An Evaluation of a Human Machine Interface based on Attentional-resources Effectiveness

Jun Su Ha and Poong Hyun Seong
Department of Nuclear and Quantum Engineering, KAIST
373-1, Guseong-Dong, Yuseong-Gu, Daejeon, South Korea, 305-701

1. Introduction

Measures of attentional-resource effectiveness during monitoring and detection tasks in nuclear power plants (NPPs) have been developed based on cost-benefit principle and validated with experimental studies [1]. The underlying principle of the measures is that information sources should be selectively attended according to their informational importance. One of two measures is Fixation to Importance Ratio (FIR) which represents attentional-resources (eye fixations) spent on an information source compared to importance of the information source as:

$$FIR^{N}(i) = \frac{\dfrac{N_i}{\sum_{i=1}^{k} N_i}}{\dfrac{\omega_i}{\sum_{i=1}^{k} \omega_i}} \quad (1)$$

$$FIR^{D}(i) = \frac{\dfrac{D_i}{\sum_{i=1}^{k} D_i}}{\dfrac{\omega_i}{\sum_{i=1}^{k} \omega_i}} \quad (2)$$

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

Frequency and/or duration of eye fixations of an operator on information sources are used as attentional-resources. The importance of information sources is evaluated with the AHP (analytic hierarchy process). The other measure is Selective Attention Effectiveness (SAE) which incorporates the FIRs for all information sources as:

$$SAE = \frac{\sum_{i=1}^{k} \left| FIR(i) - 1 \right|}{k} \quad (3)$$

The FIR represents specific effectiveness for an information source. Relative attentional-resources spent on an information source should be equal to relative importance of the information source in order to maximize the attentional-resource effectiveness. Consequently, the FIR should approach to unity for the best effectiveness. The SAE represents overall effectiveness for all information sources and should approach zero for the best effectiveness.

The FIR and the SAE are used as effective tools to evaluate a human machine interface (HMI) design of a NPP simulator. Deficiency in a HMI design and poor mental model of an operator are considered main factors affecting the effectiveness in monitoring and detection tasks. If a monitoring and detection task is ineffectively conducted, which can be evaluated with the FIR and the SAE, the ineffectiveness is thought to be caused by deficiency in a HMI design given that the operator has well-constructed mental model.

2. Theoretical and Empirical Background

The selective attention is affected by four factors such as salience, expectancy, value, and effort. Hence performance in monitoring and detection is also affected by the four factors. An operator in a NPP may obtain the expectancies and the values of various information sources more clearly, as the mental model of the operator is getting well developed through experiences and trainings. This is the reason why experts show better performance than novice in information searching tasks [2]. On the other hand, the salience and the effort are matters to be considered during designing a HMI. Important information should be designed considering appropriate salience and effort to access. If an information source cannot be distinguished clearly from adjacent information sources, sometimes the information source may be missed by the operator. In addition, if it is too difficult to find out an information source important to understand a situation, the operator eventually gives up finding out the information source. Poor performance in monitoring and detection can be mainly caused by poor mental model of operators and/or poor design of HMI.

Poor performance in monitoring and detection is usually coupled with difficulties such as poor situation awareness, frustration, excessively physical or/and mental load, and so on. The difficulties are thought to be mainly caused by a poor HMI design such as poor salience and/or heavy effort required by the poor HMI design, given that an operator has well-constructed mental model. Hence deficiencies in the HMI design can be assessed and then identified by evaluating the difficulties coupled with poor performance (or effectiveness).

3. Experiment & Results

Experiments are conducted with FISA2/PC real time micro-simulator, which simulates a PWR type NPP [3]. Complex diagnostic tasks in NPPs are performed by 15 graduate students (14 males and 1 female). The 15 subjects have nuclear engineering background for 5.2 years in average. Monitoring and detection are required during the diagnostic tasks. FaceLAB™ 3.0 is utilized for the measurement of eye fixation data. Two different GUIs of the FISA-2 simulator such as an ordinary GUI and a faulty GUI are intentionally used in the experiments. In the faulty GUI, digit number indicators for both S/G (A) and S/G (B) levels are intentionally removed from the ordinary GUI, which was evaluated as a design fault in the previous study [1]. Hence it is not easy for the subjects to get aware of S/G (A) and (B) level changes with the faulty GUI. 6 tasks including SGTR (A) and SLB (B) out of 14 diagnostic tasks are randomly given to the subjects. The ordinary GUI is used in SGTR (A) experiments and the faulty GUI is used in SLB (B) experiments. The subjects participate in the experiments before and after training of dynamics of the FISA-2 simulator. The underlying hypothesis is that a well-constructed mental model after training shows better effectiveness in monitoring and detection than a poor mental model before training.

The overall effectiveness in monitoring and detection is evaluated with the SAE. The specific effectiveness on an information source is evaluated with the FIR. The SAE is evaluated lower in the cases of "after the training" (Table 1). Lower SAE values (to zero) mean better performance.

* BT : before training, AT : after training

	Ordinary GUI - SGTR (A) case -		Faulty GUI - SLB (B) case -	
	BT	AT	BT	AT
SAE	0.6213	***0.4170***	0.7475	0.5385

Table 1. SAE values averaged over 15 subjects

Empirically, the SAE value of 0.5 is used as a criterion for poor performance. 3 cases except for the SGTR (A)-AT case may be candidates for a further evaluation. Most of the FIR values get closer to unity after the training (Table 2). However, regardless of the training, the FIRs of the indicators for the S/G (A) and (B) levels in faulty GUI cases are far from the unity, which means that few fixations were made on the S/G level indicators compared with the importance of the indicators. Hence the indicators of S/G(A)_L and S/G(B)_L, on the faulty GUI are identified as the information sources which may have a design fault. It is reported that most of the 15 subjects could not easily figure out the changes in S/G (A) and S/G (B) levels with the faulty GUI, through interviews after the experiments.

* PRZ : pressurizer, S/G (A) : loop-A steam generator, L : level, P : pressure, T : temperature, FF : feed flow, SF : steam flow

Information sources	Ordinary GUI - SGTR (A) case -		Faulty GUI - SLB (B) case -	
	BT	AT	BT	AT
PRZ-L	1.40	1.31	2.00	1.83
PRZ-P	0.67	0.87	0.61	0.73
PRZ-T	0.73	0.69	0.71	0.74
S/G (A)_L	0.77	0.96	***0.30***	***0.40***
S/G (A)_FF	0.64	0.79	0.90	0.86
S/G (A)_SF	0.61	0.97	0.69	0.98
S/G (B)_L	1.05	1.19	***0.39***	***0.45***
S/G (B)_FF	1.08	0.84	1.04	1.03
S/G (B)_SF	1.14	1.36	0.90	1.29

Table 2. FIR values averaged over 15 subjects

4. Discussions and Further Study

Measures of attentional-resource effectiveness during monitoring and detection tasks in NPPs, the FIR and the SAE, are used as an effective tool for evaluating a HMI design. The information sources which may have a design faults can be found out by analyzing the FIR and the SAE. A method is needed to figure out root causes of the design fault. A qualitative method such as questionnaire-based evaluation can be a promising one. Hence, a systematic way incorporating the quantitative method (the use of FIR and SAE) and qualitative methods is needed for further improvement.

REFERENCES

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