Supporting Situation Awareness in Demanding Operating Environments through Wearable User Interfaces

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Abstract. The military environment is physically and mentally extremely stressful. Tasks in the operating environment are varied, demanding and hazardous. Due to these challenges, new user interfaces (UIs) are required providing improved soldier protection and performance both in day-time and night-time conditions. The new UIs should, e.g., improve the soldier's situation awareness, i.e., perception of information, integration of pieces of information, determination of their relevance to one's goals, and projection of their status in the future. The aim of the Finnish project called "Supporting situation awareness in demanding operating environments through wearable interfaces" is to develop UIs for wearable computers that help the special force soldier carry out his/her main critical tasks, e.g., detection and identification of enemies and features of the surrounding environment, navigation and self-localization, development of tactics and communication between and within military units. The main portions of the work are task and work analysis, and conceptual design and evaluation of prototype systems. The present paper present the project and the methods that are used in the functional analysis of military tasks.

Keywords: Situation Awareness, Cognitive Task Analysis, Military Domain, Wearable User Interface, Future Soldier, Future Warrior.

1 Introduction

New user interfaces (UIs) developed into military environment are required providing improved soldier protection and performance both in day-time and night-time

D. Harris (Ed.): Engin. Psychol. and Cog. Ergonomics, HCII 2009, LNAI 5639, pp. 13–21, 2009.

conditions. The new UIs should, e.g., improve the soldier's situation awareness, i.e., perception of information, integration of pieces of information, determination of their relevance to one's goals, and projection of their status in the future. The aim is to keep the soldier aware of what is going on around there and make him/her possible to act and react quickly in accordance with the general goals and objectives.

In the numerous studies introducing novel technologies and UIs for infantry soldiers, little attention has been paid to the fact, that the physical and cognitive demands brought along wearable technology should not increase the physical and mental workload of soldiers. Doubtless, this situation should have a significant effect on the technology and UIs to be introduced for military use. Additionally, it will cause demands on the methods to be applied in the analysis of complicated working environments of the present and future infantry soldiers.

The Finnish project SAWUI ("Supporting situation awareness in demanding operating environments through wearable interfaces") aims to research and develop novel UIs for wearable computers that help a special force soldier carry out his/her main critical tasks, i.e. detection and identification of enemies and features of the surrounding environment, navigation and self-localization, development of tactics and communication between and within military units. The main stages of the development process are task and work analysis, conceptual design and evaluation of prototype systems. The project started in August 2008 and it will end in July 2010. The project will be proceeded with the research institutes, companies and Finnish Defence Forces.

The aim of the present paper is to present the SAWUI project, especially focusing on the methods used in the functional analysis of military tasks. These methods have a basic role in requirements capturing process of the new wearable military UIs. The solutions we study, design and present in this study are based human-centric design approach.

2 Background

Generally speaking, the focus of the development of the future soldier systems is to improve the lethality and survivability of an individual soldier. The aim is that the performance of a soldier becomes faster and more effective, and his/her ability to adapt to tactical changes is more effective. In order to reach this aim, the soldier should, for example, perceive better in a dim light and at long distance range; the soldier has a direct connection to supporting systems; he/she is able to utilize advanced weaponry, and the weapons he/she uses are reliable and accurate. Since the soldier is constantly integrated into a communication network he/she is able to communicate with others all the time. However, the soldier is not a robot or a cyborg, since he/she should be able to adapt those systems he/she is integrated with.

Several countries have a program or programs for the development of future soldier systems underway. For example, they are including LandWarrior and Future Force Warrior (USA), Félin (France), IdZ (Germany), FIST (UK) and Integrated Soldier System Project (Canada). In many of these projects the aim is specifically to develop a system that improves soldiers' performance in urban operating environments.

According to literature, the basic elements of a future soldier system are 1) an operating centre including a wearable user interface, a positional and navigation system and a system supporting situation awareness; 2) a modular weapon system; 3) individual equipment including clothing, protection and a carrying system; 4) a communication system including a short-distance radio and a rescue radio and 5) a training system [7]. In a similar way, according to the Finnish STAE-report, the development of a system supporting a soldier's performance should be considered as an integrated whole including clothing, ballistic protection, different types of sensors, weaponry and all kinds of devices and equipment supporting the soldier's performance [5].

A future soldier equipped with these devices and systems can be thought as some kind of a node in a large information network: On the one hand, he/she is a passive sensor and node in a communication network, on the other hand, he/she is also an independent actor in the operational field. In other words, he/she is a subsystem in a system that is a part of a larger system of systems.

