R 05-80

AugCogifying the Army's Future Warfighter

Patricia May Ververs, Stephen D. Whitlow, Michael C. Dorneich, Santosh Mathan

Honeywell Laboratories
Minneapolis, MN
[redacted]

James B. Sampson

US Army Natick Soldier Center
Natick, MA
[redacted]

Abstract

The U.S. Army wants to ensure that the Future Force Warrior (FFW) will see first, understand first, act first and finish decisively as the means to tactical success. The Army of the future conceives of small combat units with netted communications enhanced with information from distributed and fused sensors, tactical intelligent assets enabling increased situation assessment, and on-the-move planning (FFW, 2004). The increase in information flow won't come without a cost, however. Information management will be a key aspect of this distributed system. The availability of such technologies as Augmented Cognition (AugCog), will allow the system to be tailored to the situational and cognitive needs of the warfighter. This paper describes an example of AugCog technology applied to a Communications System.

1 The U.S. Army Transformation

The U.S. Department of Defense (DoD) has embarked on a process of change called Transformation to create a highly responsive, networked, joint force capable of making swift decisions at all levels and maintaining overwhelming superiority in any battle space (Parmentola, 2004). In response the U.S. Army is shaping its Future Force to be smaller, lighter, faster, and smarter than its predecessor. The network will be characterized by a network of humans collaborating through a system of C4ISR (command, control, communications, computers, intelligence, surveillance, and reconnaissance) technologies.

Evidence of the Army Transformation could already be seen in the Operations Enduring Freedom and Iraqi Freedom. Some of the most visible and valuable benefits were seen in the speed of operations enabling reduction in the time to plan missions, make decisions, and coordinate and move large groups of soldiers. What was created was a more dynamic and adaptive operation built on the collective capabilities of all the participants. Unprecedented levels of integration took place among the air, naval and land forces. Stone (2003) reports, for instance, that in the middle of Afghanistan special operations soldiers could link with a Navy F-14 or link with a B-52 to pursue a target. "Special Forces on the ground have taken 19th century horse cavalry, combined it with 50-year-old B-52 bombers, and, using modern satellite communications, have produced truly 21st century capability," is a perfect example of the effect of the Transformation (Wolfowitz, 2002).

The wars in Iraq offered an opportunity to examine the direct effect of the Army Transformation. Although there are many similarities between Desert Storm and Operation Iraqi Freedom which were both conducted in the Middle East with similar objectives, to liberate Kuwait or Iraq, with similar successful results, the similarities stop there. In the time between the two wars, the Transformation was enacted, enabling operations to be conducted with substantially fewer troops (540,000 vs. 100,000 ground forces) and resulted in fewer casualties due to fratricide (Keaney & Cohen, 1993; Rumsfeld, 2003; Krepinevich, 2003). The second Gulf War used additional capabilities in Blue Force (friendly force) tracking, GPS technologies and tactical situation displays versus relying heavily on voice transmission. General Tommy Franks, who led the U.S. military operation to liberate Iraq, exploited the effectiveness that small units on the ground can have when supported by airpower. Franks recognized that linking intelligence operations with military operations was a very powerful tool for both intelligence and operational purposes (Barnes, 2003). One of the most highly publicized events, the capture of Saddam Hussein, was enabled due to the rapid intelligence gathering, network structure and high-speed decision making (Stone, 2003).

One of the core capabilities of the Transformation is the availability of netted communications enabling information sharing and real-time collaboration enhancing the kind of situational understanding that drives decisive actions. Just as was seen in Operation Iraq Freedom, FFW will be dependent on the Army command covering more area with fewer warfighters. The Future Force Warrior will have unparalleled connectivity to build situation awareness conceivably right down to the individual soldier. Part of the success will be dependent on the individual warfighter's ability to sort through the vast array of continuous information flow afforded by a full range of netted communications.

