Development of Tactile and Haptic Systems for U.S. Infantry Navigation and Communication

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Abstract. In this paper we discuss plans initiated to develop and evaluate multisensory displays (i.e. visual, haptic, tactile) to support dismounted (i.e., not in vehicle) Soldier movement, communication, and targeting. Human factors studies of an array of military operational roles have shown significant demand for focal visual attention that diminishes the capacity for task-sharing and attention allocation, especially in the context of unexpected changes and events. If other sensory modalities can be effectively used in a military environment, the benefit could be significant in increasing survivability, information flow, and mission achievement. We discuss operational task demands and two efforts supported from a 2010 SBIR (Small Business Innovative Research) topic.

Keywords: Tactile displays; Haptic displays; Soldier navigation; Soldier performance; Multisensory displays; Intuitive displays.

1 Introduction

Tactile and haptic interfaces have long been used for intuitive displays and controls. Consider our daily use of devices such as steering wheels, joysticks, and computer mice (haptic), and cell phone vibrating alerts (tactile). Haptic devices incorporate the sense of touch and/or kinesthesis from motor activity based in the skin, muscles, joints and tendons, and includes tactile sensing [1]. Tactile devices are thus haptic by definition, but are based more specifically on stimulation of the skin—usually mechanical, but also including chemical or heat stimulations. It should be noted that haptic, and sometimes tactile, interactions are often in the form of input-output feedback loops, as opposed to more passive reception. That is, the user is actively interacting with the device.

While simple versions of haptic and tactile devices are commonplace, more sophisticated applications are also proving their worth, in areas such as virtual reality [2], [3], robotic telepresence [4], and spatial orientation [5]. At the same time, research has focused on a number of human factors issues regarding multisensory display, such as sensory adaptation, spatial masking, temporal masking, and cross-modal interactions [6]. A series of meta-analyses comprising hundreds of experiment-based comparisons, has shown significant advantages can be gained from addition of

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tactile information to existing visual displays [7]. In this paper, we will describe some applications of haptic and tactile devices to military performance, particularly Soldier performance, and plans for further instantiations of this capability as it can apply to combat Soldiers.

1.1 Military Applications

Haptic Systems. Haptic systems for military applications include devices such as haptic joysticks and gloves for control of robots and exoskeletons [8]. Haptic-controlled exoskeletons have been demonstrated to ease physical workload and also to aid in rehabilitation of patients with stroke or head injuries [9]. Haptic capabilities have been demonstrated in virtual reality simulations that can be used for training or telepresence [10]. In addition, gesture-based controls can also be considered haptic in nature.

Tactile Systems. Tactile systems for military performance have demonstrated their potential with regard to capability achievement and performance advantage, across a number of applications. Experiments and demonstrations have been conducted across a wide range of settings, from laboratory tasks to high-fidelity simulations and real-world environments. Operators of these various tactile systems have successfully perceived and interpreted vibrotactile cues in averse, demanding, and distracting situations, such as combat vehicles [11], aircrew cockpits [12], high-speed watercraft [13], underwater environments [14] and during strenuous movements [15]. Also, tactile alerts have effectively supported performance during robot control [16] and UAV control [17].

1.2 Some ARL Soldier-Based Experiments of Tactile Displays

While tactile cues have been associated with better or faster performance, we cannot assume that all tactile cue displays will be effective. However, if we consider predictions of performance gained through (a) alleviation of sensory overload [18] or (b) alleviation of cognitive deliberation [6] we should expect that given a high workload multitask and multisensory situation, that a multisensory approach including a tactile channel will reduce workload and improve performance, assuming the tactile display is easily perceived and comprehended.

Several HRED experiments conducted with Soldiers support these expectations. We started with task analysis information that identified key situations in which Soldiers are visually overloaded [19] then initiated several HRED studies to investigate effects of tactile cues in context [20]. The studies further supported the ability of Soldiers to detect not only single alerts but also patterns of multiple tactors to represent different communications [15]. It is particularly promising that these patterns can be perceived during strenuous movements [21].

