbox	4.947
General control of robot	Xbox	5.105
Adjust the speed of robot	Xbox	5.053

5.   Discussion and Conclusions

5.1 Soldier Communication

The purpose of this study was to identify the best options for communicating spatial information to an operator. In this study, we compared three methods of communication of direction and distance: 1) tactile—both direction and distance through a tactile display, 2) mixed—tactile for direction and speech for distance, and 3) speech—both direction and distance through speech communications. Twenty Soldiers participated in the three communication conditions, with each condition providing information on 10 targets. Performance measures included response time and accuracy of direction and distance.

Results were consistent with exceptions. The mixed condition (tactile for direction and speech for distance) was more effective and preferred, compared to the all-tactile or all-speech communication conditions. For direction, the mean error for the mixed condition was lower (0.065) than for tactile (0.115) or speech (0.125) conditions. The difference between mixed and tactile was statistically significant. While the difference in means was greater between mixed and speech, that

difference was not significant due to a larger variance in performance accuracy in the speech condition. A few Soldiers had many errors in the speech condition—even with the added advantage of starting in the north direction—that were ameliorated in the mixed condition. Thus, the use of the tactile cues for direction was most helpful for the Soldiers having the most problem interpreting the speech–direction cues. The practical implication of these results is that the tactile direction cue is particularly helpful for those Soldiers who need it the most.

For communication of distance, the mixed condition was associated with no error (mean = 0.00) compared with the tactile condition (mean = 0.085) or the speech condition (mean = 0.045). The difference between the mixed condition and the tactile was significant, while the difference between the speech condition and the tactile was not. This is interesting as it was expected the speech communication of distance would be more easily understood than counting the tactile "beats", thus expecting both speech and mixed conditions to be associated with higher accuracy than the tactile. This suggests a "bonus" effect of the mixed condition, in that the advantage of the speech communication of distance is enhanced when there is tactile communication of direction (i.e., the mixed condition). It is possible that, in the mixed condition, workload was easier due to tactile portrayal of direction, allowing the user to pay more attention to the speech description of distance.

Regarding overall time to respond to communications of direction and distance, the mixed condition was significantly faster than either the tactile or the speech condition. This was expected. Thus, overall results indicate distinct and significant advantages to using the tactile modality for communication of direction when accompanied by speech communication of distance. Several Soldiers commented on this combination as their preferred choice as demonstrated by remarks made during the study as well as comments captured on the survey (Appendix H). "I really liked the direction by tactile and distance by smartphone. It was the most 'dummy proof method'," said one Soldier-participant. "I felt like with this method, most of the work was done for me. I naturally reacted to the vibration and then the distance was just read to me. Simpler seems to be better in a chaotic situation such as reacting to contact."

This illustrated the advantage of multisensory presentation of information. Utilizing the tactile modality to augment the already overloaded traditional modalities is key, particularly for the communication of direction. Torso-mounted tactile displays provide an intuitive means of conveying direction that is immediately and easily understood. Recent systems that integrate torso-mounted tactile displays have allowed Soldiers to more quickly understand, communicate, and respond to

battlefield dynamics. Given these technological developments, further research and guidelines are needed to optimize the use of these multimodal options.

5.2 Robot Control

Given that the glove condition showed faster completion times for the touch time than for the drive time, we can conclude the glove is better suited for faster completion of manipulation tasks. However, the accuracy for the task was lower in the glove condition. Since the gamepad-style controllers are a common consumer product, additional user training with the glove controller may increase the glove-controller performance compared to the gamepad for chassis control and/or manipulator arm accuracy. Additionally, alternate control mappings of glove-sensor input to robot-motor activation may show higher performance. The index-finger mapping was selected as the most intuitive; however, other approaches might be more effective for manipulation speed and accuracy.

The results of the drive time by controller type show similar distributions—with the exception of two outlier data points for the glove-control condition that, if eliminated, would significantly reduce the difference between the mean values of the Xbox and glove controller. Depending on the task, speed may take priority over accuracy or vice-versa. For example, during a building reconnaissance, deployment of a camera payload that is mounted to a manipulator arm may require speed over accuracy due to the nature of the mission in progress.

Soldier feedback on the instrumented glove (Appendix I) was of most interest in this preliminary evaluation. Some issues were anticipated due to having a single glove size. Additional feedback from the Soldiers with regard to glove–robot–camera integration will aid in further refinement of the glove as a viable option in operational settings.

Because the glove technology integrates into existing combat attire, the glove-control solution provides an overall weight reduction to the Soldier's combat load as it eliminates the need for a dedicated controller. Current ruggedized operator control units are bulky and add extra weight to the Soldier's load. The sensors in the glove controller add approximately 70 g of weight, in comparison with about 205 g for an Xbox controller. Additionally, unlike holding a game controller, the Soldier using the glove controller can quickly and easily transition from robot control to individual rifle deployment, thus maintaining a higher level of defensive posture.