Wearable multimodal user interfaces are supposed to improve the detection and identification of critical information by directing the soldier's attention to the right direction; they should provide sensory enhancement by improving the operator's ability to localize targets and self and navigate in the environment; they should give better dynamic information by keeping the operator up to date on changes and situational factors in the operating environment; they should provide information sharing between members of the team and support planning and dynamic decision making; and finally they should foster distributed decision making by providing information across teams and between commanders and the team and by supporting different ways to comprehend and integrate information [4].

In order to reach these goals, wearable systems should be context-sensitive, proactive, 'prosthetic' and user-friendly [6]. They should be context sensitive so that they are able to identify the action possibilities and constraints of a situation, make these possibilities visible to the user, and help users to become aware of the meaning of different activities. They should be proactive in a positive way, and help users to engage to different activities. They should also be 'prosthetic' and augment performance on tasks in which the hands are busy. In addition, they should be non-obtrusive and easy to use. To that aim, it should be useful if novel visualization techniques, browsing methods and multimodality are applied.

3 Goals of the SAWUI Project

In order to be able to develop new technical systems for the military environment the key task we have to perform in the project is to define and characterize soldiers' physical, perceptual and cognitive activities, analyze their task performance and describe the environments in which soldiers perform (i.e. work domain and task analysis). Furthermore, and based on it, we have to define the physical, perceptual and cognitive requirements that have to be supported by the new UIs introduced for military use. As a result of these analyses, we will be able to obtain an understanding of the user and system requirements and a view of the strengths and weaknesses of the existing systems and technologies.

Based on the results and recommendations received from the work domain and task analysis, the next step is to specify the user and system requirements of wearable UIs to be used in the military related purposes. At the same time, the user experience and the ability of wearable UIs in maintaining situational awareness with minimum disturbing stress and cognitive load for the user will be studied.

Finally, based on the requirements captured, as described above, a prototype system will be implemented. Such prototype can be used, e.g., for training and for gaining user feedback from real end users. The evaluations will take place both in a laboratory (simulated contexts) and in the real life conditions. The focus of the evaluations will be on the technology maturity and applicability, on system usability and on cognitive load and ergonomics of the wearable system implemented.

The work will be supported by military experts from the Finnish Defence Forces who will give their assistance in each step of the project.

4 Methods

The development of a wearable multimodal soldier system consists of several steps [3]. First, the aim is to characterize the information requirements of infantry soldiers for some representative operational tasks. Secondly, the requirements for a wearable multimodal soldier system are specified. This includes user requirements for information processing and specifications for applications supporting situation awareness, decision making and communication and collaboration in demanding environments. Thirdly, based on the studies mentioned above, wearable soldier system proof of concept will be implemented. Finally, an evaluation of the prototypes in terms of their usability and functionality will be carried out.

4.1 Background Preparation and Domain Familiarization

The aim of this phase of the study is to determine the user group, the planned tasks and functions together with the existing technologies. The purpose is to familiarize the researchers involved to the military domain, to define the scope for the task analysis, to select the most critical tasks for further analysis, to define the key aspects of the task and to determine the perceptual and cognitive skills that are supported. Furthermore, the aim is to familiarize to the future user interface systems that are based on pervasive and ubiquitous computing technologies and to prepare a literature review on the application of these technologies in the military domain.

4.2 Observations and Knowledge Elicitation

The key requirements are identified through interviews, literature reviews and observations of real soldier performance in the field context. Different tools will be used to break down activities into meaningful functions and tasks and determine which of them are likely to be perceptually and cognitively challenging to soldiers. A modified Decision-Centered Design Method is applied consisting of the following five stages, preparation, knowledge elicitation, analysis and representation, application design and evaluation [2]. This phase includes the identification and understanding of the military domain, tasks and users and identification of cognitively complex tasks. Knowledge elicitation methods are used to understand the information needs, attentional demands and critical decisions and to identify team structure and communication. The analysis and representation stage are used to decompose data into discrete elements and to identify the users' decision requirements.

4.3 Study and Analysis of Wearable UI Technologies

Studies on commercially available wearable UI technologies will be carried out in this phase. This is made by providing expert evaluations for a set of most promising wearable UIs and by studying their prospects and limitations in the case of military context of use. This task will provide a more in-depth understanding of the requirements of wearable UI technologies from the cognitive, operational, human factors and ergonomic point of views, and it will give more specific user and technical requirements for wearable user interfaces of a future soldier in maintaining situational awareness in an increasing and simultaneous flow of information from different sources. This analysis will take into account the special characteristics, such as climatic and time of day circumstances.

