

The Importance of Psychophysiological Methods in Identifying and Mitigating Degraded Situation Awareness

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Abstract—Herein we delineate the relationship between poor joint human automation interaction (HAI) system performance and situation awareness (SA) focusing on the effect of system design. Degraded SA is one reason that human users make poor interaction decisions that cause joint system performance to suffer. One key reason for degraded SA is the hierarchical design where the human user is at the apex of the command hierarchy. Within this structure the human user is not able to be fully integrated into the system, which can lead to ‘out of the loop’ performance issues. We propose that SA could be measured in real time by leveraging psychophysiological methods often used in cognitive neuroscience research. We then discuss a potential framework that could not only identify degraded SA in real time, but could mitigate these degradations. Such a framework would be successful because it would genuinely integrate the human user into the system, essentially closing the loop that underlies joint system failures.

Keywords—*psychophysiology; human automation interaction; cognitive neuroscience; decision making; situation awareness*

I. INTRODUCTION

Human automation interaction (HAI) systems continue to pervade modern life, but HAI system performance has yet to completely meet expectations for multiple reasons. A key reason for this failure is that the inclusion of automation fundamentally changes the way humans perform tasks, typically by putting the human user into a supervisory role. This role most often results from hierarchical automation designs in which the human user is most often put at the apex of the command pyramid. In a supervisory role, humans tend to be poorly integrated with the automated systems often resulting in their being ‘out of the loop’ [1-4]. When the human user is ‘out of the loop’, or not fully integrated into the system SA may become degraded. This is because SA is a function of the human user’s available attention and working memory with which to acquire and interpret environmental information [5] and when a user is ‘out of the loop’ attention may not be directed to the current task. Degraded SA leads to decreased awareness of automation mode or knowledge of task completion [6-8] and has been linked to poor interaction between humans and automated agent [1, 2, 7] Furthermore,

this degradation can be exacerbated by excessively high or low workload [10]. Degraded SA can result in tragic consequences in high risk domains such as in military or nuclear power plant applications [5, 8]

Given the consequences of degraded SA, identification and mitigation of instances when it is degraded could be considered an important aim in improving joint human automation system performance. We propose that modern methods for monitoring and measuring psychophysiological variables such as electroencephalography (EEG), galvanic skin response (GSR), and eye tracking might be utilized to identify degraded SA. This approach diverges from the standard approach that uses a freeze probe paradigm. Further, herein, we describe an extension of a control theoretic framework that we and our colleagues at the Army Research Laboratory (ARL) are developing and testing. In our particular application of this framework, we aim to leverage psychophysiological and control-systems methods in order to mitigate degraded SA by facilitating improved integration of the human user into the system in a real world application. This paper discusses the importance of SA to HAI system performance, and forwards psychophysiological methods and approaches that might be leveraged to effect a more seamless integration of the human user into the HAI system, essentially closing the loop, which would result in HAI systems meeting performance expectations.

II. SITUATION AWARENESS AND ITS IMPORTANCE IN HAI SYSTEM PERFORMANCE

Situation awareness is critical for human operators interacting with automated systems. In many, if not most, current human-automation systems, human users assume a supervisory role where any human action is assumed to be correct. Because humans are not ideally suited to the role of a monitor, human users can find themselves ‘out of the loop’ [4], and are therefore often not fully integrated into the HAI system. Given enough time, humans often fail to remain vigilant about the current state of task completion, and of the automation functioning. Poor vigilance might be an important contributor to decreased SA, and SA is immensely important

to the performance of human-automation systems. The current lack of perfect automation means that it is necessary for a human user to maintain optimal SA (high vigilance) to be able to intervene in a timely manner, particularly in tasks of high consequence. However, vigilance studies have shown that maintaining this level of SA over time is extremely difficult [6]. Maintaining optimal SA requires the ability to measure SA levels frequently, and perhaps continuously, in order to determine when SA levels become suboptimal. Further, it would be ideal to be able to mitigate degraded SA, but this mitigation remains a challenge [6, 9].