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Appendix A. Informed Consent

Informed Consent

Principal Investigator: Gina Hartnett Version Date: 29 Jun 2016 Project Number: ARL 16-064

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Site of Research: ARL-HRED IMT Course, Fort Benning GA
RESEARCH PARTICIPANT CONSENT FORM
ARMY RESEARCH LABORATORY
Project Title: Communication-based Operational Multi-Modal Automated Navigation Device (COMMAND) Soldier-Robot Team
Sponsor: Department of Defense
Principal Investigators: Gina A. Hartnett, ARL-HRED, Air and C2 Systems Branch (AC2SB), Fort Rucker AL, 334-255-2135, Regina.A.Hartnett.Civ@mail.mil
Associate Investigators: Linda R. Elliott, ARL-HRED Soldier and Small Unit Branch, Fort Benning GA, 706-545-9145, Linda.R.Elliott@us.army.mil
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Anna.Skinner@atinc.com
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Rodger Pettitt, ARL-HRED Soldier and Small Unit Branch, Fort Benning GA, 706-545-9145, Rodger.A.Pettitt.civ@mail.mil
Lisa Baraniecki, AnthroTronix, Inc., 301-495-0770 x116
Lisa.Baraniecki@atinc.com
Location of Study: Fort Benning, GA
Time Required to Complete Study: 1 week
Time Period of Data Collection: 1 week
Date: 1 July 2016
You are being asked to join a research study. This consent form explains the research study and your part in it. Please read this form carefully before you decide to take part. You can take as much time as you need. Please ask questions at any time about anything you do not understand. You are a volunteer. If you join the study, you can change your mind later. You can decide not to take part right now or you can quit at any time later on. Principal Investigator: Gina Hartnett Version Date: 29 Jun 2016 Project Number: ARL 16-064

ARMY RESEARCH LABORATORY IRB *Approved 1 July 2016*

Why is this research being done?

The purpose of this user evaluation is to introduce new technology that uses vibration-based signals for Soldier communication and orientation. You will be introduced to equipment concepts and capabilities, trained on operation, and requested to interact with the system. Afterward, you will be asked for your opinions with regard to operational relevance and user requirements. You will be asked to review the system, participate in experiment sessions where you may use an instrumented glove, experience tactile pattern sensations similar to cell phone vibrations from a belt, and use a GPS-enabled handheld computer. You will then provide feedback on the system components.

What will happen if you join this study?

Prior to beginning the study, you will fill out a demographics questionnaire that asks for information about your work experience. You will be briefed on the purpose and procedures of the study. During the demonstration of the equipment, you will be asked to don a belt containing two rows of 8 tactors each that, when activated, will provide vibrations like those emitted from a cell phone. You will also be asked to wear a glove with embedded sensors to record your hand movements and gestures; this glove will be used to drive a robot. You will also be asked to use a GPS-enabled handheld computer for communication and navigation tasks. During the robotic control task, you will be asked to wear an electroencephalography (EEG) cap which will passively collect brain wave data while you are performing the task. After interacting with the system, you will be asked to complete a questionnaire and participate in discussion of the equipment.

How much time will the study take?

Your participation will take up to 8 hours.

What are the risks or discomforts of the study?

The risks associated with this experiment are considered minimal. The risks that will be encountered during this investigation are typical of the risks encountered when training and performing indoor duties in non-combat routines. You may be requested to walk outdoors in a parking lot and open field environment. There is a risk of tick bites and the potential for Lyme disease. You should inspect yourself frequently for ticks. Flying insects at the site are also a concern. You are encouraged to use insect repellent, which is available on site. Please notify the principal investigator if you are bitten so that closer visual monitoring can occur. Please inform investigators if you experience any discomfort or problems during the investigation such as lightheadedness, nausea, fever, swelling or pain. In the unlikely event of an injury, a range radio or cell phone will be used to call the '911' on-post emergency medical personnel.

Are there benefits to being in the study?

There are no personal benefits for you for taking part in this study. However, your participation will provide valuable information about Soldier performance that will

assist in the design of future Army systems. Principal Investigator: Gina Hartnett
Version Date: 29 Jun 2016 Project Number: ARL 16-064
ARL ICF Template 10 Mar 15 Page 3 of 4
ARMY RESEARCH LABORATORY IRB *Approved 1 July 2016*
Will you be paid if you join this study?
You will receive no payment for taking part in this study.
Can you leave the study early?
If you decide not to participate, or wish to withdraw during the study, you can convey your choice privately to one of the researchers. Your withdrawing will not be passed on to anyone outside the research staff, including anyone in your chain of command and the researcher will say that you did not meet experimental criteria. However, since you are taking part in this study as part of a group, it might not be possible to hide the details of your withdrawal from the other participants, and because of this your confidentiality cannot be completely protected.
How will your privacy be protected?
Your participation in this research is confidential. You will be assigned a participant number to ensure anonymity. The data will be stored on a secure server and secured in a password protected file. In the event of a publication or presentation resulting from the research, no personally identifiable information will be shared, unless you give permission below in the section requesting consent for us to photograph you. After transfer of the data to a computer file, the paper copies of the data will be shredded. This consent form will be retained by the principal investigator for a minimum of three years.
The research staff will protect your data from disclosure to people not connected with the study. However, complete confidentiality cannot be guaranteed because officials of the U. S. Army Human Research Protections Office and the Army Research Laboratory's Institutional Review Board are permitted by law to inspect the records obtained in this study to insure compliance with laws and regulations covering experiments using human subjects.
We would like your permission to take pictures and/or video during the experimental session. The pictures and/or video may be used in publications and presentations. Although we may photograph or video your activities during the experiment, we will blur your face and any other identifying information to protect your identity. Please indicate below if you will agree to allow us to photograph and/or video you. You can still be in the study if you prefer not to be recorded.
I give consent to be photographed and/or videoed during this study: ___Yes ___No please initial:____
Where can I get more information?
You have the right to obtain answers to any questions you might have about this research both while you take part in the study and after you leave the research site. Please contact anyone listed at the top of the first page of this consent form for more information about this study. You may also contact the Human Protection Administrator (HPA) of the Army Research Laboratory Institutional Review Board, at (410) 278-5928 with questions, complaints, or concerns about this research, or if you feel this study has harmed you. The HPA can also answer questions about your rights as a research participant. You may also call the HPA if

