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Mental Workload and Situational Awareness Evaluation of APR1400 Engineered Safety Features- Component Control Activation Systems using Augmented Reality

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1. Introduction

It was the intention of this study to explore how Augmented Virtual Reality (AVR) can be used in NPP control systems to determine whether 1.) Operator(s) performance could be enhanced by introduction of an improved cognitive method of monitoring plant information during an Emergency Operating Procedure (EOP) and 2.) In correlation, inform the performance of the diverse safety systems on the basis of human factors. [2]

In the study, an Augmented Reality procedure guidance support system concept was designed and used as a tool for the measurement of mental workload and Situational awareness of an SRO (Senior Reactor Operator). The EOP was chosen as the scenario for testing because it is the one of the critical plant conditions that requires human intervention [7] and it represents (one of the more) conservative approaches to the test scenarios that are possible. The system is expected to realize an improvement in the level of Situational Awareness and mental workload which have been demonstrated by previous studies to be directly linked with the system response to an emergency situation [5, 8] in the MCR. The planning and design of the project adhered to a Systems Engineering approach in order to provide an optimized framework for ensuring the successful implementation of the system design. [1,4]

2. Methods and Results

This section describes the method used to design the system.

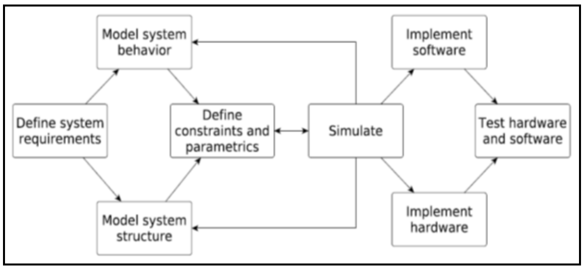

Fig1. Design method

2.1 System Requirements Definition

The elicitation was conducted by interviews, conversations and consultations. Experts consulted included; authorities in the field of human factor engineering; professionals with experience in operating nuclear power plants; and other industry professionals with proven track records and a wealth of experience in the Nuclear Power Generation. Further, consultation was conducted by examining books, journal papers, case studies and system manuals in order to understand and discover any shortcomings in the systems in question [3]. Table 1 shows the result of the consultancy.

Table 1: System Requirements

Concern	Elaboration
Safety	**S1.** The AVR system shall be used during EOP-LOCA along with the CPS.
	S2. The AVR system shall provide critical information/data needed by a Senior Reactor Operator (SRO) during an Emergency Operation Procedure (EOP) for his monitoring/ checking/advisory tasks.
	S3. The AVR system shall assure that the correct transition of plant procedures
	S4. The AVR system shall validate the Entry conditions for emergency operation.
	S5. The AVR System shall not affect the normal execution of the current system
Compatibility	**C1.** The AVR system software shall be integrated with existing system without requiring down time
Practicality	**P1.** The AVR system shall reduce/release work burden to the STA during the EOP
	P2. The AVR system shall, by introduction of improved situational awareness, be more intuitive to the STA than existing system.
	P3. The AVR system shall reduce the amount of navigation required by STA during EOP execution.
	P4. The AVR system shall seek to find a means of reducing the human factor related operator performance degradation **during safety critical operations** (EOP)–stemming from human errors, and reduced readability.
	P5. The AVR system shall provide more comprehensive plant status information to the STA to enable him to more effectively keep track of the changing plant conditions

2.2 Modelling the system structure and behavior

The existing computer based procedure system is described in figure 7 illustrates the progression EOPs as perceived and/or performed by the operator during a

LOCA in the APR1400 simulator.

The representation shows the procedural flow of actions and indicate where the process needs to break off to perform a contingency action before proceeding (where Cont. Represents the Contingency Actions). High mental workload is expected to be placed on the user at these points because of the need to consult separate screens. The decision diamonds depict a requirement for the system user to consult and confirm procedure steps with outside input action. They therefore represent the highest awareness loss areas.