4.4 Work Domain and Task Analysis

The main aim at this phase is to gather and analyze information from different sources concerning the requirements that are critical to the effective performance in the military domain. This will provide us with a deeper understanding of the tasks and contexts in which the wearable UI system will be used, and the aim is to characterize the key requirements of the battlefield domain. This becomes necessary in order to understand the physical, perceptual and cognitive activities and perceptual and cognitive constraints presented by the environment as well as to understand the knowledge, behavior and strategies of soldiers.

The basic methods and techniques in the acquisition of these requirements are cognitive task analysis techniques and work domain analysis techniques joined together with a profound understanding of the perceptual and cognitive mechanisms that underlie the soldier performance [3]. Cognitive task analysis techniques applied here area set of techniques to describe the perceptual and cognitive demands of the soldier's tasks, e.g., soldier information needs, decision making strategies, critical decisions and how technology may support performance [3]. The aim is to determine and analyze which kind of information is used in those critical tasks and how this information is received.

Work domain analysis provides information of the constraints of the military environments. It complements the cognitive task analyses by providing some of the constraints and possibilities of the environment that may have an impact on the soldiers' physical, perceptual and cognitive activities.

The work domain analysis consists of the hierarchical representation of the domain including functional goal-means decomposition of the application domain. The aim is to understand and analyze the goals to be achieved and the functional means for achieving the goal. Different methods and techniques can be used to collect data for the work domain analysis [3]. Cognitive work requirements analysis includes the determination of the cognitive demands for the domain model [3]. Cognitive work requirements (i.e. detection, recognition, attention control/focusing, monitoring, problem solving, decision making) are determined for each work domain concept. Information and relationship requirements analysis includes the identification of the information and actions required ("what is needed"), i.e. a set of information elements and action possibilities needed for the settling the above-mentioned requirements [3].

The cognitive task analysis leads to the determination of perceptual and cognitive demands of the soldiers' tasks. Cognitive demands are difficult, challenging and frequent decisions and tasks within the military domain including relevant information about why the activities are challenging and difficult, what strategies are used to carry out these tasks, what supporting information is needed and what are the common errors and difficulties in conducting the task [2]. The most important aspect of this work task is to define what the strategies are that are used by the soldier to conduct a particular task and by which way new information technologies could support these strategies. A detailed specification of the requirements will provide input for what activities must be supported and what content must be provided to the soldier.

4.5 Research on Human Information Processing Capacity

A central aim of the experimental work at this stage is to clarify the limitations of human information processing in relation to the use of wearable UIs. Exceeding human limitations would result in reduced task performance, increased amount of errors, and unnecessary visual and/or cognitive load. Adequate ergonomic design of user interfaces reduces perceptual and cognitive strain related to the use of wearable computers and therefore, helps avoiding potentially detrimental health effects of the devices. For example, in the use of wearable displays, various potential problems related to human information processing can be recognized. These include small size of wearable and mobile displays, short viewing distance, detrimental interaction between perception of displayed and external information, and light adaptation when a wearable display is used in low ambient light conditions [1].

The second aim is to study and model the integration of multimodal information and allocation of selective attention in demanding operating environments. The wearable UI should support the timely and adequate allocation of attention between different sense modalities and provide resistance to unnecessary interruptions.

The third aim is to study the critical dimensions of soldier psycho-physiological state (both psychological and psycho-physiological factors). This information is needed when evaluating the physiological and psychological condition of the soldier in order to assess his/her capacity to perform the task, definition of physical, perceptual and cognitive requirements and strategies for supporting design decisions.

4.6 Human Information Processing Requirements for Multimodal Adaptive Interfaces

The aim is to define specifications for a wearable multimodal computer system which supports perception and comprehension of critical operational information. The ergonomics and usability of the displays and input devices must be optimized. The optimization of visual displays in terms of visual conditions is challenging. Special challenges are caused by demanding usage conditions, dim light, dazzling sunlight and fast changes in lighting conditions. For example, the changes of lighting conditions require that the system must be adaptable. One of our aims is to recognize the problems caused by lighting conditions and generate solutions to these problems.