you cannot reach the research team or wish to talk to someone who is not a member of the research team. Principal Investigator: Gina Hartnett Version Date: 29 Jun 2016 Project Number: ARL 16-064
ARL ICF Template 10 Mar 15 Page 4 of 4

ARMY RESEARCH LABORATORY IRB *Approved 1 July 2016*

Voluntary Participation

Your decision to be in this research is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawal from this study will involve no penalty or loss of benefits you would receive by staying in it.

Military personnel cannot be punished under the Uniform Code of Military Justice for choosing not to take part in or withdrawing from this study, and cannot receive administrative sanctions for choosing not to participate.

Once your questions about the study have been answered, and if you want to continue your participation in this study, please sign below.

WE WILL GIVE YOU A COPY OF THIS CONSENT FORM

Signature of Participant Printed Name Date

Signature of Person Obtaining Consent Printed Name Date

Appendix B. Demographics Questionnaire

Demographics Questionnaire

Date: _____Participant ID (ROSTER): _____

1. General Information

   a. Age (yrs): _____   b. Gender: M   F   c. Handedness: L   R

   d. Glove Size _____   e. Uniform Size _____

   f. Do you have any of the following (Circle all that applies):

   Astigmatism   Near-sightedness   Far-sightedness

   Other (explain):_____

   _____

   g. Do you have corrected vision (Circle one)?   None   Glasses
       Contact Lenses

      If so, do they correct for items listed in e. above (Circle one):   Yes   No

   h. Do you currently have any skin sensitivities on your torso (chest, waist) that might be irritated by
       wearing a tactile belt (for example, poison ivy, insect bites, rash, etc.)?

   _____

   _____

   i.   On a scale from 1 to 5, how ticklish are you? (chest/waist area)

1 = Not at all_____2_____3_____4_____5 = Very ticklish

2. Military Experience

a. How many years have you been in the military? _____ Current rank _____

b. What is your MOS? _____

c. Please list all combat deployments (Iraq, Afghanistan, etc.) and the length (Years / Months) of each.

Location   Time

_____   _____

_____   _____

_____   _____

_____   _____

_____   _____

_____   _____

d. Do you have operational experience in complex urban terrain? ___Yes ___No

If yes, where _____

e. Do you have any experience with scanning tasks (e.g., searching for targets)? ____Yes ___No

      If yes, please explain   (dismounted infantry) (mounted-vehicle)

_____

_____

_____

f. Have you ever conducted security patrols in complex urban terrain? ___Yes ___No

      If yes, where

_____

_____

g. Have you ever used camera systems to conduct local security? ___Yes ___No

      If yes, which systems

_____

_____

h. Have you any experience with military robots? If so, what type and purpose?

Type   Purpose

_____   _____

_____   _____

3. Educational Data

a. What is your highest level of education received? Select one.

      ____ GED

      ____ High School

      ____ Some College

_____ Bachelor's Degree

_____ M.S/M.A

_____ Ph.D.

Other: _____

4. Computer Experience

a. How long have you been using a computer?

__Less than 1 year ___ 1-3 years ___4-6 years ___7-10 years ___10 years or more

b. How often do you use a computer?

___Daily: over 2hrs/day   1-2hrs   less than 1 hr/day

___Weekly   ___Monthly ___Once or twice a year

c. Where do you currently use a computer? (*Circle all that apply*)

Home   Work   Library   Other_____
Do Not Use

d. How often do you play computer/video games? (Circle one)

___Daily: over 2hrs/day   1-2hrs   less than 1 hr/day

___Weekly   ___Monthly ___Once or twice a year

e. Which type(s) of computer/video games do you most often play?

_____

f. How familiar are you with typical gamepad video game controllers (i.e. Xbox 360)

___Not at all familiar   ___Slightly familiar   ___Moderately familiar

___Very familiar   __Extremely familiar

Appendix C. NASA Task Load Index (TLX) Rating Scale

NASA TLX   Definition of Task Demand Factor

Mental demand

How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Physical demand

How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Temporal demand

How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Performance

How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Frustration level

How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Effort

How hard did you have to work (mentally and physically) to accomplish your level of performance?

NASA-TLX Mental Workload Rating Scale

Please place an "X" along each scale at the point that best indicates your experience with the robot controller you just used.

Mental Demand: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low |___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___| High

Physical Demand: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low |___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___| High

Temporal Demand: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low |___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___| High

Performance: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low |___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___| High

Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low |___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___| High

Frustration: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low |___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___| High

Appendix D. Robot Control Survey

_____

This appendix appears in its original form, without editorial change.