Because tactile alerts have been demonstrated to effectively and easily portray spatial orientation [5] it is reasonable to assume that a torso belt would convey direction information that is also immediately understood. Three experiments investigated the efficacy and suitability of a torso-mounted tactile belt for Soldier navigation [22]. For all experiments, researchers used a tactile navigation system developed by the Netherlands Organisation for Applied Scientific Research – TNO

(Toegepast-Natuurwetenschappelijk Onderzoek), for U.S. Army Soldier land navigation (see Figure 1). Land navigation occurred at the Fort Benning training site for Soldier navigation – a challenging terrain that requires careful attention to one's surroundings for threat from terrain and natural wildlife. In experiment 1 participants navigated three waypoints along 600 meters through heavily wooded terrain, using each system: the TNO tactile system, a map and compass, and with a handheld Army GPS system. Performance measures included quantitative measurement of navigation error, along with other objective and Soldier-based assessments (see figure 2).

Fig. 1. Personal Tactile Navigator System

In a second experiment researchers used terrain similar to the first experiment with the additional challenge of night operations during intermittent thunderstorms. Soldiers navigated three waypoints while also searching for live and silhouette targets, using (a) handheld GPS device, (b) head-mounted map-based GPS, and (c) the tactile GPS system. Experiment 3 had participants navigate with (a) a commercial GPS arrow display, (b) the tactile GPS system, and (c) both together. Given this series of results, more extensively discussed elsewhere [22], it was concluded that tactile navigation displays can be used in strenuous outdoor environments and can outperform visual displays under conditions of high cognitive and visual workload. In addition, Soldier comments were highly in favor of this capability, stating that the system was "hands-free, eyes-free, and mind-free."

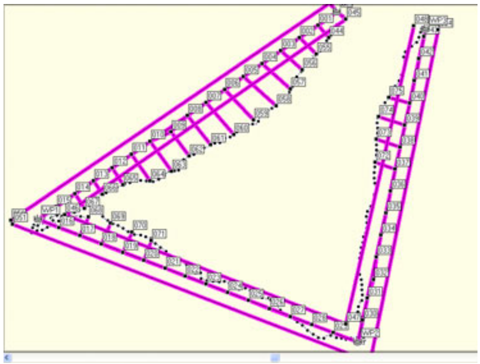

Fig. 2. Quantitative MapQuest-based approach to performance measurement (navigation)

A torso-mounted tactile belt was also demonstrated as useful for robot control operations [23]. In this experiment, three types of robot controller navigation map display configurations were evaluated for effects on beyond line-of-sight robotic navigation tasks. First was a larger split screen visual display that presented both a map display and a camera-based driving display on a 6.5 inch screen. Two smaller alternatives were also evaluated. One alternative was a 3.5 inch display that allowed the operator to toggle back and forth between the driving display and the map display. The third option added a torso-mounted tactile display to the toggle-based display in order to provide direction information simultaneously with the camera display and thus reduce the need to toggle as frequently to the map display. Each display option was evaluated based on objective performance data, expert-based observations, and scaled subjective Soldier questionnaire items. Findings indicated that operators' navigation performance with the smaller, toggle display was much worse than with the larger split screen display. However, when the tactile display was added to the toggle display, performance was as effective as with the larger display.

2 SBIR Topic

The experiments described above establish the potential of tactile systems for supporting Soldier performance while easing workload and gaining high user acceptance. At the same time, Soldiers provided many suggestions for device design before a system can be practically used in combat. Certainly, the device must be made to be lightweight, comfortable, rugged, and easily maintained. The device must enable wireless communication among Soldiers, to enable commanders to easily and covertly signal Soldiers regarding alerts or movements. This would build upon battlefield visualization techniques now common to command and control, by enabling the commanders to quickly relate critical communications as to where to go or where to shoot. In this way, the integration of a visual command center with distributed tactile communications enable dynamic battle maneuvers with intuitively understood signals.

