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Cognitive Models Applied to Human Effectiveness in National Security Environments (Ergonomics of Augmented Cognition System Design and Application

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Ergonomics of Augmented Cognition System Design and Application

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Abstract

In complex simulation systems where humans interact with computer-generated agents, information display and the interplay of virtual agents have become dominant media and modalities of interface design. This design strategy is reflected in augmented reality (AR), an environment where humans interact with computer-generated agents in real-time. AR systems can generate large amount of information, multiple solutions in less time, and perform far better in time-constrained problem solving. The capabilities of AR have been leveraged to augment cognition in human information processing. In this sort of augmented cognition (AC) work system, while technology has become the main source for information acquisition from the environment, the human sensory and memory capacities have failed to cope with the magnitude and scale of information they encounter. This situation generates opportunity for excessive cognitive workloads, a major factor in degraded human performance. From the human effectiveness point of view, research is needed to develop, model, and validate simulation tools that can measure the effectiveness of an AR technology used to support the amplification of human cognition. These tools will allow us to predict human performance for tasks executed under an AC tool construct. This paper presents an exploration of ergonomics issues relevant to AR and AC systems design. Additionally, proposed research to investigate those ergonomic issues is discussed.

Keywords

Ergonomics, human factors, augmented cognition (AC), augmented reality (AR), human performance analysis

1.0 Introduction

In today's work systems, the human operator is facing an increasing amount of data and information at the workplace. Consider the pilot, information gadgets in the cockpit provide such an enormous amount of information during flight that information workload is itself a problem [1]. In the military domain, increased data availability to military personnel has led to ever increasing demands being placed on the individual. In the air traffic controller station or monitoring command centers used in monitoring urban traffic, the operator can be overwhelmed by information creating problems associated with human error. In the described modern work systems, human operators work more with automation as either collaborators or as assistants. One of the several benefits of automation is a decrease in human crew size because of less demand for human operators to perform high risk and monotonous tasks. As a consequent of increased human-automation interaction, human tasks are now more cognitive than physical. Better-engineered systems must be developed, tested, and analyzed to support the human operator in performing cognitive tasks. This cited problem provides researchers with varieties of interest in the development of cognitive aids or devices. Among these devices is augmented reality (AR), a technology, which, among other applications, has the potential to augment and/or amplify human cognition [2].

In complex simulation systems where humans interact with artificial computer-generated agents, information display and the interplay of virtual agents have become dominant media and modalities of interface technologies. Augmented reality (AR) is an example of system in which live participants (humans) interact with computer-generated agents in real-time. Typically, AR systems involve the embellishment of a real scene, often live video, with computer-based information [3]. However, any augmentation of live exercises by virtual agents can be considered a form of AR.

AR systems can provide large amounts of information, facilitate the generation of multiple solutions in less time, and perform far better in time-constrained problem solving. Both humans and artificial agents can interact either inactively or actively to realize the system goal [4]. AR provides new paradigms for human interaction with modern information-centric work systems [5].

While AR systems provide human operators with extra assistance in performing tasks, just like the human-human work system, conflicts do exist. Unfortunately, the conflicts in human-automation systems turn out to be sensory, and are responsible for cognitive workload. This may be attributed to two important factors. One is due to human bandwidth that is often less than that of automation [6] and the other is attributed to overwhelming fatigue and stress brought to bear by human as a result of sensory conflicts between the human and the automation [7]. These situations often lead to a decrement in human performance, a condition that requires further research, so as to continue to develop better automation for human support during task performance.

2.0 Human Factors Issues of Augmented Reality and Augmented Cognition

AR presents human factors opportunities. Shewchuk, Chung, and Williges [8] assert that the "success of AR applications depends mainly on the way information is transmitted to the human operators rather than the immersive feeling or fidelity within the virtual environment". The effective fusion of reality (the real scene) with appropriate supplemental virtual objects in a single display space introduces a unique HCI design dilemma [9][2]. This dilemma pertains to human factors and related psychophysical considerations.

Psychophysical Issues
Schiffman [10] defines psychophysics as the study of the relationship between environmental stimulation (physical aspect) and sensory experience (cognitive or psychological aspect. Psychophysics is concerned with describing how an organism uses its sensory systems to detect events in its environment. This description is functional with respect to sensory system processes. Psychophysical methods allow us to ask the question: how, and how well, do people sense and resolve intensive, spatial and temporal variations in input to the human sensors. There are sparsely reported psychophysical studies relevant to AR domain. In a study by Emura & Tachi [11], subjects used AR to judge the distance, velocity and acceleration quite consistently, but with systematic errors. Delayed visual feedback (which produces a disagreement between the seen and felt time of occurrence of an event) drastically impairs performance on many tasks. Delays of 100 milliseconds can render the rapid and accurate control visual control of behavior impossible and delays greater than one (1) second essentially eliminate the visual control of behavior.

Display and Sensing Issues
When information cues are sensed through sensors at the remote site and then displayed to the operator there is always some loss of information. This loss occurs because the sensors do not pick up all the cues adequately and then again they cannot be reproduced for the operator with a high degree of fidelity. Some cues such as visual cues are easy to pick up through video cameras. Other cues such as tactile cues, are much more difficult to sense, as the technology to sense and display such cues is not yet, adequately, advanced enough. Of the many cues that could be transmitted from the remote site, visual feedback is considered vital for teleoperation [12]. According to Massimino and Sheridan [13], in presence of force feedback a decrease in the quality of the viewing conditions will have a smaller negative affect on performance than when visual information alone is present.