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Roster number _____ **Date:** _____

Robotic Control Task Survey

You just used two systems to maneuver a small robot: (1) Glove and (2) Gamepad. The following questions are to get your feedback on each system.

Training of both systems

1	2	3	4	5	6	7
Extremely negative	Very negative	Negative	Neutral	Positive	Very positive	Extremely positive

Training							
Overall effectiveness of training for glove	1	2	3	4	5	6	7
Overall effectiveness of training for gamepad							
Hands-on training for the glove							
Hands-on training for the gamepad	1	2	3	4	5	6	7
How prepared did you feel for using the glove	1	2	3	4	5	6	7
How prepared did you feel for using the gamepad	1	2	3	4	5	6	7
How easy was it to learn to use the glove	1	2	3	4	5	6	7
How easy was it to learn to use the gamepad	1	2	3	4	5	6	7

Comments

_____
_____
_____
_____
_____

Glove

1	2	3	4	5	6	7
Extremely negative	Very negative	Negative	Neutral	Positive	Very positive	Extremely positive

Comfort / Fit							
Comfort of Glove	1	2	3	4	5	6	7
Fit of Glove	1	2	3	4	5	6	7

If the glove did not fit, was it (please circle)
    Too tight   Too loose

Comments

_____
_____
_____
_____

Ease of use: How easy was it to use the glove to:							
Start the robot moving	1	2	3	4	5	6	7
Move the robot straight	1	2	3	4	5	6	7
Turn the robot left or right	1	2	3	4	5	6	7
Stop the robot	1	2	3	4	5	6	7
Adjusting the speed of the robot	1	2	3	4	5	6	7
Generally control the robot	1	2	3	4	5	6	7

Were there any problems using the glove (e.g, time delays, wrong response, etc.)

_____
_____

Gamepad Controller

1	2	3	4	5	6	7
Extremely negative	Very negative	Negative	Neutral	Positive	Very positive	Extremely positive

Design							
Ease of use of buttons (within reach, etc)	1	2	3	4	5	6	7
General ease of use	1	2	3	4	5	6	7

Comments

_____
_____
_____

Ease of use: How easy was it to use the gamepad to:							
Start the robot moving	1	2	3	4	5	6	7
Move the robot straight	1	2	3	4	5	6	7
Turn the robot left or right	1	2	3	4	5	6	7
Stop the robot	1	2	3	4	5	6	7
Adjusting the speed of the robot	1	2	3	4	5	6	7
Generally control the robot	1	2	3	4	5	6	7

Were there any problems using the gamepad (e.g, time delays, wrong response, etc.)

_____
_____
_____
_____
_____

Which system did you prefer to use? Why?

_____
_____
_____

GLOVE CONTROLLER CONCEPT

The following questions have to do with the overall concept of the GLOVE system. Using the scale below, please provide feedback with regard to the <u>POTENTIAL</u> usefulness of this capability, **assuming the system was developed to be combat-ready (reliable, rugged, lightweight, etc.)**

a. In your opinion, how likely is this technology to be useful for Army operations

1	2	3	4	5	6	7
Extremely unlikely	Very unlikely	Unlikely	Neutral	Likely	Very likely	Extremely likely

b. If unlikely to be useful—why?   If likely to be useful, what situations first come to mind?

_____
_____
_____

c. How would you improve the system?

_____
_____
_____

Appendix E. Soldier Communication Task Survey

Soldier Communication Task Survey

Roster number_____
Date_____

For this task you received direction and distance information three ways
1. Direction and distance through tactile belt
2. Direction by tactile and distance through speech (smartphone)
3. Direct and distance through smartphone

The following questions pertain to each condition

System Training

1	2	3	4	5	6	7
Extremely negative	Very negative	Negative	Neutral	Positive	Very positive	Extremely positive

Training							
Overall effectiveness of training for tactile belt	1	2	3	4	5	6	7
Hands-on training	1	2	3	4	5	6	7
How prepared did you feel for using the glove	1	2	3	4	5	6	7
How prepared did you feel for using the tactile belt	1	2	3	4	5	6	7
How prepared did you feel for using the smartphone	1	2	3	4	5	6	7
How easy was it to use the glove	1	2	3	4	5	6	7
How easy was it to use the tactile belt alone	1	2	3	4	5	6	7
How easy was it to use the tactile belt/smartphone	1	2	3	4	5	6	7

Comments

_____
_____
_____
_____

Tactile belt

1	2	3	4	5	6	7
Extremely negative	Very negative	Negative	Neutral	Positive	Very positive	Extremely positive

Comfort / Fit							
Comfort of tactile belt	1	2	3	4	5	6	7
Adjustability of tactile belt	1	2	3	4	5	6	7
Fit of tactile belt	1	2	3	4	5	6	7

Comments:

_____

_____

Ease of feeling tactors							
Ease of recognizing Direction	1	2	3	4	5	6	7
Ease of recognizing Distance	1	2	3	4	5	6	7

Comments:

_____

_____

_____

1	2	3	4	5	6	7
Disagree Completely			Neutral			Agree completely

DISAGREE - AGREE							
"It was easy to feel each tactile signal in general"	1	2	3	4	5	6	7
"The tactile signal should be stronger"	1	2	3	4	5	6	7
"The tactile signal was annoying"	1	2	3	4	5	6	7
"The tactile signal felt ticklish"	1	2	3	4	5	6	7
"It was easy to understand what each signal meant"	1	2	3	4	5	6	7
"I was very certain what each signal meant"	1	2	3	4	5	6	7
"I recognized each signal immediately"	1	2	3	4	5	6	7
"The tactile cues are a good means of silent communication"	1	2	3	4	5	6	7
"The tactile cues are too noisy for regular patrols"	1	2	3	4	5	6	7
"The tactile cues are too noisy for covert missions"	1	2	3	4	5	6	7
"The tactile cues are a good substitute when radios cannot be used"	1	2	3	4	5	6	7
"The tactile cues help keep my attention on my surroundings"	1	2	3	4	5	6	7
"The tactile cues are a useful way for Soldiers to communicate"	1	2	3	4	5	6	7
The tactile system should warn me with a tactile signal before I receive a communication	1	2	3	4	5	6	7
The tactile system should repeat the message until I have acknowledged that I have received it	1	2	3	4	5	6	7
The tactile system should repeat a message upon command	1	2	3	4	5	6	7
The tactile system should be used for critical information that represents imminent danger	1	2	3	4	5	6	7
The tactile system should convey a sense of urgency of the communication	1	2	3	4	5	6	7
The tactile system should convey a sense of priority of the communication	1	2	3	4	5	6	7

Mobile Device for Speech

1	2	3	4	5	6	7
Extremely negative	Very negative	Negative	Neutral	Positive	Very positive	Extremely positive

Ease of Hearing							
I was able to hear all the communications	1	2	3	4	5	6	7
I could easily recognize the direction spoken	1	2	3	4	5	6	7
I could easily recognize the distance spoken	1	2	3	4	5	6	7
The volume was too low	1	2	3	4	5	6	7
The volume was too high							

Comments:

_____

_____

Glove

1	2	3	4	5	6	7
Extremely negative	Very negative	Negative	Neutral	Positive	Very positive	Extremely positive

Comfort / Fit							
Comfort of Glove	1	2	3	4	5	6	7
Ease of using Glove to send signals	1	2	3	4	5	6	7
Fit of Glove	1	2	3	4	5	6	7

Comments:

_____

_____

_____

_____

Please rate effectiveness and ease of use of each approach

1	2	3	4	5	6	7
Extremely negative	Very negative	Negative	Neutral	Positive	Very positive	Extremely positive

Overall effectiveness							
Distance and direction by tactile belt	1	2	3	4	5	6	7
Distance and direction by smartphone	1	2	3	4	5	6	7
Distance by smartphone and direction by tactile belt	1	2	3	4	5	6	7

Overall ease of use							
Distance and direction by tactile belt	1	2	3	4	5	6	7
Distance and direction by smartphone	1	2	3	4	5	6	7
Distance by smartphone and direction by tactile belt	1	2	3	4	5	6	7

Did you have any problems with any of the systems?

Which system did you prefer? Why? What was good about it?

_____

_____

_____

How could the system(s) be improved?

_____

_____

_____

Appendix F. Medical Status Form

This appendix appears in its original form, without editorial change.

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Medical Status Form

Experiment participant: Please answer all questions honestly and completely. It will not be entered into your official health records and will be treated confidentially.

Roster Number: _____ Date: _____

1. Do you have any physical injury at the present time?

Yes _____ No _____

If   yes,   please
describe._____

2. Have you had any surgery in the last two months?

Yes _____ No _____

If   yes,   please
describe._____

3. Are you presently on a profile of any type?   Yes _____ No _____

If   yes,   please   describe   your   current   limitations.
_____

4. If the APFT (Army Physical Fitness Test) were held today, could you obtain a passing score on it?   Yes _____ No _____

6. Have you had any type of eye surgery or eye injury?   Yes _____ No _____

If yes, please describe. _____

Appendix G. Demographics Data

Demographics Data

The following table provides a breakdown of participant characteristics by roster number.

Roster	Age	Gender	Handed	Glove Size	Uniform Size	Years Served	Rank
1	23	M	L	L	L	0.33	E-4
2	24	M	R	.	M	0.33	E-4
3	25	F	R	S	S	0.33	E-4
4	28	F	R	M	S	0.33	E-4
5	28	F	R	M	XS	0.5	E-4
6	30	M	R	S	S	0	E-4
7	27	M	R	M	S	0	E-4
8	23	F	.	M	M	1	OCS
9	29	M	R	L	M	9	SSG
10	24	F	R	S	S	0.33	E-4
11	26	F	R	7	S	0.75	E-4
12	22	M	L	L	L	0.33	E-4
13	26	F	R	S	S	0.33	E-4
14	25	M	R	L	L	1	E-4
15	24	M	R	M	M	0	E-4
16	29	F	R	S	S	1	E-5
17	27	F	.	S	S	1	E-5
18	32	F	R	L	L	1	E-5
19	23	F	R	S	S	0.75	E-4
20	25	M	R	L	M	0	E-4
21	27	F	R	M	M	3	SGT
22	22	M	L	M	M	0.33	E-4
23	31	M	R	M	M	1	E-4
24	25	M	R	M	S	1	OCS