In addition to visual displays, the aim is also to investigate auditory and tactile interfaces that can provide supporting information. Specifically, we will study the integration of information through different sensory channels in wearable user interfaces, and guidelines will be generated for the presentation of multi-sensory information. It will also be studied the possibility to use peripheral visual information in these kind of displays.

Our purpose is to optimize the input and output properties of the wearable user interface taking into account the physiological and cognitive boundary conditions of the human information processing system. We will also study how to improve localization and navigation in demanding operating environments, and how to support communication and collaboration between soldiers and operative decision making. One of our key aims is to identify psycho-physiological parameters or combinations of parameters measuring in the optimal way mental and physical stress in demanding operating environments and study how acceleration sensors can be used in the measurement of the user's actions and posture.

The target at this phase is to discover requirements for the presentation of information of the user's psycho-physiological state and specifications for the adaptive interface utilizing sensor information.

5 Development of the Prototype System

Based on the design requirements, the aim is to develop an integrated networked UI prototype including a wearable computer capable of gathering information from the operating environment and from the user through sensors. The system will provide context-sensitive services through multimodal user interfaces.

5.1 Wearable User Interfaces

In the development of user interfaces for wearable displays it must be taken into account the fact that novel technologies enable new types of multimodal displays. With these displays there are completely new types of user interface requirements. For example, the interface must enable fluent performance in the task; it has to provide to the user information about critical incidents without interfering the current task, i.e., the situational awareness remains intact. One possibility is to utilize ambient visual, auditory or tactile signaling. When using visual signals interface features could change slowly their color, saturation or size; when using auditory signals the interface provides a peripheral awareness of people and events. In order to provide an ability to interact with the information display while performing in external task new interaction techniques are needed. Also, there is a need for visualizations that support task performance.

Input/output devices for use with the wearable display should be carefully designed. Overall, wearable UIs present several challenges for input due to small display volume and resolution and difficulties in managing information within small screen space. Reducing the visual size of elements allows for displaying larger quantities of elements, but also makes it harder for the user to select those tiny elements. Display and input could be unattached and isolated so that the control of the device is separated from getting information from within the display.. It has to be taken into account mapping issues, visual feedback on actions (integrating tactile, auditory) and the fact that the visual space moves with the head. Input surface is also different, and the buttons are generally not visible to the user. Possible solutions to these problems have been suggested [1]. For example, the virtual targets presented in user interfaces can be "active", that is, the user interface can modify its appearance and functionality based on the users' actions. Haptic and/or auditory feedback can also be used.

5.2 Wearable Sensors

Context sensitivity can be defined as the system's ability to adapt its behavior or properties to changes in its environment. A user's context may be related to the physical attributes (e.g., time, temperature and physiological state of the body) or to the social environment of the user (e.g., recognition and identification of nearby persons and objects). Context sensitivity is based on the fact that the environment can recognize the user and the usage situation. Knowledge on time and location are typical examples, but sensors can also collect information of other features of the user and of the environment. The challenge in the development of context-sensitive systems is to recognize the user in a correct manner and to be able to predict his/her needs or to be able to behave according to the pre-specified instructions in a situationally correct manner.

The aim is to collect data from different sources and processes. Different types of sensors can be used that can be integrated to the clothes or to a separate wearable sensor platform for pre-processing. In addition, different physiological parameters can be measured, e.g., heart rate, respiration, body temperature, posture and movement. Information from the operating environment can be collected from physical location, temperature, humidity and chemical concentrations; in addition, video and sound information can be collected and transmitted. The system should also support communication within a group and between different organizational levels. In addition to speech communication, the system should be able to support the transmission of information through head-up displays or tactile displays.

6 Conclusions

One of the main lessons that we have learned from other future soldier system projects is that it is very difficult to improve an infantry soldier's situational awareness, decision-making ability, performance efficiency and performance accuracy. Therefore, we are also gathering user requirements from other demanding operating environments such as fire fighting, police operations and extreme sport. Some examples of basic requirements for a wearable system for these environments are that we should design and develop a system that does not overload cognition but supports it and provides redundancy. The system should not prevent information acquisition from the environment, and it must be ensured that critical information is always received. We should also strive for a simple and well-integrated system that is easy to use. In addition, we should carefully supervise that the weight and energy consumption of the system are minimized.

Another lesson we have learned concerns the methods for collecting data and analyzing it: Cognitive task analysis methods if applied rigidly do not necessarily provide the answers we are searching for. Therefore, these methods have to be tailored to the characteristics of the application domain and to the characteristics of the design task.

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