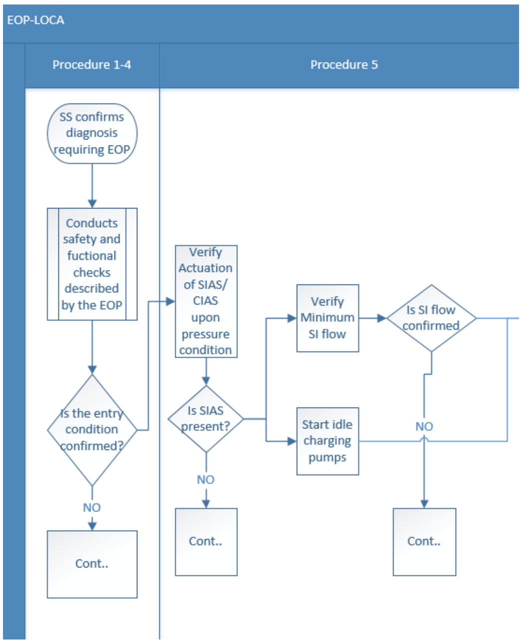

Fig 2: Representation of the existing EOP

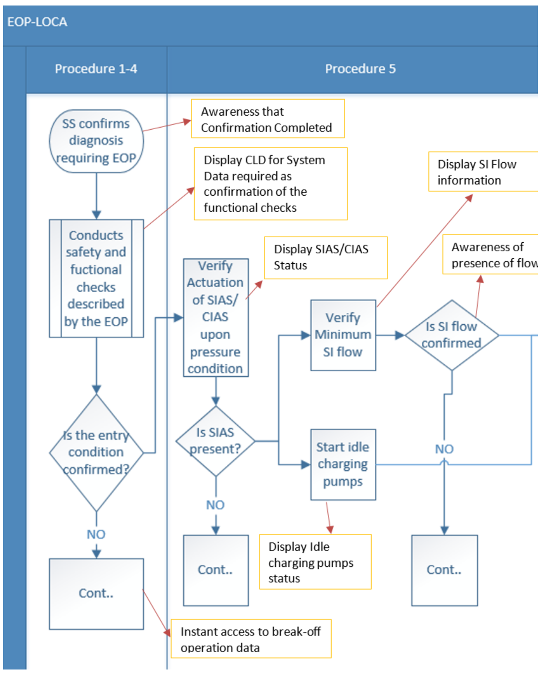

Fig 3: Representation of AVR Enhanced EOP

The conceptualized design was performed as an experiment whose goal was to achieve the stated objective of the study. It comprised of two major design components further explained in figure 3 below: 1.) The experimental augmented reality hardware and software and 2.) An analysis and inference made

In order to investigate the effect of the modelled system on the operator's mental workload and situational awareness, two scenarios described in the next section, were run using data from an APR1400 simulator with the subject being a trained APR1400 SRO or equivalent.

Data collection method

Scenario 1 was conducted as detailed by fig 4 in an APR1400 simulator training environment. The objective of which was to obtain the baseline data. During the experiment the SRO executed the EOP LOCA as detailed by the plant operations procedure documentation and the CPS. Only the first eleven (11) procedures of EOP-LOCA were carried out because they represented the diverse operation of at least one ESF-CCS function in the LOCA scenario.

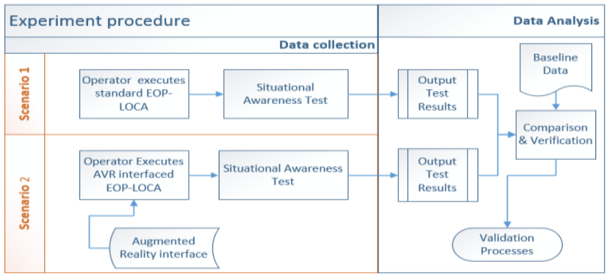

Fig 4: Summary of the data collection method

Scenario 2 was conducted as detailed in the first scenario but incorporating additional AVR data interface. Figure 3 shows targeted parameters that were incorporated into the AVR in order to improve the situational awareness and mental workload during procedures.

It is to be noted that the reduced number of procedures was sufficient to perform the workload and situational awareness measurement without introducing errors such as forgetfulness of workload aspects after tasks and recall errors. Further, it was justified in minimizing influence of workload on situational awareness measurement.