Roster	Glasses*	Contacts*	Ticklish**	Exp w/ RC cars/other
1	0	0	1	2
2	1	0	3	1
3	0	0	2	2
4	0	1	1	2
5	0	1	1	2
6	0	0	2	2
7	0	1	2	4
8	0	0	2	1
9	1	0	2	1
10	0	0	1	2
11	0	0	2.5	1
12	0	0	2	3
13	0	0	1	1
14	0	0	1	3
15	0	1	2	3
16	0	1	1	1
17	1	0	3.5	2
18	0	0	1	1
19	0	0	1	2
20	1	0	1	3
21	1	0	2.5	1
22	0	0	2	3
23	1	0	1	3
24	0	1	1	2

* All using glasses or contacts indicated corrected vision

** Rating scale from 1 = not at all to 5 = very ticklish. No one reported any skin sensitivities in the torso area.

Appendix H. Soldier Communication Task Survey Comments

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The belt felt very comfortable, almost second nature. I could feel the direction I needed to go and didn't need to second guess my cardinal directions.
Comfortable fit – may be warm in the heat
Need to make sure the belt is always centered and doesn't move during maneuvering.
Would need to develop a system to always automatically start counting when it being to vibrate.
System needed to initially be restarted as well as once more when tactile was vibrating in wrong direction.
I like the combination of both because I could feel the direction I need to go without thinking about it and it told me the distance so I didn't have to divert attention to counting.
Make sure there is a way the belt stays in place or marks a way to stay in line with the belt buckle so in real time it doesn't move, thus sending you in the wrong direction.
I though speech and tactile worked best. When it was just speech, I had to concentrate harder and it delayed my reaction and also distracted me in a way because I was concentrating so hard to hear the distance because it came first that it made me mess up on the distance and when I tried to recollect the distance I had forgot or was unsure.
Could have been tighter. I am a slim guy. Couldn't be adjusted.
Unless vibration gets stronger, I wonder if I'd feel it while on a mission with my other gear on.
For test, maybe have the 4 cardinal direction the same letter to create less confusion when needing to face a combined direction (NW/SE).
Tactile and Audio; combined hearing and feeling. Made it easier to process mentally.
Make it a stronger vibration to improve it.
It was somewhat difficult to determine which direction the belt was indicating I should go. I recommend making the vibration pads narrower so that it is easier to distinguish the direction. The only reason I gave a 6 instead of 7 was because the instructors/evaluators did not specify they wanted all feedback after the training was completed.
Belt had very little range of size divisibility.
Volume should be adjustable depending on the covertness of the operation.
Have the tactile direction given by the belt and the distance via audio given at the same time so that commands can be given more quickly (for urgent scenarios).

I thought using audio for the distance and the belt for directions, made it really easy to accomplish the task.
It needs to be able to adjust tighter so it doesn't move around as much.
The distance you had to pay close attention to you would need to be expecting it or the pulses could occur quickly without remembering to count.
They kept having to reset the phone. It forgot to give me the distance one time.
I like the mixed systems the best.
Make the belt where the vibrations are based on the body part and not the location of the belt, that way if the belt moves then it can still be effective.
When using the audio, it tool longer for me to think about which direction.
The belt was much too large on me and couldn't be adjusted.
The vibrations made little room for error with direction.
The audio was not quite loud enough.
It was the same situation. The audio could have been louder.
I preferred the condition with both audio and tactile because they worked quicker and more efficiently.
I like having both audio and tactile so I didn't have to count distance by tactile vibrations.
The belt worked great and the vibrations were strong enough to feel and react to.
The belt would need a more secure or 2nd method of securing the belt in a field environment.
A slightly longer delay would be helpful between vibrations for counting distance.
I preferred both together. Direction was very clear but I could see how counting vibrations for distance could be miss counted and throw you off.
The belt was lose, but after adjustment it fit somewhat better. It was a bit difficult to fully detect direction of the vibration due to it being cinched up from tightening it.
Full concentration was required to remember direction and distance when both were tactile.
The belt was difficult at times to determine exact direction. It required complete focus/multitasking to understand the direction and distance at the same time.
I like the concept of utilizing the tactile belt for direction and distance. It could be improved through repetition in case the signal was not received/understood the first

time. A more quite vibration would be required for complete noise discipline. Overall, it would be a great tool on missions where radio and noise can't be used.
The belt could come in various sizes and repeat commands.
Tactile belt and audio is the best option in my opinion.
Both systems were preferred because it required the least amount of time to react.
Every system has their pros and cons. Tactile is the easiest to use, but I understand the need for tactile in convert operations where silence is a must.
I really liked the direction by tactile and istance by smartphone. It was the most "dummy proof method". I felt like with this method, most of the work was done for me. I naturally reacted to the vibration and then the distance was just read to me. Simpler seems to be better in a chaotic situation such as reacting to contact.
Most of the time the vibration was pretty clear on the direction. I was never off by more than one letter when I was off.
I had no problems hearing the audio portion. However, more time was needed for me to orient myself and remember what I was told.
Tactile for direction and audio for distance was the best method by far. I felt as though my body naturally reacted to the direction portion and that all I had to do was focus on the distance. It was the simplest method and allowed me to orient myself quickly and correctly. In an ambush or react to contact situation, I would prefer this method.
I thought this was very beneficial training and will be beneficial piece of equipment.
Size adjustment for the belt would be an improvement. It fit loose on me, but luckily did not affect feeling of vibration.
The vibration of distance worked in the scenario, but I did not feel as confident vibrations for distance especially as distance increased. I could see this being a potential issue in patrol/combat situations.
Audio for distance was a useful addition to vibration for direction. It made distance easier to recognize rather than relying on vibrations.
I think this has a lot of potential and will make communication between soldier easier; as well as decrease weight load eliminating other equipment.
I like tactile and audio as it was easier to pick up distance rather than focusing on # of vibrations.
Audio for both took me longer to think about rather than just reacting.
When using the audio for direction, I had to think about the direction before I could move.