2 How Augmented Cognition can Support the Warfighter

As part of the FFW program, the Honeywell Augmented Cognition (AugCog) team is developing warfighting concepts that could substantially increase the combat effectiveness of infantry small combat units. The objective is to enhance human performance and improve survivability through more effective information management. This can only be done if we improve the overall situation awareness from the top of the command down to the adaptable small units and individual soldiers.

The Honeywell AugCog team has developed a set of cognitive measures based on real-time neuro-physiological and physiological measurements of the human operator. The capability to assess cognitive state by determining how resources are being allocated also provides the opportunity to modify the soldier's current task environment by driving adaptive strategies to mitigate information processing bottlenecks. The end result can be the appropriate allocation of attention to the right information at the right time, which is important to FFW because it directly affects two cornerstone technology thrusts within the FFW program: netted communications and collaborative situation awareness.

Early in the program, task analysis interviews concerning existing military operations identified factors that could negatively impact communications efficacy. In one such interview was with a former Army commander from the Vietnam War. The commander reviewed the breakdowns and chaos that can ensue during the execution of a raid. In this famous raid, known as the Son Tay Raid -- a mission to rescue American prisoners of war, the commander recalled the inability to hear and focus on commands once they landed at the site (D. Turner, personal interview, September 19, 2003). Even with the highly rehearsed mission, many things went wrong that day from the breakdown intelligence to the lack of the ability to communicate between teams and the ground force commander. Though the mission was not successful (i.e., the POWs were not rescued), the highly skilled units managed to fight off the enemy without a single causality to their units. The raid highlighted the need to improve the suboptimal method of communications because the soldiers and commanders were intensely focused on the tasks at hand. This need will only intensify for the Future Force Warrior, who will be inundated with information through visual displays and verbal communications, particularly during mission execution. Adding to the challenge is the requirement to cover more ground with fewer troops; these warfighters will be more reliant than ever on the communications and digital information imposed by the additional NLOS (non-line of sight) operations.

3 A new kind of information management

The research described in this paper is aimed at validating the applicability of established non-invasive neuro-physiological and physiological state detection techniques during dismounted soldier combat operations. The system takes as input the soldier's cognitive state and alters information flow and modality of presentation. The incoming information is managed by scheduling the communications to be received by the soldier at the most optimal period, offloading information or task assignments to automation when the soldier is overwhelmed, and providing information in multiple modalities (audio, visual, tactile) to ensure reception and improve comprehension. High task load conditions prompt the automation to defer all but the highest priority information, offload tasks, or change the modality of information presentation; whereas low task load conditions that lead to subsequent cognitive disengagement from the task, indicates an appropriate time for interruption to prompt greater levels of soldier participation in on-going tasks. Without these augmentations the soldier can become overloaded with information having to decide when and where to focus attention among the myriad of high priority communications and high priority tasks. By adapting the soldier's workspace to his or her cognitive state, overall joint human-automation performance can be improved.

4 AugCog Evaluation

The FFW's ability to expand the effect of the Future Force is based on the application of the full range of netted communications and collaborative situational awareness. This paper briefly describes an evaluation conducted to test the AugCog system with Army relevant operational tasks. The evaluation was aimed at collecting the physiological information and using information on the participants' workload level to drive decisions in the communications scheduling.

The evaluation was aimed at mitigating high levels of cognitive workload as induced by information overload due to high task load demands induced by a large number of communicated messages between squad members. This closed loop integrated prototype evaluation integrated a neural-net based classification of cognitive state with an adaptive system designed to maintain levels of performance under increasing task loads. The evaluation involved participants performing three Army-relevant tasks simultaneously and evaluated how effectively a sensor-driven augmentation mitigation strategy addressed increases in cognitive workload. The basic premise was to test the effectiveness of having cognitive state classification drive decisions in the communications flow to the participant. Both the effectiveness of the classification algorithms to detect the user's cognitive state and the augmentation mitigation strategies to moderate high workload states through scheduling communications was evaluated. Six participants from Honeywell Laboratories completed the 3-hour evaluation.