At the same time, we also need the development of tactile systems that can be used as research testbeds, to enable further research in multisensory performance issues while being fully grounded to Soldier task demands. Thus, systems must also provide the means by which performance can be easily assessed—tracking communications, time-stamped performance events, GPS-enabled assessment of navigation performance, user-based assessments of situation awareness, and data logs. The purpose of the SBIR topic was to solicit approaches to such a tactile system—one that can serve to illustrate the advantage to Soldier performance, while offering a testbed for research. Of course, the resulting capabilities would generalize to many other military, government, first-responder, and commercial (e.g., hiking, hunting, tourist navigation) applications.

2.1 Tactile System with Navigation guidance

Engineering Acoustics, Inc. (EAI) has a long history of tactile system engineering, for many military applications—such as situation awareness support for aircraft pilots [24]. Guided by experiments, sensory perception research, and user requirements, EAI has engineered specialized tactors that are very easily perceived by users, more accurately than other types of tactors, even during combat movements [21]. The military environment is severe, placing demands on equipment, system and Soldier. War-fighters may be under conditions of extreme physical noise and stress and, in critical situations, cannot afford to "miss" information. As part of this SBIR effort, EAI will demonstrate advanced tactors designed to overcome problems that can occur (e.g., poor perception, slow spin-up times, vulnerability to loading). Particularly, they will attend to the problem of auditory signatures, to enable a system that is more completely covert. The potential of a wearable vibrotactile system has been impeded by a lack of suitable tactors and sensors and non standardized tactile symbology. Figure 3 shows the EAI tactor types and steady state displacement performance into a skin load.

Figure 4 shows a block diagram for the system. The system comprises visual display hardware(for Phase I we propose using a handheld or Tablet computer for this task) , EAI tactor controller and belt array, a COTS (Commercial off the shelf) GPS / compass sensor interfaced directly to the tactor controller and software components.

In addition to engineering the system, EAI will address human factors considerations, building upon accumulated knowledge, with particular focus on Soldier requirements. The use of multiple tactile locations in vibrotactile displays for spatial orientation is known to be intuitive; however, effective design must, from the start, be based on user task demands and the context of performance. While the system will be constructed toward user requirements, it will also enable systematic research with regard to impact of multisensory systems on workload, grounded towards the context of Soldier navigation, communication, and performance. Thus the system and the research it enables are expected to support the core performance domain for Soldiers – to move, to shoot, and to communicate.

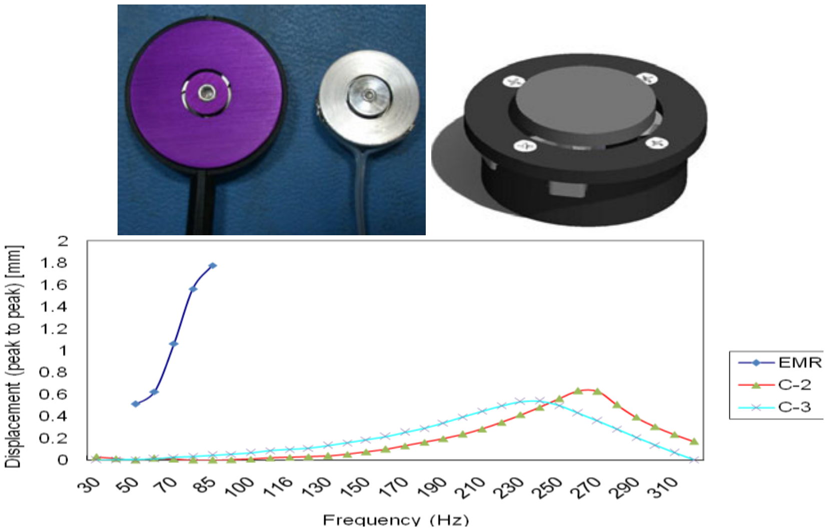

Fig. 3. The EAI C-2, C-3 and EMR vibrotactor transducers (top left to right respectively) together with their operational displacement output (measured with an optical fiber displacement sensor on a silicone skin phantom)

Fig. 4. Block diagram for the proposed ATAC-NavCom system

2.2 Tactile System with Haptic Communications

The COMMAND (Communication-based Operational Multi-Modal Automated Navigation Device) system, in development by Anthrotronix, will build upon their previous work for Office of Naval Research, which led to the development of a Haptic Automated Communication System (HACS) that utilizes an instrumented glove for real-time communications based on hand signals. The instrumented glove includes 6 embedded accelerometers, a gyroscope, and a digital compass for automated recognition of standard hand and arm signals, gestures, pointing, and weapon firing. It also includes a torso-mounted accelerometer and digital compass for Soldier location and stance (e.g., upright, prone). Also included is a haptic display vest with 20 tactors for pattern-based communications, and a GPS-enabled handheld computer (see Fig 5).

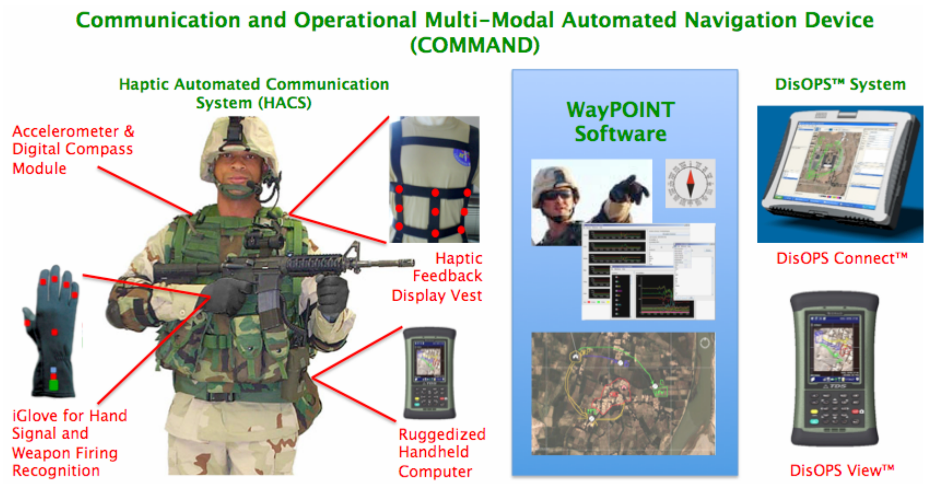

Fig. 5. COMMAND System

While initially the system will demonstrate a proof of concept, there are plans to eventually provide real-time geospatial reports and tools for pre-mission planning and review. This would entail integration with the Lockheed Martin DisOPS™ (Distributed Operations) System, which is composed of a software package and a ruggedized handheld computing system, visualized to be used by Army squad and fire team leaders.

The COMMAND system is visualized to integrate these technologies and incorporate a novel software system (WayPOINT) to provide intelligent, automated, multimodal information processing and display to support dismount infantry operations. The resulting system will enable gesture-based communications, as well as tactile-based navigation and communications.

3 Discussion

Multiple experiments and demonstrations have proven the theory-based predictions regarding advantages of haptic and tactile cues to support performance in high-workload situations, particularly multi-tasked situations with high demands for focal visual attention. Task analysis models identified that Soldiers have very high demands for visual attention, particularly when Soldiers are moving or shooting. Subsequent experiments proved the value of tactile systems to support Soldier navigation and communication. At the same time, systems must be improved and refined before they can be practical in combat situations. They must be made lightweight, comfortable, rugged, networked within a command and control system, and they must be easy to use and easy to maintain. As tactile displays are increasingly used for communication of more complex and multiple concepts, it will become evident that tactile and multisensory systems in general must be designed for rapid and easy comprehension. This paper described efforts underway toward the goal of effective support of Soldier performance, and the development of a system that can also be used for grounded research (i.e.,high generalizability to military operations) in multisensory perception and comprehension.

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