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Optimal design methods for a digital human-computer interface based on human reliability in a nuclear power plant
Part 2: The optimization design method for component quantity

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ABSTRACT

This is the second in a series of papers describing the optimal design method for a digital human-computer interface of nuclear power plant (Npp) from three different points based on human reliability. The purpose of this series is to explore different optimization methods from varying perspectives. This present paper mainly discusses the optimal design method for quantity of components of the same factor.

In monitoring process, quantity of components has brought heavy burden to operators, thus, human errors are easily triggered. To solve the problem, the authors propose an optimization process, a quick convergence search method and an affinity error probability mapping function. Two balanceable parameter values of the affinity error probability function are obtained by experiments. The experimental results show that the affinity error probability mapping function about human-computer interface has very good sensitivity and stability, and that quick convergence search method for fuzzy segments divided by component quantity has better performance than general algorithm.

1. Introduction

Usually, most events are caused by human errors, for instance, 60–90% accidents (He and Huang, 2007; Hollnagel, 1998) are related to human error operations, also, 70% events of nuclear power plants (NPPs) in China (Huang and Zhang, 1998), the accident at Three Mile Island(TMI) in 1979 and the nuclear accident at Chernobyl in 1986 (Paulo et al., 2006) are related to human error operations. Particularly, the situation in digital control systems is more prominent. There are two ways to decrease human errors. We can improve operator adaptive capabilities including status response, decision making and handing emergent events in digital human-computer interface, or optimize the digital human-computer interface based on human reliability. The authors in this paper propose an optimization method to decrease human factor accidents caused by defects of the human-computer interface in a NPP.

Studies have been completed on the design and optimization of human-machine interface, but there are few methods for optimization of quantity of components in digital human-computer interface. In 1989, an international standard was enacted concerning how to plan a design of control room at NPPs. