The Design and Evaluation of THATO: A Mobile Tactile Messaging System to Assist Dismounted Soldier Tactical Operations

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Here we describe the design and evaluation of the THATO (TeleHaptic Assistance for Tactical Operations) mobile tactile messaging system, developed to aid dismounted soldier communications, situation awareness, and navigation during tactical operations. The THATO Android application stores tactile messages that are played through its interface to Tactile Control Units (TCUs) when programming logic determines a command has been received from another soldier or the soldier's location relative to a planned route or landmark/entity of interest triggers a particular message. The evaluation of the system has included multiple human-technology performance evaluations with increasing incorporation of system technologies and task fidelity as the technology has evolved.

INTRODUCTION

Tactical operations can impose significant demands on Soldier senses, limiting their ability to perceive and communicate through normal auditory and visual pathways (Hancock & Szalma, 2008). Noisy (e.g., weapon fire, vehicle engines) and murky (e.g., smoke, sandstorm) conditions can hinder the ability to see and hear critical data such as relevant threat information, and it can also limit the ability to signal even simple squad movement instructions among soldiers. Wireless communication technologies connecting soldiers, with mobile computing devices and sensors (e.g. GPS, electronic compass, and health monitoring), have the potential to support critical information exchanges when squads are engaged in tactical operations, but there is also a need to enhance the communication modality options for receiving that information. The use of tactile displays to present directives and information about the surrounding area offers several benefits: 1) According to multiple resource theory (Wickens, 2002) offloading overloaded auditory and visual channels by using another modality such as touch can alleviate sensory bottlenecks and reduce interference with or degradation of visual and auditory perception, 2) Some information can be more efficiently processed in a tactile form, 3) Tactile displays can enable their users to receive and interpret valuable information without compromising the simultaneous utilization of other modalities (Merlo, Stafford, Gilson, & Hancock, 2006), and 4) Tactile displays are non-illuminating and can potentially be made to be acoustically covert, allowing the soldier to maintain a stealth advantage when required.

In this research and development effort we have sought to identify tactical operations supporting information that can be communicated via a tactile display, what particular tactile form that information should take to be usable, and how it can be integrated in a practical mobile messaging system. This paper presents a summary of the messages identified and the design and evaluation of the THATO (TeleHaptic Assistance for Tactical Operations) system for delivering those messages. From soldier interviews and a review of field and training manuals we have identified three basic types of message that can support tactical operations and for which there is research suggesting it is feasible for those messages to be effective in the tactile form: (1) navigation, (2) commands, and (3) entity descriptions.

Tactile Messaging for Navigation

It has been shown that localized vibration on a belt around the torso can effectively provide direction cues to the wearer (Elliott, van Erp, Redden, & Duistermaat, 2010). For the soldier following a route needing to develop and maintain an awareness of which direction to head in, for how long/far, and perhaps at what pace, it is valuable to eliminate the cognitive burden of performing navigational calculations. This is particularly valuable when there are limited visible landmark or terrain features to aid the navigational task. In addition to helping guide a soldier along a preplanned route a tactile messaging system can help guide the soldier to "new destinations" as events occur in the field. For instance, if a soldier were to request (or a health sensor indicated the need for) the assistance of a combat medic the hurt soldier's relative bearing and distance from the combat medic could be determined by using GPS data for both soldiers and compass data for the combat medic. Similarly, when needing to return to a vehicle the dismounted soldier could be given directional information if the vehicle has a networked GPS.

Tactile Messaging for Commands

Arm and hand signals, such as those described in US Army Field Manual 21-60, are frequently used for soldier-to-soldier communications, but sometimes visual communications are difficult. For instance, if a team leader of a squad on patrol visually signals a "Halt" command, the soldiers in front of the team leader in particular may not see the visual command. If all soldiers in the squad are not synchronized in their response to this command some will become involuntarily separated. In situations such as this soldiers may adapt and use verbal commands to complement or replace visual signals, but it won't always ensure the command is received and may expose the squad to detection. In a field experiment soldiers performing an obstacle course were able to receive, interpret and accurately respond to tactile commands for "Halt", "Rally", "Move-Out", or "NBC" faster than when the information was passed by a leader in the front or back of a wedge formation using conventional arm and hand signals (Merlo, Stafford, Gilson, & Hancock, 2006). Soldiers also commented they were better able to focus on negotiating obstacles and the local area when receiving tactile signals than when maintaining visual contact with their leaders.