I liked tactile the best. No question. I could already be looking in the direction, maybe even moving after just 1 buzz. It's silent and all I have to do is react.

Listening to the distance and direction was challenging for me. It reminds me of taking directions while operating a vehicle which I do not prefer.

I preferred tactile for both distance and direction because it processed through my mind faster than listening to a command.

I preferred tactile for both distance and direction. It was quicker to respond to tactile vs waiting for the audio to finish.

Audio only training felt the hardest because you have to process distance and direction from instructions while imagining yourself on a compass so you can turn the correct direction. Audio distance with tactile direction felt easiest/fastest because it was easier to translate direction feedback to body position and not have to count vibrations.

It was a little difficult counting the distance vibrations while turning to the target. I would separate the direction/distance inputs to where the direction was given and then the distance was given through the front only.

It was sometimes difficult translating audio cues to body position. With practice, I don't think it will be a long term issue.

Audio for distance and tactile for direction felt the easiest/fastest.

I preferred audio distance and tactile direction because it was easier and faster to feel the direction and rotate while still listening to the audio cue.

Separate direction and distance input. Give direction first, then distance only through front sensor.

Belt and audio was easier and faster to react to.

I think it worked very well.

I preferred tactile for direction and audio for distance. This seemed to be the easiest and quickest way to get the information. Also you did not have to worry about keeping track of vibrations.

Having a warning sign in the belt to let someone know they are about to get information would be an improvement.

To me, tactile and audio had a quicker or perhaps the quickest response time to determine distance and direction.

Direction and distance could be misinterpreted in high stress situations if both were tactile.

Direction should be given before distance when both are audio.

Tactile and audio was my preference. Audio and tactile cues reinforce the information delivered. Tactile tells you where to turn.
Improvements would be stronger vibrations and have the direction given before the distance.
Combination of the belt and audio required the least amount of thought and least time to react.
Distance by audio and direction by belt was by far the easiest to react to.

Appendix I. Robot-Control-Task Survey Comments

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This appendix appears in its original form, without editorial change.

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Training:
Once you practice a few times with the glove, the controls become much easier.
I think it's assumed most people are familiar with game controls so additional explanation wasn't needed.
Glove was easier than I thought it would be. Only exception was controlling the arm. Didn't feel sure about how I needed to position my finger to get the robot to move in sync.
The glove was intuitive except for the arm functioning.
The Gamepad was a lot more touchy to use.
The gamepad was like second nature, whereas the glove was very sensitive and hard to use.
The gamepad was pretty unfamiliar to me so was awkward to get hang of. I felt better with both devices after a couple of tries.
The glove was easier to control than the gamepad.
The finger function was hard to control (up and down).
Glove:
Comfort/fit
Need left handed one.
The glove fit well, but I do have small hands so a glove with shorter fingers would have worked better.
The fit of the glove was fine, I just preferred the console controller for maximum control and accuracy.
Problems:
It seems to have issues turning the robot and driving it forward at the same time. And adjusting the speed seemed to be a little difficult.
Needed to remember cues for changing direction. Seemed to be a little slow to start.
Make it so that if your hand is flat/level, the arm will not move.
Seemed like arm did not respond properly.

There were slight time delays and it didn't always get my left and right turns immediately
It was tough for me to turn right smoothly. (middle finger down). Left was easy (pointer finger down).
I found the glove very sensitive, making changing direction pretty difficult.
The arm control didn't always respond; when it did, it felt overly sensitive to movement causing quick, jerky movements.
The finder for the arm movement was a little harder to adjust to.
Too sensitive therefore, hard to use.
Gamepad controller:
Design
Very easy to understand and learn. Very familiar to the generation of Soldiers that would be using this technology. Would be easy to train any soldier on this platform.
Took a few times to get the feel of the thumb stick, how hard to hit it when steering. Gamepad easier to control arm with.
The inverted screen adds a level of complexity and is counter intuitive.
The buttons were explained, but could have shown how the joints work on the robot so there was no confusion.
In a video game era, it makes sense to use the controller for operating the robot. For most Soldiers, Xbox is a breeze to operate. Familiarity wins out in this situation.
Problems
Sometimes the robot seemed to jump. Small, detailed maneuvers are a little tricky.
Hard to remember to reverse right and left turn. Controller was a super sensitive and wanted to veer left and right.
Just controlling speed of robot in turning movements and using it in combination with the mirrored screen.
The gamepad made it really hard to control the speed.

