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Empirical verification for application of Bayesian inference in situation awareness evaluations

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ABSTRACT

Bayesian methodology has been widely used in various research fields. According to current research, malfunctions of nuclear power plants can be detected using this Bayesian inference, which consistently piles up newly incoming data and updates the estimation. However, these studies have been based on the assumption that people work like computers—perfectly—a supposition that may cause a problem in real world applications. Studies in cognitive psychology indicate that when the amount of information to be processed becomes larger, people cannot save the whole set of data in their heads due to limited attention and limited memory capacity, also known as working memory.

The purpose of the current research is to consider how actual human aware the situation contrasts with our expectations, and how such disparity affects the results of conventional Bayesian inference, if at all. We compared situation awareness (SA) of ideal operators with SA of human operators, and for the human operator we used both text-based human machine interface (HMI) and infographic-based HMI to further compare two existing human operators. In addition, two different scenarios were selected how scenario complexity affects SA of human operators. As a results, when a malfunction occurred, the ideal operator found the malfunction nearly 100% probability of the time using Bayesian inference. In contrast, out of forty-six human operators, only 69.57% found the correct malfunction with simple scenario and 58.70% with complex scenario in the text-based HMI. In infographic-based HMI, however, 93.48% subjects found the correct malfunction with simple scenario and 84.78% found the correct malfunction with complex scenario.

This paper shows the difference of SA between human operators and ideal operators. In addition, SA is affected by complexity of scenarios and design of HMI. It can provide useful insight in to enhancing human performance for securing the safe operator of nuclear power plants.

1. Introduction

Failure of safety critical systems such as nuclear power plants (NPPs), airplanes, and railways may cause the loss of life, significant property damage, or damage to the environment (Knights, 2002). A report by the Institute of Nuclear Power Operation (INPO) says that about 48% of the total NPP events from 2010 to 2011 were a result of human error (KONIS). The Chernobyl accident, attributed mainly to human error, illustrates the importance of human performance (Meshkati, 1991). In this regard, a vast amount of research has been conducted in order to reduce the occurrence of human errors in safety critical systems (Bogner, 1994; Mason et al., 2001).

For that, there have been plenty of researches to increase situation awareness (SA) of operators which are used to explain to what extent operators of safety-critical and complex real systems know what is going on in the system and the environment (Endsley, 1995a,b). Thus, the need for operators to maintain SA in complex and dynamic environments is frequently cited as key to effective and efficient performance considering that SA dictates the ability to initiate correct actions given a particular situation and to respond properly to system feedback (Lee et al., 2012).

So far, several qualitative SA models have been developed, with most of these qualitative SA models providing descriptions for the SA process (Endsley, 1995a; Bendy, 1999; Adams, 1995). These models essentially describe the basic principles and general features regarding how people process information or interact with the environment to attain SA. Though these models are very helpful for understanding the process of SA when analyzing events retrospectively, their descriptive and qualitative nature is limiting in terms of helping us predict what will happen in various situations (Kim and Seong, 2005).

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To understand the behavior of operators under off-normal situations in NPPs, we need quantitative (prescriptive) models that can be used to predict what will happen in various situations. Currently, however, only a few quantitative SA models, such as that by Miao et al. (Miao, 1997), have been developed (Kim and Seong, 2005). There have been several papers related to the SA of operators using Bayesian inference, but those papers all assumed that operators are ideal or highly experienced (Kim and Seong, 2005; Miao et al., 1997).

It is indisputable that not all human operators in NPPs are either highly experienced or ideal. Human operators who are not ideal may not be able to perfectly follow Bayesian inference. Thus, it is necessary to understand the SA process by actual human operators.

The first objective of this study is to estimate the SA of human operators using Bayesian inference. The result of estimating human operators' SA is then compared to the results of ideal operators' SA. The second objective is to investigate how human operators' SA can be changed if the complexity of scenario and design of HMI is changed. In order to achieve these objectives, the SA of ideal operators were calculated and human operators' SA were estimated using lab-scale experiments. In addition, by improving HMI, the SA of human operators significantly increased. This can provide useful insight into enhancing human performance for securing the safe operation of NPPs.

2. Literature review on SA

2.1. Existing methods for evaluating SA

SA is defined as a person's "Perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1988). SA consists of three levels: perception of elements in the environment (level 1 SA); comprehension of their meaning in relation to task goals (level 2 SA); and projection of their status in the near future (level 3 SA). It is said that operator achievement of higher levels of SA is dependent upon the extent to which one accurately and completely perceives states of the task environment (Ma and Kaber, 2005).