Currently, SA levels are commonly assessed by instruments that query human user's perceptions of their own levels of SA at discrete times, such as the Situational Awareness Global Assessment Technique (SAGAT) [10-12]. Instruments such as the SAGAT, while perhaps not cognitively intrusive [12], have limited temporal resolution because they are temporally discrete queries, and require interruption of the task at hand. Further, they are unable to objectively measure psychological states such as workload, and therefore, unless coupled with other instruments such as NASA-TLX they are unable to disentangle the interaction between these psychological states and vigilance based SA degradation. This inability means that these methods alone do not necessarily inform an appropriate action needed to improve SA [12]. These measures are valid at identifying the state of all three SA levels [13], and SA research has provided valuable design assistance to human factors engineers [9], but there currently lacks a robust method to continuously measure SA levels without interruption to the human user. This lack of a continuous measure hinders subsequent mitigation of degraded SA in situ. Therefore real world applications aimed at the mitigation of degraded SA in HAI systems in real time, allowing true human integration, are currently unavailable.

III. THE USE OF PSYCHOPHYSIOLOGICAL METHODS TO IDENTIFY AND MITIGATE DEGRADED SA

A. Identifying and Mitigating Degraded SA

Non-invasive psychophysiological methods can be leveraged to successfully identify degraded SA [14] through identifying psychological and physiological correlates of performance metrics. We believe that these methods may accurately allow an inference of the possible exacerbating reasons for degraded SA using state estimations derived from the psychophysiological data. If degraded SA is identified and an inference can be made as to underlying causes, it can be mitigated. Unlike other SA measures, these suggested methods can be done continuously, in real time, and without interruption to the user, thereby improving the probability of detection and mitigation of degraded SA in a real world application. We acknowledge that SA is a complex state, and will not easily be detected from simple psychophysiological methods. Instead we propose that identifying degraded SA will require fusion of information from multiple

psychophysiological methods. Two examples are highlighted below.

One potential source of information regarding SA is event related potentials (ERPs) derived from EEG data [14]. ERPs generated in response to visual targets are significantly affected by whether or not a person has conscious perception of a stimulus [15, 16]. Detection of whether a person has conscious perception of a stimulus is related to the rate of Change Blindness, which is an important indicator of SA [6, 17, 18]. Change Blindness is the inability to detect transient or intransient target changes. Algorithms designed to detect ERP changes indicative of Change Blindness may provide insight into changes in SA. While it is true that real time measurement of ERPs is difficult, algorithms allowing this are being developed for brain computer interaction applications [19-21].

While EEG based methods may provide insight into Change Blindness, eye tracking based information may provide insight into the focus of attention. Specifically, eye tracking will enable detecting attention directed towards important environmental information, which is central to SA [22]. Human gaze fixation indicates what stimuli are more likely being attended, and therefore gaze fixation literally provides a trace in time of what probable features or stimuli are the object of current cognitive processes [23-25]. If gaze fixation is not targeted on relevant information, it could be argued that the likelihood of degraded SA is high [26]. Alternatively, if gaze fixation is appropriately located, we might conclude that the person is potentially exhibiting good SA. In this case, we would rely on other measures of SA from other psychophysiological methods to clarify the current psychological state of the human user.

While we only present two here, many other psychophysiological methods could be included in a system to detect SA. For example, pupil diameter and EEG features have been related to level of arousal [27]. GSR and heart rate variability have been related to stress [27, 28], and a number of EEG based features in combination with heart rate variability, GSR, and pupil dilation have been linked to workload [27, 29-33]. Each of these states (arousal, stress, and workload) likely interacts with SA and thus estimates of these states can be coupled with the examples given above to provide a robust method for identifying changes in SA, or for disambiguating the causes for degraded SA.

If we are able to identify degraded SA, then the next step is to find techniques to mitigate this change in state. As discussed above, a critical cause of degraded SA, regardless of psychological state, is when the human user is 'out of the loop' [3, 4, 34] and not integrated within it. This lack of integration might be a direct function of the hierarchical design of most, if not all, HAI systems. It would seem, therefore, that central to mitigating degraded SA would be the genuine integration of the human into the system; to put them 'back into the loop' so that the system functions as a whole. Genuine human automation integration would allow collaboration between human and automation that leverages

each agent's unique capabilities, and allow the automation to respond to the highly varying psychological states of the human user such that tasks can be shared dynamically. While there have been multiple attempts at dynamic function allocation [35-38], most have adhered to the hierarchical design which puts the human user 'out of the loop' and assumes the human as being automatically correct, despite strong evidence of human variability and fallibility.