Tactile Messaging for Entity Descriptions

If the soldier has access to digital information describing what surrounds him or her there is the potential to translate that information to tactile representations. This can help soldiers locate important entities and receive additional information about those entities' attributes. Static entity descriptions (that won't, for instance, change their location after a mission begins) can be loaded on the soldier's computing device before a mission. The networked soldier can receive information about dynamic entities in real-time during a mission. Studies have shown the value of cueing users to information presented indoors (Ferris & Sarter, 2008) and in the air (Rupert, Graithwaite, McGrath, Estrada & Raj, 2004), and this may transfer to outdoor ground contexts.

While we consider it useful to divide tactical operations supporting messages by these particular types, we are not claiming some messages won't involve more than on category. For instance, if a "follow me" message is sent it may contain the follow command and a description of the sender and/or where the sender "entity" is located.

Technologies to Support Mobile Tactile Messaging

At the center of this effort is the development of a tactile display language to meet soldier needs that can be sent to a particular arrangement of tactors worn by the soldier, but it also has involved exploration of certain supporting technological options. One key component is the mobile computing device programmed to contain the logic to decide what tactile messages to send to the tactile display's Tactile Control Unit (TCU) and when to send them. Advances in mobile computing technologies (such as the Android and iPhone smartphones) mean that today there is the potential to have programmed, in one small and light device, there is integrated capabilities to run the programming logic to decide what tactile messages to send, while utilizing built in or attached sensors (e.g. GPS and compass sensors), and sharing information over a telecommunications network.

PRACTICE INNOVATION

Overview

Because tactile displays are not as common as visual or even auditory displays there is less guidance available on their design and implementation and so this project has also involved developing a THATO Tactile Language Design Methodology which integrates tactile language design guidance and concepts from systems engineering with practical steps for designing and implementing a tactile communication system for use in real world contexts such as this one. That methodology is the focus of a separate paper (Riddle & Chapman, 2012). In the next sections, the design and evaluation of THATO are presented.

Figure 1 provides an overview of the THATO Mobile Messaging architecture.

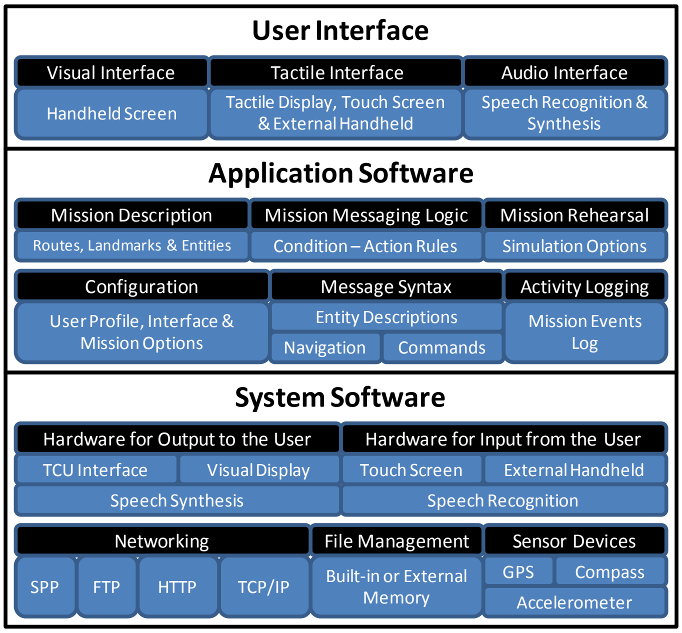

Figure 1 THATO Mobile Messaging Architecture

At the **system level** it has software to store particular tactile message designs, translate them into the language of the TCU being used, coordinate signal exchanges with the TCU, interpret GPS and compass data, support the transfer of mission description information and soldier to soldier messages, and receive input from the user. At the **application level** it has functionality to support tactical operations through multiple modalities so that modality adaptation can occur based on the current context. It also includes code to load and interpret routes and relevant environment descriptions, and a set of verbal commands that can be understood. Voice synthesis of messages equivalent to the tactile messages is included as an option.