4.1 AugCog System Description

The AugCog System was supplied neurophysiological EEG data from a BioSemi ActiveTwo System with 32 channels. The EEG data were processed to remove artifacts generated from eye blinks using an adaptive linear filter. DC drift was eliminated using a high bandpass filter. The following frequency bands were used to estimate cognitive activity: 4-8Hz (theta), 8-12Hz (alpha), 12-16Hz (low beta), 16-30Hz (high beta), and 30-44Hz (gamma). These five bands, sampled four times per second, formed the features for the cognitive state assessment (CSA). A composite classification scheme consisting of three separate models for estimating cognitive state was employed. The final classification decision was based on an agreement from two of three models, however if there was no majority agreement the output from the nonparametric estimate (i.e., Kernel Density Estimate) was used. See Mathan, Mazaeva, Whitlow, Adami, Erdogmus, Lan, & Pavel (2005) for more information on the classification methodology.

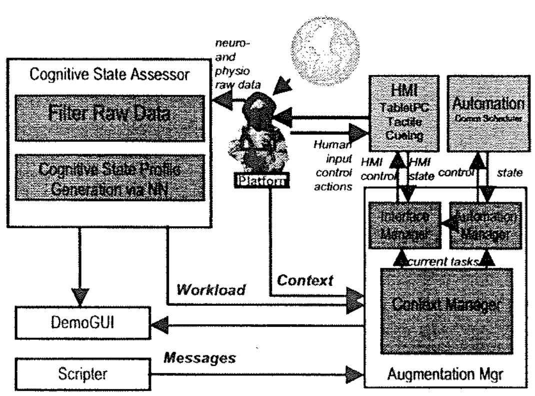

Figure 1. System Architecture

Data were integrated in an agent architecture developed at the Institute of Human and Machine Cognition. See Figure 1. The CSA, described above, determined the cognitive state of the individual and passed the information to the Augmentation Manager via a Cognitive State Profile. The Augmentation Manager contained the rules for adapting the work environment (e.g., displays, automation) to optimize the joint human-automation capability to complete specific tasks. The Communications Scheduler described below is one implementation of the Augmentation Manager.

4.2 The Communications Scheduler

The Communications Scheduler (CS) scheduled and presented messages to the participant based on the cognitive state profile, message characteristics, and the current context (tasks). Based on these inputs, the CS could pass through messages immediately, defer and schedule non-relevant or lower priority messages, escalate higher priority, divert attention to incoming higher-priority messages, change the modality of message presentation, delete expired or obsolete messages, or summarize and filter the content of messages. For this evaluation, the current CS took as input voice and text messages, reasoned over the current tasks and the cognitive state profile, and then scheduled message presentation and modality per task as needed. See Dorneich, Whitlow, Mathan, Carciofini, and Ververs (2005) for a full description of the communications scheduler.

4.3 The Tasks

The participant's cognitive state was assessed while conducting three simultaneous tasks: **target identification**, **mission monitoring**, and **maintain radio counts**. The participant acted in the role of a platoon leader. In the **target identification task**, the participant monitored static images of a MOUT (Military Operations in Urban Terrain) environment on a TabletPC for potential enemy targets. The task load varied by varying the rate of the presentation of images. See Figure 2. Simultaneously, the participant, named Red-6, monitored verbal communications comprised of two types of messages. One message type involved squad movements. In this **mission monitoring task**, communications from three squads moving in bounded overwatch were monitored. One squad (e.g., squad leader, Red-62) moved while the other two squads protected the moving squad. An example communications message included, "Red-62 to Red-6, Squad 2 is in position and ready for overwatch." The participant kept track of the location of three squads as they reported their status. When all three squads reported that they are in position (two squads ready for overwatch and one squad ready to move), the participant ordered the appropriate squad to move forward. The task load was varied by varying the rate of incoming messages. The second type of communication message involved messages between a company commander, the participant and two other platoon leaders. These messages contained reports of the number of civilians, enemies, or friendlies spotted. In this **maintain radio count task**, the participant was responsible for keeping a running total of civilians, enemies, and friendlies reported to him (Red-6), while ignoring the counts reported to the other two platoon leaders (Blue-6 and White-6). An example radio communication was, "Green-66 reporting, 4 civilians spotted, Red-6." The task load varied by varying the rate of incoming messages.