B. Proposed Framework for Mitigating Degraded SA

At the Army Research Laboratory, others and we have been working to develop the *Privilege Sensing Framework (PSF)*. The PSF aims to integrate the human user by treating her as a special type of sensor, one of many, but with certain privileges defined to dynamically account for variability in her performance as balanced against the consequence structure of the task. This approach is different than previous uses of psychophysiological methods to improve HAI, because the key here is human automation integration rather than mere interaction, an important point of discussion in the sensor fusion community [39].

As applied to the context of SA mitigation, our application of this framework would appear as represented in Figure 1.

Privilege here refers to the amount of weight given to one set of sensor data, over another, during data fusion and analysis. The privilege each sensor is accorded is not static, but dynamic and would be mathematically derived, based on confidence estimates of data quality from each sensor, consequence of the task, and on the special properties of individual agents, such as cognitive flexibility and social understanding on the part of the human sensor. Simulations using rapid serial visual presentation and EEG data in human-computer coupled target detection tasks done at ARL have shown the theoretical possibility for improving HAI performance by using one aspect of privilege, namely confidence estimates, [40] as a way to weight the value placed on data from any sensor, including a human sensor. In our proposed application of this framework, psychophysiological data from the human user would be continuously monitored for SA degradation and changes in accompanying psychological states. If a lack of SA was identified, the system could dynamically change task allocation appropriate to the current psychological state of the human user. This responsiveness to the needs of the human user engenders a collaborative effort, and both accommodates