The mission messaging logic determines when a THATO message should be played or sent over the network and how variable parts of a message (e.g. direction) should be instantiated in real-time. For a soldier initiated **command** the message is selected by saying the command, by selecting the command from the Android's menu system, or by using a dedicated physical button on a separate device connected to the Android. If, for instance, the squad leader selects the message for the squad to all rally to a particular location that would cause each recipients THATO to calculate the relative distance and bearing to the Rally Point for its user and use that in the message played. If a THATO user gives a command to the THATO system itself to "repeat the last message" or "repeat distance" or answer the question "where is private Smith?", he or she would receive an appropriately tailored message as a response.

For **entity description** and **navigation** messages THATO uses the soldier's location to determine when to automatically play a message. Mission description elements such as routes, landmarks, and entities are used in a set of rules that specify what soldier locations relative to the locations of those elements will cause particular messages to be played. These rules can be organized into three types depending upon how the triggering condition is drawn on a map - shapes, lines, and routes. For instance, a polygon on a map might be used to define an Area of Operation (considered a "landmark" in THATO), so that a message would play if a soldier's location changes from being outside the polygon to being inside the polygon, or from inside to outside. A circle might be used to specify that if a soldier comes within a certain distance of an entity a message should be played to describe that entity. Figure 2 shows pictorially how a soldier moving along a path could create the THATO conditions "Entry", "Exit", and "In Range" relative to those shapes.

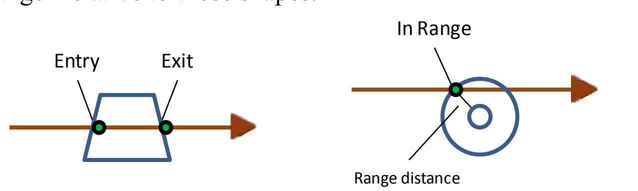

Figure 2 Example soldier location relative to a shape conditions

If a soldier crosses a specified line this can be detected, as can a soldier coming within a specified range of a line. A route is a directed polyline that serves to guide the soldier along a path. There are several conditions that THATO can detect that help with that task as demonstrated in Figure 3 - proximity to a waypoint, proximity to the route, off route, back on route again, and closer to the next line segment than the next waypoint. There are configuration options for describing how strictly the soldier is guided along routes.

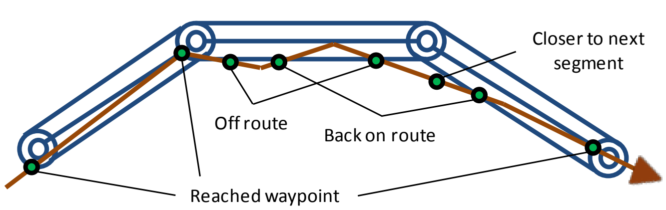

Figure 3 Example soldier location relative to a route conditions

FINDINGS

A series of evaluations were conducted throughout the THATO project. Some evaluations were inspection based considering, for instance, if a candidate message representation met the requirements of the working set of design principles. Technology performance evaluation included modular testing of components such as the message triggering logic and voice recognition system against test plan scripts. Human-technology performance was evaluated in two lab experiments and one field experiment. All three experiments involved participants at the United States Military, which meant they had some skills and knowledge in common with the intended users of THATO.

Experiment 1 (Lab) : 8 Tactor 2D Belt

Previous research (Merlo, Stafford, Gilson, & Hancock, 2006) demonstrated that ten USMA cadets could achieve almost perfect performance in interpreting four standard arm and hand signals, ("Halt", "Rally", "Move-Out", and "NBC"), and eight directional signals, represented through tactile messages on an Engineering Acoustics Inc. eight C2 tactor belt (with the 8 tactors spaced evenly around the waist). In the first lab experiment the same tactor hardware was used, but the language was expanded from five signals to fourteen. The types of message were also expanded (by adding formation directives, and enemy and casualty descriptions), and the syntax was expanded so that different related information could be communicated in specific phases of a message. For messages with more than one phase earlier phases act a preparatory cues for what may follow.

Eleven participants took part in the experiment. Participants were solicited during the Summer 2009 semester from a pool of available combat experienced instructors at West Point. The overall syntax rules for the language were first presented to participants in a visual form. This was followed by a description of the metaphors used for each base message type, practice, and testing on the bases, before repeating the process for the full 14 message language, with each message played one time in a random order during testing. Participants verbalized their interpretation during testing and also indicated their level of confidence in their response on a 5-point scale.