When the Communications Scheduler was activated in the mitigated condition and a high workload state was detected, all the radio count messages were deferred to the TabletPC message box as text messages while the higher priority messages regarding the squad movements were passed through. The participant was able to total the counts during a lower task load period, when the other tasks were completed. Once a high workload state activated the scheduler to redirect the low priority messages, all later messages continued to be redirected until the trial was completed. The automation etiquette and the theory behind the adaptive automation decisions are discussed by Mathan & Dorneich (2005).

Participants completed three experimental trials: low workload trial (E1), high workload with no mitigation (E2), and high workload with the mitigation strategy (E2M). The mitigation strategy (communications scheduler) was triggered by the cognitive state assessment of individual's cognitive state via neurophysiological EEG profile. Performance was measured on percentage of targets correctly identified, correct and timely response to squad movements, and correct reports of enemies, civilians and friendlies spotted by squad members.

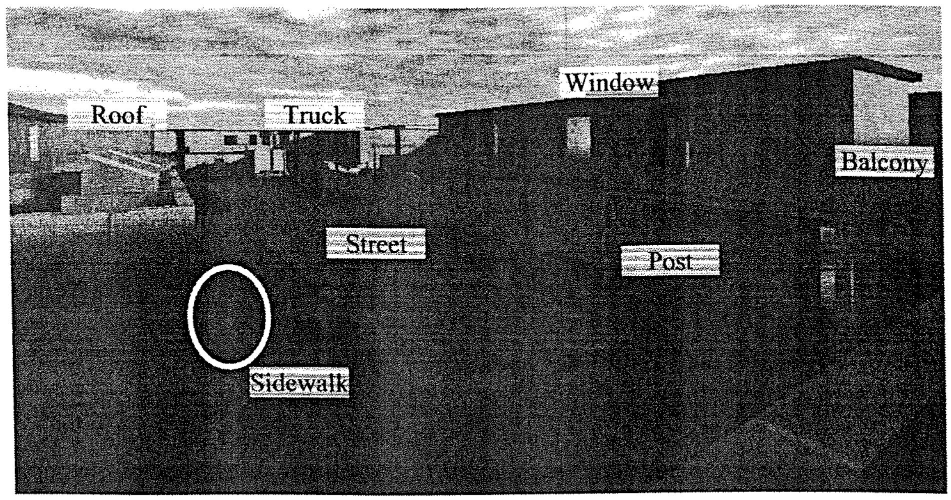

Figure 2. Target Identification Task with target identified in circle

4.4 Preliminary Findings

The main goal was to improve performance in the high task load condition when high cognitive workload states were induced by the increase in radio messages. The communications scheduler assisted the participant by rescheduling tasks to lower task load conditions. All the findings will not be covered here but a brief demonstration of the effectiveness of the cognitive state classifier and its ability to drive the mitigation strategy is described, as well as the overall effectiveness of the communications scheduler to mitigate the high workload effects induced by high task load conditions.

4.4.1 Cognitive State Classification

During the testing prior to the experiment, the system was trained on the first third of the spectral data from each experimental block and tested with the remaining two-thirds of the data; classification accuracy was close to 95%. The classifier correctly indicated a high or low workload state while the participant was performing in the corresponding high or low task load condition. However, the performance of the classifier was limited by the inherent non-stationary aspects of the EEG spectra over large time periods. Findings indicated that the classification performance dropped when the training and testing datasets were from corresponding workload conditions but different experimental blocks. When the classifier was trained and tested in this manner, classification performance ranged from 52% to 77%, with a median accuracy of 68%. Our current efforts focus on the development of technical approaches to address the problems posed by long term non-stationarity of EEG.