The speed control and adjustment (left and right) was jerky and the joystick was touchy. It was difficult to find the right amount of pressure for a smooth response.
The control stick was very sensitive and would move L/R with a slight adjustment.
The only "negative" I have is that it was a little sensitive on direction control. But, I understand sensitivity is also necessary to fit into tight places.
Turning the robot was difficult and felt it "overreacted" to adjustments.
It took longer to make minor directional/speed changes but the arm was easily maneuverable.
Turning was very sensitive. Sometimes this made it difficult to line up.
Disliked inverted left-right turn. In addition, the joystick was very sensitive to slight movements.
System Preference:
Gamepad. Very easy to control. Direction were cut and dry versus the glove. Could be used by anyone who came in contact with it.
Glove. Less over analyzing of how to use the equipment. Essentially a base zero for all volunteers.
Gamepad. I'm more accustom to it from video games. Glove was a little uncomfortable on my wrist and hand having to hold it in the air.
Gamepad. It was much easier for me to use the game pad particularly when it came to articulation the arm tip.
Gamepad
No preference
Glove. It was more correct and accurate to what I wanted it to do.
Glove. The movement was smoother. The robot moved and turned in unison together more effectively.
Gamepad. The gamepad was much easier to use die to lots of gaming experience. Glove was somewhat tough but with lots of practice it can be very smooth and fluid.

Glove. It was easier to control the arm for the target marking. I would just need to practice more to work on turns, speed, etc. It was more accurate than the gamepad.
Gamepad. It was easier to use. Maybe because playing video games before, but it felt normal to use a controller instead of a glove.
Gamepad. The gamepad was so familiar to me as someone who has grown up playing video games. It was much more user-friendly. Plus, I'd imagine gamepads would be cheaper and easier to produce on a large scale.
Glove. The glove felt a little easier to get a hang of.
Glove. I like the direct control the glove offers, even though it was a little harder to use with development, I think it will be more accurate.
Glove. All around easier and quicker.
Gamepad. Gamepad gave me more control and it was less sensitive.
Gamepad. The gamepad seemed to offer more control.
Glove. Movements were smoother, and one could move forward and turn at the same time easier.
Glove Controller Concept:
Likely to be useful
I am not sold on the concept of the glove. It seems to me that in regards to cost effectiveness, this concept may not add up.
If it's used to spy or disable things like explosives, it's useful in that it saves lives, less risk. I still fell humans have a faster response. I wouldn't know what else to us it for.
With time, I could get use to controlling robots with glove! It was nice to be able to control something with just my hand. Required less focus than the game controller.
For people who are not used to using game console controllers, the glove may be an easier option for articulating the robot.
EOD, Recon, Security

As a final product I believe it could be used in EOD situation as well as in item recovery if utilizing a claw arm or for smoke/frag deployment if a throwing/spring arm was used.

It would be very useful during situations that would not be an extensive amount of them mental focus and arm use could decline over a long time, especially as the arm tires from keeping it straight out and in perfect position.

Anything in regards to situations where you don't want to put a Soldier's life at risk. I.e. EOD.

I see no reason why to use the glove over the gamepad, especially with regard to cost, easiness of use, and initial adjustment period.

I'm not sure what systems are in place at this time but it seems there would be more advanced technology already in place.

Quick recon with the robot. I can also see this being used to investigate ordinance.

Improve the System

The glove needs to be designed in such a way that the controls are more deliberate. There is a lot of "dead space" in the controls as it stands.

Find a way to make the volunteer situationally aware of how much space is needed to avoid obstacles. The arm is difficult but maybe with more practice.

The index finger system when controlling the arm of the robot didn't seem in sync, but it could have just been me.

Give some vertical control of the camera. It was difficult to tell if the arm was in danger of hitting overhanging obstacles (i.e., the bottom or edge of tables). This is in regard to the robot system in general (not just the glove testing).

Make the fingers correlate to the direction.

Arm functioning seemed to sensitive and was not responding intuitively.

Make switching from movement to arm control easier/more effective. Or have arm control or a different finger than direction control.

A quitter track may help if being used indoors in a more covert or tactical environment. Camera should be more secure. It slipped too much. An adjustable camera may be useful as well.

The glove would hand to fit each user's hand so that proper execution could happen.
If possible, be less sensitive on turning and speed moving forwards/backwards.
Smoother transitions with glove and controller.
I like the concept of the robot, but I flat out wouldn't use the glove. Today's generation of Soldiers as well as ………play video games. Take advantage of that!
I'm not putting down my weapon to mess around with my phone or a computer screen in enemy territory.
Hand sensors more accurately fitted to an individual's hand.
Gloves in different sizes.
Less sensitivity. Wide camera angle.
Better camera and orientation systems in a place. Quicker reaction time for the glove.

List of Symbols, Abbreviations, and Acronyms

ANOVA	Analysis of Variance
ARL	US Army Research Laboratory
ATinc	AnthroTronix, Inc.
COMMAND	Communication-based Operational Multi-Modal Automated Navigation Device
COTS	commercial off-the-shelf
DOF	degrees of freedom
EAI	Engineering Acoustics, Inc.
EMR	electromagnetic resonance
GPS	global positioning system
HMM	hidden Markov model
HRED	Human Research and Engineering Directorate
IED	improvised explosive device
IMU	inertial measurement unit
N	Number of participants
NASA	National Aeronautics and Space Administration
PUI	perceptual user interface
SD	standard deviation
TLX	Task Load Index
UGV	Unmanned Ground Vehicle
USB	Universal Serial Bus

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