Annals of Nuclear Energy 94 (2016) 750–758

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

Optimal design method for a digital human–computer interface based on human reliability in a nuclear power plant. Part 3: Optimization method for interface task layout

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A R T I C L E I N F O

Article history:
Received 13 January 2016
Received in revised form 21 April 2016
Accepted 22 April 2016
Available online 29 April 2016

Keywords:
Digital human–computer interface
Optimization method
Shortest moving path optimization algorithm
Human reliability

A B S T R A C T

This is the last in a series of papers describing the optimal design for a digital human–computer interface of a nuclear power plant (NPP) from three different points based on human reliability. The purpose of this series is to propose different optimization methods from varying perspectives to decrease human factor events that arise from the defects of a human–computer interface. The present paper mainly solves the optimization method as to how to effectively layout interface tasks into different screens.

The purpose of this paper is to decrease human errors by reducing the distance that an operator moves among different screens in each operation. In order to resolve the problem, the authors propose an optimization process of interface task layout for digital human–computer interface of a NPP. As to how to automatically layout each interface task into one of screens in each operation, the paper presents a shortest moving path optimization algorithm with dynamic flag based on human reliability. To test the algorithm performance, the evaluation method uses neural network based on human reliability. The less the human error probabilities are, the better the interface task layouts among different screens are. Thus, by analyzing the performance of each interface task layout, the optimization result is obtained. Finally, the optimization layouts of spurious safety injection event interface tasks of the NPP are obtained by an experiment, the proposed methods has a good accuracy and stabilization.

1. Introduction

The interface task in this paper refers to event procedures and assistant information. The assistant information is considered some helpful tasks associated with corresponding event procedures. The interface task layout refers to how the interface tasks in digital human-computer interface are automatically arranged into different screens in some point of time.

In general, interface tasks are distributed on different screens in different time, so an operator whether primary loop or secondary loop in a NPP need to move among different screens to deal with an event. The cost time that an operator moves among different screens decreases with decreases in moving path. The moving path is influenced by following factors: (1) the navigation distance between two screens; (2) organizational distance. The navigation distance takes dominant position at the cost of information visited (Seidler and Wickens, 1992), namely, the time to visit information increases with increases in distance between two objects.

Aiming at the situation mentioned above, this study will propose an optimization method of interface task layout that can automatically layout interface tasks into appropriate screens in each point of time so that each moving distance among different screens for an operator is minimum, then, the cost time to perform event or visit information will be decreased, further, the human error event will be decreased.

Studies have been completed on the optimization and design of the human–machine interface, but there are few methods to

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http://dx.doi.org/10.1016/j.anucene.2016.04.036
0306-4549/