Unfortunately, after the first five participants completed the experiment it was determined the belt used was not presenting messages as they were programmed in the ultramobile computer communicating with the TCU and inter-burst pauses were significantly shorter than programmed. A second belt and TCU without this problem was used for the remaining six participants. Table 1 summarizes their performance data. The conclusions that can be drawn from the results are limited due to the number of participants who had reliable tactile displays. However, unlike the earlier Merlo study, where there was almost perfect performance, these results provided an opportunity to consider how to interpret and use data on errors made.

Table 1 Exp. 1 messages tested and the % recognized completely

Base	Subcategory	Qualifiers	% correct (confidence)
Take Cover	-	-	100% (5)
Attention	-	-	100% (4.8)
Casualty	-	-	100% (4.6)
Formation	File	-	100% (4.7)
Formation	Wedge	-	83% (4.3)
Movement		Direction [+ Distance]	100% (4)
Movement	Rally	-	100% (5)
Movement	Move out	-	100% (3.7)
Movement	Halt	-	67% (4.5)
Movement	Follow me	Direction [+ Distance]	100% (3.8)
Movement	Eyes on me	Direction [+ Distance]	67% (3.2)
Enemy	Imminent	Direction	67% (3.7)
Enemy	Contact	Direction [+ Distance]	67% (2.3)
Enemy	In sight	Direction [+ Distance]	50% (3.8)
			Overall: 86%

The distance values represented were *near*, *far*, and *unknown,* as before the experiment soldiers indicated that would normally be sufficient.

Participants accuracy was 87% on the base only testing, but the base part of the complete message was interpreted at a 92% level of accuracy suggesting a learning effect from increased exposure or perhaps that the additional information in the message helped determine which message it could logically be. The number of pieces of information in the message to accuracy relationships were (1) 100%, (2) 91%, (3) 85%, and (4) 57%. This perhaps suggests a general trend for more information to mean less accuracy, but also important in the development life cycle was that recording the incorrect answers provided valuable information in terms of which messages needed to be made more distinct from each other. Further, the confidence ratings on individual messages helped determine if a participant would likely act on that erroneous interpretation or if they were more likely guessing and in reality might take actions to determine what the message was by requesting it (or part of it) be repeated or presented in a different modality. A thorough Failure Mode and Effects Analysis (FMEA) of a more final language might consider how serious each misinterpretation would likely be, how likely it would occur (based on the confidence ratings) and how frequently such messages would be played. Overall, the average confidence rating was 4.3 when participants were correct and 2.3 when they were not.

When asked to rate their level of agreement with the statement, "a tactile communication system would be useful for receiving some messages in the field" on a 5-point scale (where 4 indicated *agree* and 5 indicated *strongly agree*) the average response was 4.8.

Experiment 2 (Lab) : 24 Tactor 3D Belt

In the second lab experiment (conducted in November 2011) the number of tactors was increased so that three layers of 8 tactors provided an additional dimension to utilize in message design, meaning a message like "take cover", which soldiers indicated made them think of dropping to the ground, could be represented as a sensation of downward movement by activating tactors at a successively decreasing height. Additionally, only the nine tactors on the back were used to describe entities and their qualifying information in an attempt to help users separate entity descriptions from other message types. Entity descriptions began with a message base where enemy and friendly representations were designed to feel very different. The direction was described on the 3x3 grid with the top row meaning in front of the soldier and the bottom row meaning behind, and other groups of three tactors representing six other directions to again provide a direction for every 45 degrees surrounding the soldier. After the directive description the size of force (small, medium, or large) was presented, if considered known, by activating a size dependent number of tactors in the same direction. A different form of move directive was explored involving three bursts of tactors, progressively moving towards the final direction to create the sensation of movement in that direction, and to facilitate suggesting different paces of movement (slow, medium, fast).

To increase fidelity, a secondary task involved viewing a photograph and indicating if a camouflaged soldier was in the image. The experiment involved using a Mide Corporation TCU and set of piezo tactors. Fourteen cadets were given messages on the 24 tactor 3-layer display, but unfortunately there were again non-visible hardware problems such that, after the first six participants, messages that involved playing more than two tactors at a time may not have played correctly. The results shown in Table 2 summarize performance by those six participants.