Motion Cues
The apparent motion of objects caused by movement of the observer through the environment provides information about the layout; for example, near objects appear to move past a moving observer more rapidly than far objects. Information is not available about objects that are too close relative to the velocity of movement to be tracked, and decreases its effectiveness to about 100 m, again, depending on the velocity of movement by the user [14].

Time Delay Issues
Task performance with AR systems is impacted by a time delay between the control input by the operator, information transmission, and the consequent feedback of its control actions visible on the display [15]. A continuous closed loop control becomes unstable at a particular frequency when the time delay in the control loop exceeds half the time period at that frequency. AR users will usually experience time delay in communication between the operator and the AR gadget, and it is sensitive to many factors that include, information bandwidth, speed of data transmission, or to computer processing capacity, and so on. Apart from the speed of communication,

considerable time can be taken by signal processing and data storage in buffers at various stages between the local site and the remote site [16][17].

Bandwidth of Communication

Communication bandwidth is a significant factor in limiting the transmission of visual data between human operators and digital information generation mechanisms. For example, the bandwidth demand of video data high and can pose tremendous time delays for the operators. Decreasing frame rate, resolution, number of bits/pixel, or using image compression devices can reduce bandwidth demand. In general, operator performance has been shown to be adversely impacted by decreases in the frame rate, resolution and grayscale [18]. For example, Massimino et al [13] reported more than a 100% increase in the task completion time when the video frame rate (in a monoscopic video) rate was dropped from 30 frames/second to 3 frames/second. In addition, a low bandwidth also contributes to a time delay, as a single visual display frame will take longer to reach the local site.

Attention

Attention is often referred to as a spotlight, with only information within the parameters of the spotlight being attended [19]. Direction of this spotlight is often modulated using attentional cueing [10]. Often employed in AR design to guide or direct the human operator's attentional resources, attentional cueing facilitates a more optimal allocation of attention in a given information space [19]. Though demonstrated to benefit the human operator's performance (i.e. target detection times), attentional cueing has been found to incur both attentional and trust costs [19]. The implementation of attentional cueing within the AR environment must be done with full consideration of human factors and ergonomic issues to mitigate the impact of these identified costs [19].

Memory

Miller [20] is one of many researchers who showed that the span of immediate memory is about 7 items in length. We can perceive large quantities of sensations, and we can hold vast amounts of information in our long-term memory, but immediate memory is the bottleneck in this information processing system. How AR and information amplification affects memory functions remains a subject of investigation in human factors.

Change Blindness

In change blindness the hypothesis is that when an object changes position within the display or disappeared completely, the observer's eyes comes to rest without noticing the change in magnitude or position. This condition is often attributed to the inattention blindness effect [21]. This effect is due to failure to notice unattended objects in the direct line of sight. Change blindness takes place while the visual scene is changed and the eyes are in motion. Substantial change blindness research has been conducted to understand this internal representation construct. O'Regan [22] provides an overview of findings as applied to the way humans build internal representation:

- the internal representation of the visual world is much sparser than suggested by subjective experience
- attention is paramount in encoding an aspect of the scene into this representation
- visual transients as residual of scene changes can bring attention to the location of the change.

These findings can be exploited in the design of the AR system.

3.0 Conclusion

Synthesis

Human factors/ergonomic issues remain a formidable challenge in AR/AC research and applications. Attention to human factors issues is paramount in AR system design; for the primary goal of the augmentation is to support the user in task performance. From rudimentary HCI design theory [2], if the user is presented appropriate information (augmentation) and that information is presented in a contextually inappropriate manner (e.g. position, frequency, size, etc.), then sub-optimal use of the information will be realized.

In summary, human factors issues are a critical component in the further development of AR technologies. Unfortunately, these issues have not received the attention they should [23][24]. This is a significant gap since our knowledge of human factors, perceptual studies and cognitive science can facilitate the design of effective AR systems. Stedmon and Stone [23] further assert that without greater attention to human factors issues and challenges the full exploitation of AR as a means for augmenting cognition will not be realized.

Future Work

Research is planned to investigate those human factors and, specifically, psychophysical issues in AR systems related to human task performance. Two primary research objectives have been defined. These objectives include:

1. Investigate the performance of human signal detection in an AR environment. This will consider multiple and simultaneous changes in sensory information characteristics. The main task is to understand how humans distinguish signal from surrounding noise using an AR system.
2. Develop quantitative models that can be used to characterize human signal detection performance in an AR environment. It is assumed that human signal performance is influenced by the quality of signal and contextual knowledge of the task.

Attentional cueing, as implemented via an AR interface, will be investigated to understand the impact of an AR environment on target detection performance.

This planned research is in support of a complex visual environment as offered by an AR interface (e.g. head-mounted display unit (HMD)) as anticipated for use by dismounted infantry in urban battlefield scenarios. It is the authors' conjecture that appropriately presented attentional cueing improves target detection performance. Experimentation will be designed to respond to the continued research calls [19] to determine presentation techniques that mitigate key ergonomic issues (e.g. attentional concerns such as cognitive tunneling) that inhibit full exploitation of AR as AC technologies.

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