4.4.2 Performance data

Performance data are summarized for each of the experimental conditions: E1 – low task load, E2 – high task load, E2M – high task load with mitigation in Figure 3. In all cases in the mitigation trials, the participant's measured workload, as determined by the cognitive state assessor, reached a level to trigger the mitigation. Findings indicate that performance on the radio count accuracy and mission monitoring queries during the mitigated high task load condition (E2M) was equivalent to the performance in the low task load condition (E1). See Figure 3.

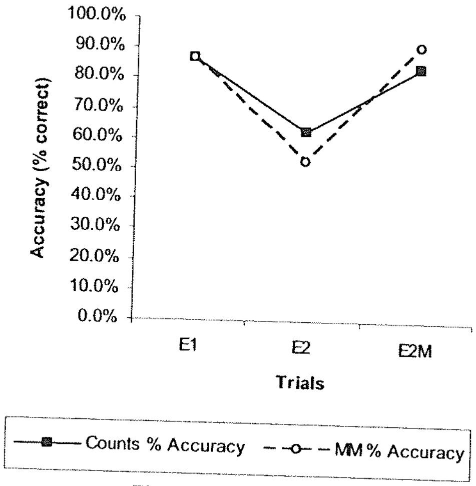

Figure 3. Percent correct (composite score) on Radio Count and Mission Monitoring tasks across three experimental conditions.

Each participants' performance was characterized as a percentage improvement in a mitigated high workload (E2M) as compared to the same condition unmitigated (E2). Overall there was a 94% improvement in the mission monitoring task [$F(1,4) = 31.91$, $p < .01$] and 36% improvement [$F(1,4) = 23.89$, $p < .01$] in the radio count recall task when the communications scheduler was available in the high workload trial as compared to the no mitigation condition. See Table 1. The scheduler offloaded the lower priority radio count messages to the visual modality and sent them to the TabletPC thereby allowing the participant to review the messages during a lower workload period. It is interesting to note that the benefit of the scheduler enhanced performance not only on the radio count task that was offloaded and completed without time pressure, but also the mission monitoring task that could be completed without the competition for resources by the competing task.

Table 1. Percentage performance improvement in mitigated condition vs. unmitigated condition.

Performance Improvement		
Participant	**Radio Count Recall**	**Mission Monitoring**
S1	27.24%	63.64%
S2	57.92%	20.54%
S3	18.51%	53.41%
S4	41.40%	110.94%
S5	47.15%	260.00%
S6	23.77%	55.56%
All	**36.0%**	**94.0%**

4.4.3 Subjective workload

The participants' perceived workload was measured using Hart and Staveland's NASA TLX scales (Hart and Staveland, 1988) for each of six indices of workload: mental demand, physical demand, temporal demand, performance, effort and frustration. Workload levels in the mitigated conditions (E2M) mirrored those of the low task load conditions (E1) and were statistically improved in the unmitigated condition (E2) for ratings of perceived frustration ($p < 0.05$), and approached significance for temporal demand ($p = 0.10$) and effort ($p = .06$). See Figure 4.