Table 2 Exp. 2 messages tested and the % recognized completely

Base	Qualifiers	% correct
Take Cover	-	83%
Rally	-	86%
Halt	-	100%
Move	Direction + Pace	79%
Enemy	Direction [+ Size]	83%
Friendly	Direction [+ Size]	87%
		Overall: 83%

The move component is implied when direction and pace are presented.

Participant accuracy was 97% on the base part of the messages and 83% on all messages. Importantly, no participant confused the representation of enemy with friendly or vice versa. The number of pieces of information in the message to accuracy relationships were (1 - commands) 90%, (2 - navigation and some entity descriptions) 79%, (3 - some entity descriptions) 89%. The accuracy improvement between 2 and 3 pieces of information is perhaps due to the fact that when three pieces of information were presented the third (size) actually reinforced the second (direction). Qualifier accuracy was move direction (79%), pace (92%), entity direction (82%), and size (95%). Direction accuracy would likely have been higher if the belt had fit better for some participants, and if participants had been instructed to point to the direction rather than say "north", "north-east" etc.

Experiment 3 (Field) : 40 Tactor 3D Belt

In the field experiment the primary goal was to measure the impact of geographically triggered tactile messages on performance when participants were engaged in a tactical operation outdoors. A scenario was created by a military subject matter expert that involved navigating between waypoints in a wooded and hilly terrain and a need to identify enemy and friendly units while traversing the course. In a within subjects design one condition involved utilization of a paper map and compass, while the other involved the same equipment plus THATO and a tactile belt with 40 tactors (i.e. the same as used in Experiment 2, but with 16 additional tactors added at the back to better support entity descriptions). Additionally, at predefined check points the participants would use a tactical radio to provide a situation report (SITREP) and receive updated intelligence information. It was hypothesized that compass logs would reveal significant differences in both speed and accuracy of navigation between the two conditions. It was also hypothesized that the SITREP reports would indicate better detection and recognition of entities (implemented as silhouettes) under the THATO condition.

The messages included are shown in Table 3. The move message was a single tactor activation, repeated regularly, but more quickly when closer to a waypoint. Entity types were unit, observation post, and minefield. The direction and proximity qualifiers for entities were played using the same directional mapping as for the move message (i.e. not using the back grid of tactors as was done in Experiment 2) as during outdoor walkthroughs of the scenario before the experiment it was considered much easier to interpret what the direction really meant relative to the surroundings that way.

Table 3 Exp. 3 messages included in the scenario

Base	Subcategory	Qualifiers
Move out	-	-
Move	-	Direction + Proximity
Arrived at Waypoint	-	-
Outside Area of Operation	-	-
Crossing Phase Line	-	-
Entered Known Area of Interest	-	-
Enemy	Type	Direction + Proximity
Friendly	Type	Direction + Proximity

A set of geographic-trigger-tactile-action rules was created for these messages using the software Geo-Docent (Chapman, Riddle, & Merlo, 2009). Geo-Docent allows shapes, lines, and routes to be drawn on a map and then associated with specific rules. They were then imported into THATO.

Another goal was to run THATO on Android smartphones. However, the system software to enable Bluetooth communication between Androids and the TCU could not be made sufficiently reliable before the scheduled April 2012 experiment, so a contingency plan to use Sony VIO VGN-UX280P ultramobile computers instead was exercised.

Eighteen cadets completed the two courses with condition to course assignment randomized as well as the ordering of the courses for participants. Unfortunately, the ultramobile computers proved to be insufficiently ruggedized and after the first two trials of the THATO condition both ultramobiles returned inoperable. Despite the known software issue, the Androids (Samsung Exhibit II) were used for the other participants as this provided an opportunity to pilot the experimental protocol for a potential repeat of the experiment in Fall 2012/Winter 2013. As expected, with only a subset of the tactile messages playing, the results were not meaningful.

DISCUSSION

This paper has described the THATO mobile messaging system and how we have evaluated particular sets of tactile messages to support tactical operations - learning from each evaluation and improving the tactile language and supporting technologies, and increasing testing fidelity over time. Since the field experiment the Android Bluetooth communications problem has been solved and Mide Corporation is developing self-diagnosing tactor display hardware. Despite the challenges of evaluating multiple interacting emerging technologies with human-technology testing we believe there is no significant evidence that THATO can't assist dismounted soldier tactical operations and that with these improvements additional testing will demonstrate performance improvement.

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