Can Operator's Thought Be Inferred from Eye Movement Data?

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1. Introduction

Correct situation awareness (SA) has been considered a crucial key to improving performance and reducing error in NPPs [1]. There are a lot of information sources that should be monitored in nuclear power plants (NPPs), but operators have only limited capacity of attention and memory. Operators in NPPs selectively attend to important information sources to effectively develop SA when an abnormal or accidental situation occurs. Selective attention to important information sources is continued while maintaining SA as well.

The authors have developed measures of attentional resource effectiveness in information searching such as FIR (Fixation to Importance Ratio) and SAE (Selective Attention Effectiveness) which represent how effectively an operator attends to important information sources [2]. The FIR is the ratio of attentional resources (i.e. the number and the duration of eye fixations) spent on an information source to the importance of the information source as follows:

$$FIR^N(i) = \frac{\frac{N_i}{\sum_{i=1}^{k} N_i}}{\frac{\omega_i}{\sum_{i=1}^{k} \omega_i}} \quad \text{and} \quad FIR^D(i) = \frac{\frac{D_i}{\sum_{i=1}^{k} D_i}}{\frac{\omega_i}{\sum_{i=1}^{k} \omega_i}}$$

$$FIR(i) = \frac{FIR^N(i) + FIR^D(i)}{2} \tag{1}$$

where, $FIR^N(i)$ = FIR with respect to number of fixations
$FIR^D(i)$ = FIR with respect to duration of fixations
N_i = the number of eye fixation on information source - i
k = total number of information sources
ω_i = importance of information source - i

The SAE incorporates the FIRs for all information sources.

$$SAE = \frac{\sum_{i=1}^{k} |FIR(i) - 1|}{k} \tag{2}$$

Theoretically, the SAE should approach to zero for the best effectiveness. The underlying principle of the measures is that information sources should be selectively attended to according to their informational importance. The importance of information sources depends on the state of a NPP. For example, the importance of the pressurizer level for loss of coolant accident (LOCA) is different from that for steam line break (SLB). Hence, sets of importance for information sources should be evaluated for all possible events. The FIR and the SAE have also been used as performance measures in a HMI evaluation method named "DEMIS (Difficulty Evaluation Method in Information Searching) [3].

In this study, Operator's thought is inferred with the eye movement data during complex diagnostic tasks in NPPs. SAEs are calculated with the eye movement data for all possible events (e.g., accident, incident, or transient) in NPPs. Inference of operator thought is made by analyzing the calculated SAEs. Theoretically, the event coupled with the best SAE value should be the real situation (real event).

2. Method of Approach

Information-processing theory claims that perceived information always passes through a filter, i.e. some information is cognitively processed, while other information is not [4]. Usually, operators in NPP MCRs (Main Control Rooms) are trained periodically to get the knowledge for operating a NPP. Well constructed knowledge facilitates establishing the mental model regarding plant system dynamics during NPP operation. Importance of individual information sources can be determined based on the mental model (or the knowledge). Operators diagnose a situation by actively searching relevant information, which is a thinking process of operator. If an operator focuses on several information sources relevant (or important) to a specific event (situation), the operator's thought can be inferred from the eye movement data. This kind of eye movement pattern is analyzed with the SAE evaluation in this study. Hence, if an event occurs, for example, LOCA or SLB, a well-trained operator should show the best SAE value calculated with a set of informational importance of the relevant event among SAE values calculated with sets of informational importance of all possible events.

3. Experimental Study and Results

An experimental study was conducted to see whether the inference of operator's thought with the SAE evaluation is applicable or not. FISA-2 simulator was used to simulate a PWR type NPP. Fifteen events were selected and assumed to be a mutually exclusive set possible in FISA-2 operation. FaceLAB^{TM} 3.0 was utilized for the measurement of eye fixation data. Fifteen graduate students (14 males and 1 female) with nuclear engineering backgrounds of 5.2 years on average participated as operators. Sets of informational importance were evaluated by applying the Analytic Hierarchy Process (AHP) [2][3]. Six tasks including LOCA, SGTR (A), and SLB (B) out of 15 diagnosis tasks were randomly given to subjects (LOCA was excluded in experiment 2, because the subjects reported LOCA was relatively easy to diagnose with the FISA-2 simulator). After each trial, subjects were asked to answer the current event (situation). The degree of operator knowledge was considered as an independent variable and controlled by a training program (BT: Before Training and AT: After Training) and the time interval (6 months, which represent the forgetting effect) between experiments (i.e. experiment 1 and experiment 2). Dependent variables were a Concordance Rate (CR) which represents whether an actual event is the same as the event determined from the best SAE evaluation (CR-1) and another CR given that the operator gives correct answer (CR-2).

Table I. Results of Concordance Rate (CR)

	Event	Training	CAR^{+} (%)	CR-1^{++} (%)	CR-2^{+++} (%)
1st Exp.	SGTR(A)	BT	13	20	50
		AT	100	87	87
	SLB(B)	BT	0	60	N/A
		AT	93	80	86
	1st AVG.	**BT**	**7**	**40**	**50**
		AT	**97**	**83**	**86**
2nd Exp.	SGTR(A)	BT	40	60	83
		AT	100	87	87
	SLB(B)	BT	20	53	67
		AT	100	73	73
	2nd AVG.	**BT**	**30**	**57**	**78**
		AT	**100**	**80**	**80**
Total	**AVG.**	**BT**	**18**	**48**	**82**
		AT	**98**	**82**	**83**

CAR^{+} : Correct Answer Rate, BT: Before Training, AT: After Training
CR-1^{++}: CR between actual event and inferred event from the best SAE evaluation
CR-2^{+++}: CR-1 given that operators diagnose event correctly

As shown in 1st experiment AT results of Table I, there was observed concordance of 83 % (CR-1) on average between operator's thought (diagnosis results on current events given by their answers) and events inferred from the best SAE evaluation. Focusing on cases in which operators gave correct answers, concordance of 86 % (CR-2) on average was observed. In experiment 2, all the operators (subjects) gave correct answers after training, that is 100% correct answer, and hence both CR-1 and CR-2 show the same value of 80%. Considering experiment 1 and 2 at the same time, 82% of operators' thought could be inferred from the best SAE evaluation given that they had well-constructed knowledge which could be obtained through a well-organized training course.

4. Discussion and Conclusion

Even in BT cases, the best SAE evaluation showed better CR-2 than CR-1, which means that operators look at information sources more effectively if they know the situation correctly. However operators' thought can not be inferred from the best SAE evaluation, if their knowledge on the system dynamics is not well-constructed, which was shown in the results of all the BT cases.

Do you want to know operator's thought? Then ask him what he thinks. This is the simplest way. However we want to know operator's thought without asking, because it can provide a lot of opportunities for useful applications in NPPs such as SA evaluation, operator support and/or validation system, and the out-of-the-loop problem in automation. In this study, a novel approach to infer operator's thought without asking was proposed and validated with an experimental study. In the experiments, about 80% of operator's thought can be correctly inferred from the proposed method. This method may provide a great opportunity for advanced applications in digitalized MCR.

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