Freeze probe techniques, real time probe techniques, observer rating techniques, subjective rating techniques, process indices, performance measures, and team measures are representative SA measurement tools as addressed by the Human Factors Integration Defense Technology Center (HFI, 2007). SA global assessment technique (SAGAT), developed by Endsley, is currently the most popular freeze probe technique (Wilson and Sharples, 2015). The SA rating technique (SART) is a widely used subjective rating technique developed by Taylor (Endsley et al., 1998). The SA behavioral rating scale (SABARS) is an observer rating technique developed by Matthews and Beal (Matthews and Martinez, 2005). There are a huge number of SA measuring methods (techniques) based on seven approaches. Even though these models are very helpful for understanding the process of SA when analyzing events retrospectively, their descriptive and qualitative nature is limiting in terms of helping us predict what will happen in various situations (Kim and Seong, 2005). In this study, in order to estimate SA quantitatively, Bayesian inference was applied, providing predictions for what will happen in various situation.

However, current researches using Bayesian methodology to evaluate operators' SA assume that all operators are ideal or highly experienced operators that can process information like a computer during the study (Kim and Seong, 2008; Lee et al., 2008; Lee and Seong, 2009). Such ideal operators always judge the situation perfectly; they receive information (input data) without exception and handle (process) this information without any mistakes. In addition, they are not affected by their work environment or personal feelings. In contrast, non-ideal human operators often cannot observe or memorize all information—as such, they sometimes make mistakes.

2.2. Influencing factors of SA

The SA of ideal operators and human operators are different because human information processing is seriously affected by human attention and memory, as shown in Fig. 1 (Wickens, 2012). Human information processing is significantly related to operators' SA. The human information processing has been best represented by Endsley's theoretical three level of SA (Stanton et al., 2001). Once operators receive information, they are then able to understand the situation. Three factors affect human information processing. First, working memory is a part of the human memory system with a limited capacity that combines temporary storage and manipulation of information in the service of cognition. Second, long-term memory refers to the storage of information over an extended period. If someone can remember something that happened more than just a few moments ago, whether it occurred just hours ago or decades earlier, then it is a long-term memory. Last, attention is the behavioral and cognitive process of selectively concentrating on a discrete aspect of information, whether deemed subjective or objective, while ignoring other perceivable information. Attention has also been referred to as the allocation of limited processing resources (Anderson, 2004). Therefore, finding how attention and memory affect the SA of human operators is important—but it is not easy because every operator has a different short-term memory capacity and has different kinds of information in their long-term memory.

In the case of working memory, this study applies Miller's theory, which argues that most adults can store between 5–9 items in their working memory (Miller, 1956). Because most adults can store at least 5 items, two scenarios are needed to compare the effects of SA of human operators. This study is thus divided into two scenarios, with one scenario requiring human operators to remember proper number of items and the other scenario requiring a larger capacity of items in terms of working memory.

Attention is influenced by various contexts, such as the operators' feelings and work environment, such as HMI, alarm system (sound), etc. To induce better visual attention, an infographic tool that is based on salience, effort, expectancy and value (SEEV) model is applied in this study (Wickens, 2012). Salience and effort are bottom-up influences, while expectancy and value are top-down influences. Salience includes changes in color or shape, size of an object, flashes, and any other conspicuous factors that capture people's attention, while effort acts as a guideline, such as arrows, that help people's understanding. In contrast, expectancy and value require pre-existing knowledge. In other words,

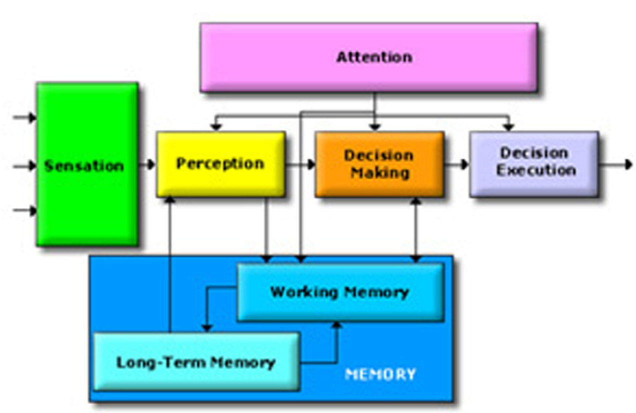

Fig. 1. Human information processing.