2.3 Constraint and Parameter definition:

Two variables NASA TLX and SART [5] that could be obtained from the outcome of the experiment were used to measure the human performance 1.) The NASA Task Load Index (NASA TLX): a subjective multidimensional assessment tool developed by NASA that rates perceived workload on six different subscales; Mental Demand, Physical demand, Temporal demand, Performance, Effort and Frustration. 2.) Situational

Awareness assessment using SART (Situational Awareness Rating Technique); an experimentally validated, retrospective measure which requires participants to rate themselves on ten dimensions that include attentional demands (D), attentional supply (S), and understanding (U) immediately following task performance [6].The ratings on each of the three dimensions are combined into a single SART value according to a formula Situation Awareness = U − (D − S).). The two measurements (NTLX and SART) were performed using questionnaires filled out after each of the EOP-LOCA procedures performed.
The NASA TLX and SART findings from both of these scenarios were compared to realize whether or not a decrease in mental workload and a corresponding increase in situational awareness was achievable.

2.4. Data analysis of the Results

Experiments that were carried out in order to analyze eleven (11) EOP-LOCA procedures were performed by an SRO using a simulated system verified by standard CPS (computer Based Procedure System) used in the APR1400 MCR.
Data collected from the workload and Situational Awareness survey tests was used to show the effect of the workload on situational awareness as well as perform comparisons to establish whether or not an improvement was achievable.

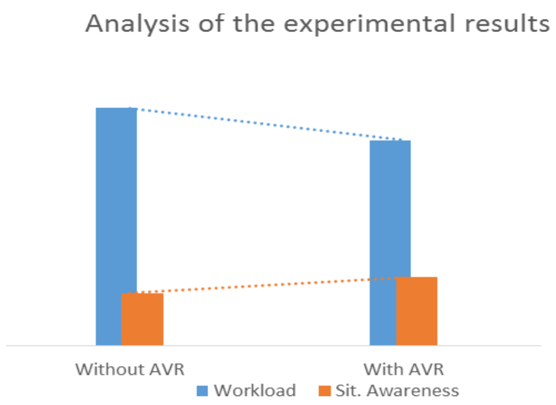

Fig 5: Comparison of workload and SA scenario results

From the results obtained shown in Fig 5, workload reduction and Situational Awareness increase could be realized by implementation of the AVR system. An Analysis of Variance, (ANOVA) conducted on the data revealed that Situational Awareness was influenced by the mental workload and on the type of procedure being conducted, ($F = 3.079$, $P<.05$) on workload and ($F = 3.3056$, $P<.05$) for Situational Awareness.

3. Conclusions

Previous study and research into this topic [6] has emphasized the importance of situational awareness in determining the human factor performance issues in the nuclear power plant Control Room operations. This paper broadly defined a technique that successfully used the operator's mental workload (using NASATLX) and Situational Awareness (using SART) as quantifying measures to evaluate the performance of specific ESF-CCS functions based on human factors. These results show that an improvement of the SA/workload could lead to an improvement of the level of certainty that the emergency situation can be brought under control. It is expected that future development work in this area will yield an actualized Augmented Reality system that could incorporate MCR team control and possibly be implemented in the system validation of other I&C systems.

Acknowledgements

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References

[1] Haskins, C, Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities. San Diego, CA (US): INCOSE, 2010.

[2] Lanyi, C.S. Applications of Virtual Reality. Croatia: InTech, 2012

[3]Sommerville, I. and Sawyer, Requirements Engineering: A Good Practice Guide. West Sussex, England: John Wiley & Sons. 1997.

[4]Sage, A.P. and Rouse, W. B, Handbook of Systems Engineering Management. George Mason University: John Wiley and Sons, 1999.

[5]Salmon, P. et al., Distributed Situation Awareness: theory, Measurement and Application to teamwork. Surrey, England: Ashgate. 2009.

[6]Yang C.W et al., Assessing mental workload and situational awareness in the evaluation of computerized procedures in the MCR, Nuclear Engineering and Design, Vol 250 713-719, 2012.

[7]Naser, J., Computerized Procedures: Design and Implementation Guidance for Procedures, Associated Automation and Soft Controls. Draft Report. EPRI 1015313. 2007.

[8]OH, I.S et al., Development of Human Factors Evaluation Techniques for Nuclear Power Plants. Korea Atomic Energy Research Institute, 1999.

[9]Kim, S.T et al., New Design of Engineered Safety Features-Component Control System to Improve the Performance and Reliability. Transactions of the Korean Nuclear Society Spring Meeting Chuncheon, Korea, May 2006.

[10]Korea Electric Power Corporation & Korea Hydro & Nuclear Power Co., Ltd, APR1400 Design Control Document Tier 2: CH 7 Instrumentation and Controls. Revision 0. Available USNRC website, December 2014.