resolve how to layout interface tasks into different screens in NPPs. To improve human–machine interaction, a decision support system was studied, the paper aims to integrate human factors and ergonomics and proposes a set of scheduler-oriented algorithms favoring human–machine cooperation (Gacias et al., 2012). To build hierarchical menu layouts and color palettes for user interface, Troiano and Bitrolo explored alternative solutions based on genetic algorithm (2014). To make up the current lack of a clear definition of HSI technology, Hugo and Gertman (2016) expresses how new design concepts in the nuclear industry can be analyzed and how HSI technologies associated with new industrial processes, they also describes a basis for an understanding of human as well as technology characteristics. To optimize the User Interfaces items on the available screen space or selecting an adequate palette of colors, Troiano and Bitrolo (2014) advocate the use of meta-heuristics to supporting different aspects of the UI design process. In this paper, building hierarchical menu layouts and selecting color palettes based on a set of constraints were discussed. To solve a particular stress on interface technology characteristics of figure user, Yan proposed how to integrate the computer technology with human by the visual expression of interface design (2011). Suvi et al. presented multi-object optimization design for user interface, the research focuses on an interaction technology of human–machine interface and communication method of information (2013). Jia et al. studied the structure and layout, failure modes, some special human factor engineering strategies of main control room in a NPP and two solutions as to the arrangement of human–machine interface (2014). In the optimization process of human–machine interface, Anuar and Kim considered function requirement and sequence figure with serial number in order to decrease workload of operators (2014), the study defined eleven function requirements that were divided into eight levers and designed a state change. Navarro-Cerdan et al. discussed a generic symbol input interaction method including an input hypothesis model, an error model, a constraint model and a user interaction scheme for human–machine interface, the methodology provides a practical advantages, keeping at the same time the error-recovery (2016). In order to design an effective user interface between different software components and between a human and computer, the process, guidelines, human factors and techniques were discussed (Oshana, 2013). Qi et al. combined human-computer interface programs with programmable logic controller programs to make human-computer interface more efficient, and that used to fault diagnosis technology to design a more optimal alarm pattern (2012). Josefina suggested that user interface design should evolve from iteration in order to maintain user interface development lifecycle in a more flexible way (2014), a methodology involving task, process, workflow, domain and context for exploring user interfaces of workflow information systems was proposed. To insure safety in NPPs, the interface design of a digital alarm system by analyzing a diagnosing process of operation information was investigated, this study emphasizes on the layout planning of alarm windows, compatibility principle and nuclear human-system interface design review guidelines (Liu et al., 2016). To promote human factors engineering at design stage, current industrial practices and standards were presented, the study focuses on how human factors engineering can significantly influence the costs and risk (Leva et al., 2015). Havlikova et al. proposed the art state in the human reliability analysis comprising human reliability assessment in man–machine system and the description of available human behavior modes, and that underlined the human factor played an important role and the failure of a human being could lead to safety risk (2015). Bellet et al. discussed a research programme for virtual design of driving assistances in order to develop an integrative simulation platform that can support a human centered design method, the paper focuses on a description of the driver model implemented on the a virtual platform (2012). To solve the layout of relative positions among different functional blocks in a digital human-computer interface of a NPP, Jiang et al. presented an optimization method involving a liner reversal genetic hybridization method and Bayesian method, and showed the proposed method had good performance (2015).

This paper proposes a shortest moving path optimization algorithm with dynamic flag to solve the optimal layout of interface task. The rest of this paper is organized as follows. An optimization process of interface task layout in digital human-computer interface of a NPP is provided in Section 2. In Section 3, problem description, mathematical model and shortest moving path optimization algorithm are presented. Human reliability evaluation method to test the proposed algorithm performance is given in Section 4. Finally, Section 5 provides an experiment and performance analysis for the proposed method.

2. An optimization process of interface task layout

Artificial Neural Networks (ANNS) is based on a natural model of brain neural structure (Elhewy et al., 2006). The optimization process of interface task layout based on neural network is made of three layers. The first layer is the input layer comprising human factors and the time spent on each interface task; the secondary layer is the hidden layer including functions and evaluation methods of human reliability; the final layer is the output layer that is responsible for outputting the human reliability probability for the interface task layout of human-computer interface. The optimization process based on human reliability is shown in Fig. 1.

3. The shortest moving path optimization algorithm for interface task Layout of digital human-computer interfaces of a NPP

Generally, there are two typical methods how to form a path (Zhang et al., 2007): ① hereditary algorithm. The method need to define a population indicating paths and utilize hereditary evolution theory to process the population and obtain new paths; ② A. Bertolino utilized a simplified control process diagram to build interface task paths. The method begins with control process diagram, then forms DT (dominate tree) and IT (implication tree), by building sub-diagrams between two adjoining control nodes, all paths between two control nodes are built. The aforementioned methods provide an aid to build interface task paths, but they are uncertain and paths formed are basic paths.

Up to now, the main methods building path are listed below (Zhang et al., 2009):

① Broad priority searching algorithm.
② Heuristic searching method.
③ Search method with same cost.
④ Broad priority searching and pruning method.
⑤ Iterative method.
⑥ Dynamic programming.
⑦ Symbol method.
⑧ Dijkstra algorithm.
⑨ Floyd algorithm.

On the basis of Floyd algorithm, the authors propose a shortest moving path optimization algorithm with dynamic flag for interface task layout of digital human-computer interface.