Human User State and Performance Sensors

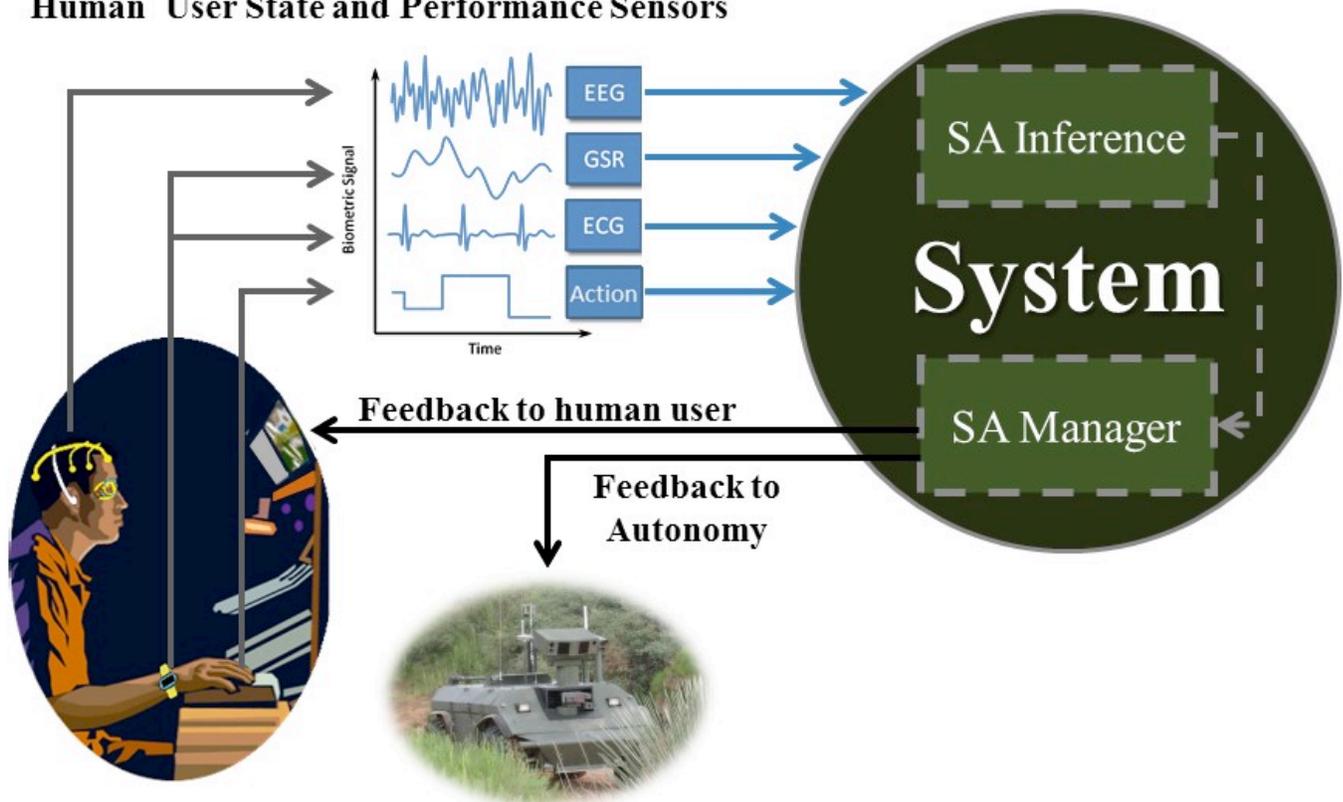


Figure 1. A representation of a proposed application of our framework to identify and mitigate degraded SA by fully integrating the human user into the HAI system. Psychophysiological data is gathered by human user state and performance sensors and interpreted by the central framework, which then acts to correct degraded SA based on the current state of the human user

and incorporates inputs from the sometimes fallible human user.

An engineering solution to such a framework would be implemented as a stable closed controlled system and might operate in the following way. Envisage a human automation integrated system designed for target detection which receives estimates from each sensor, human or automation, on the likelihood of a target existing in a visual stream. In such a system, psychophysiological data from the human user would be collected and analyzed in real time. Specifically, EEG data would be used to detect Change Blindness or, in conjunction with GSR, heart rate and pupilometry data, a change in mental state that would be likely to degrade SA. For example, high variation in pupil diameter, an increased tonic GSR level sampled in three-second epochs, and reduced heart rate variability indicates excessive workload [27, 29-33]. A central system, having identified degraded SA could adaptively respond in two important ways. First, because this is an integrated system where the human is allowed to be fallible, the system could temporarily increase the privilege of the automated sensor data until SA is regained, and overall joint system performance can be preserved. Secondly, the psychophysiological data can be used for inferring an underlying cause for SA such as increased workload or fatigue.

If an increased workload underlies the degraded SA, the system could adaptively respond by dynamically reallocating task demands, freeing up cognitive resources, and thereby allowing the cognitive processes necessary for SA recovery to begin [41]. Alternatively, if a low workload is identified, the response might be to increase task demands as boredom and low workload exacerbate degradation of SA [42].

IV. CONCLUSION

We recognize that one of the reasons HAI systems have not yet met considerable expectations is due to fallible human user decision making about how to interact with the automation. These interaction decisions are often negatively affected by degraded SA, which in part may be a result of the hierarchical HAI system design with the human at the top of the pyramid, rather than integrated into the system; making it possible for the human user to be 'out of the loop.' Optimal SA is critical to appropriate interaction decisions because in this state a human user can readily assess the state of the automation and understand implications of environmental information such that a response to an error, or an intervention, can be made in a time critical fashion. We propose that it is feasible to monitor SA in real time using psychophysiological methods such as eye tracking and EEG such that moment-to-moment levels can be measured and degraded SA identified.

We further forward the idea of using these SA estimates along with psychological state estimation to more fully

integrate the human user into the HAI system; in accordance with the concepts forwarded in this paper, the human is no longer at the top of the command hierarchy. This would allow a real time mitigation of degraded SA. Although further research is necessary to implement such a system, its benefits include an enhanced collaboration between human and automation in a system that is responsive in real time. Further research avenues into developing robust estimates of SA levels with psychophysiological data are necessary, although we believe it is possible. In addition, research into fundamental techniques for sensor fusion and management is imperative because the data features may be derived from data with multiple time scales, i.e., minutes to milliseconds, and may also contain varying degrees of corruption or error. Future research into the measuring and managing of psychological states such as SA and workload is planned and underway. Such an application of this framework would be critical for HAI systems across a number of application spaces.

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