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Original Article

Method for Inference of Operators' Thoughts from Eye Movement Data in Nuclear Power Plants

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A B S T R A C T

Sometimes, we need or try to figure out somebody's thoughts from his or her behaviors such as eye movement, facial expression, gestures, and motions. In safety-critical and complex systems such as nuclear power plants, the inference of operators' thoughts (understanding or diagnosis of a current situation) might provide a lot of opportunities for useful applications, such as development of an improved operator training program, a new type of operator support system, and human performance measures for human factor validation. In this experimental study, a novel method for inference of an operator's thoughts from his or her eye movement data is proposed and evaluated with a nuclear power plant simulator. In the experiments, about 80% of operators' thoughts can be inferred correctly using the proposed method.

1. Introduction

Sometimes, we need to figure out somebody's thoughts from his or her behaviors such as eye movement, facial expression, gestures, and motions. Usually, inference of somebody's thoughts from his or her behaviors is associated with a lot of uncertainty, because the same behaviors might have different meanings depending on the context. However, if a person is carrying out his or her job in a very specific situation, the uncertainty coupled with the inference of the person's thoughts from his or her behaviors can be reduced and the inference of thoughts could be utilized for some useful applications. Operational tasks in control rooms of nuclear power plants (NPPs) are one of the representative examples that have very specific job characteristics. Generally, operators' tasks in NPPs constitute cognitive activities such as monitoring and detecting the environment; understanding, assessing, and diagnosing situations; decision making; planning responses; and implementing responses [1]. If operators' thoughts on a situation (or diagnosis result) can be inferred from the observation of their behaviors, this knowledge would have great potential for enhancing safety during NPP operation. As shown in the Tree Mile Island accident, a correct diagnosis has been considered as one of the most critical contributions to safe operation of NPPs

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[2]. As digitalized instrumentation and control systems have rapidly been applied to various plant systems including NPPs, operators' role in advanced control rooms has been changed from a controller to a supervisor [3–5]. In the majority of cases, the primary means of information input to operators in NPP control rooms is through the visual channel. Operators in NPPs are required to monitor several information sources such as indicators, alarms, controllers, and mimic displays provided in advanced control rooms, but they have limited capacity with respect to attention and memory. Hence, NPP operators pay selective attention to relevant and important information sources to effectively understand the current status [6].

Yarbus [7] conducted an important eye tracking research, showing that the task given to a person has a very large influence on that person's eye movement. The eye movement pattern during examination of pictures was dependent not only on what was shown in the picture, but also on the problem faced by the observer and the information that he or she hoped to gain from the picture. Eye movement data have also been studied in the field of intention inference. A fuzzy inference method was proposed to infer human intentions from eye movement data during monitoring of tasks on a computer screen [8]. The intention of the observer to move eye gaze from one point to another on the screen was inferred by applying a fuzzy logic based on a fuzzy set. A truck driver's intention to change lanes could be detected and inferred from his or her eye movement data [9]. The driver's eye movement pattern while changing the lane was analyzed, and a state transition model representing the likelihood of the driver changing the lane was developed based on the analyzed pattern. The authors have developed measures of fixation to importance ratio (FIR) and selective attention effectiveness (SAE) based on eye movement data, which represent how effectively an operator attends to important information sources as measures of attentional-resource effectiveness in monitoring tasks [10]. The FIR is the ratio of attentional resources (i.e., the number and duration of eye fixations) used on an information source to the importance of the information source. The SAE incorporates the FIRs for all information sources. In this experimental study, a novel method for inference of the operators' thoughts (understanding or diagnosis of a current situation) from their eye movement data is proposed and evaluated. The inference method is based on the FIR and SAE evaluation. In the second section, the cognitive processes of attention, understanding, and diagnosis are addressed to understand the principles underlying the method of approach, and the FIR and the SAE are introduced. The inference method is explained with examples of accidents occurring in NPPs. The experimental study is addressed in the third section followed by discussion in the fourth section, and the conclusion in the fifth section.

2. Inferring operators' thoughts from eye movement data

2.1. *Attention, understanding, and diagnosis in NPPs*

NPP operators generally keep monitoring the plant systems to detect any problems that may take place during normal operation. If an abnormal situation is detected, they search for relevant information sources to figure out what the problem is. Information processing is dependent on a pool of attention or mental effort, which is of limited availability and can be allocated to processes as required [11]. In terms of attentional resources, selection of information sources for further information processing should be addressed, as well as dividing attention between tasks. Selection of information sources is governed by salience, expectancy, value, and effort [12]. Salience refers to stimuli in the environment such as alarms, alerts, or some remarkable indication prompting attention. Expectancy makes attention shift to specific sources that are most likely to provide information. The value of the information source adjusts the frequency of looking at it. If too much effort is required in comparison with the value of the information source, attention might be restricted. The first studies on monitoring or information searching behavior were carried out for flight maneuver tasks in the late 1940s and early 1950s [13–15]. The relative importance (value) of information sources was reported as a governing factor in information searching behavior during flight maneuver tasks [15]. Senders showed that bandwidth (event rate) also plays a significant role in monitoring tasks [16], which have been subsequently elaborated to consider value with the bandwidth by a lot of researchers [17–40]. The bandwidth contributes not only to expectancy, but also to value. It provides operators with the expectancy of the location of information sources and valuable information for diagnosis in more detail. For example, if there is a rupture of a pipe through which water flows, the change in the flow rate of water due to the rupture provides information on the size of the rupture. Effort and salience may influence the selection of information sources to the extent that designers have adhered to good human factor practice in display layout [26]. Hence, effort and salience should be considered during the design phase by correlating effort and salience with expectancy and value.

When multiple tasks require to be performed at the same time, a strategy must be developed for dividing attention or allocating resources between tasks [41,42]. Perception or understanding consists of three simultaneous processes: bottom-up processing, top-down processing, and unitization (or matching). Stimuli or salient information sources derive the bottom-up processing through sensing mechanisms. After detecting a stimulus, the information is matched to a mental model that is established based on knowledge and experience. The effective selection of information sources is made by expectancy derived from the mental model, which is referred to as top-down processing. The chain of bottom-up processing, top-down processing, and unitization is the process of perception or understanding. A lot of information sources are provided in NPP control rooms, and operators have limited capacity of attention and memory. Operators have to selectively allocate their attentional resources. Selective attention is employed to overcome the limitations of human attention, making use of both top-down and bottom-up processes [12]. In abnormal situations in an NPP, operators collect a bunch of information from the human–machine interface (HMI) or other operators, and try to understand the abnormal situation, which is a process of establishing a situation model based on their mental model. The situation model is constantly updated as new information is received [43]. The mental model