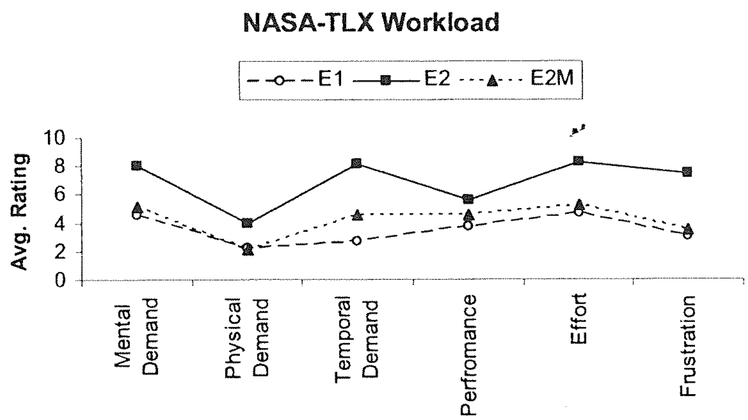

Figure 4. NASA TLX scores in three experimental conditions

5 Conclusions

The findings of the evaluation show promise for applying knowledge of an individual's cognitive state to adapt display devices to improve overall performance. However, several challenges still exist before this technology can be deployed on a dismounted mobile solder. The development of robust sensors that can reliably detect the cognitive status in real-time on a dismounted soldier in a deployed environment is a challenging endevour. However meeting this challenge provides the ability to non-invasively status the cognitive state of an individual to allow a person or system have the right information to make the right decisions and take appropriate actions. We have seen how the Army Transformation accomplished goals with fewer warfighters and resources as it attempts to harness the power of new technologies or old technologies applied in new ways. The key to success for the Future Force Warrior will be better timing, smart integration and rapid exchange of information in combat operations. The way in which the warfighters operate will continue to change. As one example, how an Army medic rapidly assesses the health of his or her distributed platoon will likely change with biosensors. As situations arise assessment of individual warfighter's level of consciousness would not be accomplished face to face manner but remotely. Therefore the ability to remotely status soldiers would better enable the right care and the right time to all warfighters. AugCog technologies could help make this happen.

The full utility of neural classifying cognitive state and its application to netted communications or other applications will continue to be explored in the future. These explorations will continue to research the use of physiological information such as heart rate, interbeat intervals, and respiration to indirectly status cognitive state as well as test the utility of neurophysiological state information generated by such devices as EEG or functional near infrared imagery (fNIR) for a more direct measure of cognitive state. If these technologies are to be deployed into a harsh battlefield environment, the sensors will need to be ruggedized and usefulness in an operational environment fully investigated.

Acknowledgments

This research was supported by a contract with DARPA and funded through the U.S. Army Natick Soldier Center, under Contract No. DAAD-16-03-C-0054, for which CDR (Sel.) Dylan Schmorrow serves as the Program Manager of the DARPA Augmented Cognition program and Mr. Henry Girolamo is the DARPA Agent. Any opinions, findings, conclusions or recommendations expressed herein are those of the authors and do not necessarily reflect the views of DARPA or the U.S. Army.

The Honeywell team would like to acknowledge the efforts of Mr. Jim Carciofini, Mr. Trent Reusser, and Mr. Jeff Rye for the implementation of the mitigation strategies, Ms. Natalia Mazaeva for EEG support and analysis, and Ms. Danni Bayn for work on the pilot studies, scenario definition, and data analyses.

References

Barnes, F. (2003, June 2). "How Tommy Franks won the Iraq war," The Commander, 008(37).

Dorneich, M.C., Whitlow, S.D., Mathan, S., Carciofini, J., and Ververs, P.M. (2005). The communications scheduler: A task scheduling mitigation for a closed loop adaptive system. To appear in the Proceedings of the 1st International Conference on Augmented Cognition, Mahwah, NJ: Lawrence Erlbaum Associates.

Future Force Warrior. (n.d.). Retrieved September 24, 2004, from http://www.natick.army.mil/ffw/content.htm.

Hart, S. G., & Staveland, L. E. (1988). Development of a multi-dimensional workload rating scale: Results of empirical and theoretical research. In P. Hancock & N. Meshkati (Eds.), Human Mental Workload. The Netherlands: Elsevier.

Keaney, T. A. & Cohen, E. A. (1993). Gulf War Air Power Survey: Summary Report. Washington, DC: Government Printing Office.

Krepinevich, A. (2003, October 21). "Operation Iraqi Freedom Outside Perspectives Capitol Hill Hearing Testimony," Available from M. Winslow, On Transformation. Retrieved on January 28, 2005 from http://www.ndu.edu/library/.

Mathan, S. and Dorneich, M. C. (2005). Augmented Tutoring: Improving military training through model tracing and real-time neurophysiological sensing. To appear in the Proceedings of the 1st International Conference on Augmented Cognition, Mahwah, NJ: Lawrence Erlbaum Associates.

Mathan, S., Mazaeva, N., Whitlow, S., Adami, A., Erdogmus, D., Lan, T., & Pavel, M. (2005). Sensor-based cognitive state assessment in a mobile environment. To appear in the Proceedings of the 1st International Conference on Augmented Cognition. Mahwah, NJ: Lawrence Erlbaum Associates.

Parmentola, J. A. (2004). Army transformation: Paradigm-shifting capabilities through biotechnology, The Bridge, 34(3), The National Academy of Engineering of the National Academies. Retrieved January 28, 2005 from http://www.nae.edu/NAE/ bridgecom.nsf.

Rumsfeld, D. (2003, July 9). Lessons Learned from Operation Iraqi Freedom Capitol Hill Hearing Testimony. DefenseLink. Retrieved January 28, 2005 from http://www.defenselink.mil/speeches/2003/sp20030709-secdef0364.html.

Stone, P. (2003). Cebrowski Sketches the Face of Transformation. Retrieved January 28, 2005, from: http://www.defenselink.mil/news/Dec2003/n12292003_200312291.html.

Wolfowitz, P. (2002, April 9). The Imperative for Transformation. Prepared Statement for the Senate Armed Services Committee Hearing On Military Transformation. United States Department of Defense, Washington, DC. Retrieved February 4, 2005 from http://www.defenselink.mil/speeches/2002/s20020409-depsecdef2.html

FOUNDATIONS OF AUGMENTED COGNITION

VOLUME 11

Edited By

Dylan D. Schmorrow

LEA LAWRENCE ERLBAUM ASSOCIATES PUBLISHERS
2005 Mahwah, New Jersey London

Lawrence Erlbaum Associates, Inc., Publishers
10 Industrial Avenue
Mahwah, New Jersey 07430

ISBN 0-8058-5806-7

Books published by Lawrence Erlbaum Associates are printed on acid-free paper, and their bindings are chosen for strength and durability.

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

Foreword

With the rapid introduction of highly sophisticated computers, (tele) communication, service, and manufacturing systems, a major shift has occurred in the way people use technology and work with it. The objective of this book series on Human Factors and Ergonomics is to provide researchers and practitioners a platform where important issues related to these changes can be discussed, and methods and recommendations can be presented for ensuring that emerging technologies provide increased productivity, quality, satisfaction, safety, and health in the new workplace and the Information Society.

The present volume is published at a very opportune time, when the Information Society Technologies are emerging as a dominant force, both in the workplace, and in everyday life activities. In order for these new technologies to be truly effective, they must provide communication modes and interaction modalities across different languages and cultures, and should accommodate the diversity of requirements of the user population at large, including disabled and elderly people, thus making the Information Society universally accessible, to the benefit of mankind.

Augmented Cognition is a rapidly evolving disciple being the brain child of Dylan D. Schmorrow, a Program Manager at DARPA and ONR, and Commander in the U.S. Navy. This book is the proceedings of the 1st International Conference on Augmented Cognition jointly held with HCI International 2005 Conference in Las Vegas, July 22–27, 2005. The 2nd International Conference on Augmented Cognition will be held in conjunction with the Human Factors and Ergonomics Society 50th Annual Meeting, October 15–16, 2006 at the San Francisco Hilton in San Francisco, CA. The 3rd International Conference on Augmented Cognition will be held jointly with HCI International 2007 in July 22–27, 2007 in Beijing, P.R. China (http://www.hcii2007.org/).

The book's five sections and 24 chapters present the theoretical foundation and operational models for the understanding, design and operation of engineering systems requiring increased interaction with humans. The effectiveness of the operation of such systems is significantly unchanged through augmented cognition integration into the human information processing utilized for decisions and actions.

The book would be of special value to individuals working in human-computer interaction, human factors and ergonomics and cognitive science who are interested to learn today where the future of the discipline will lead.

—Gavriel Salvendy
Purdue University, USA
Tshighua University, P.R. China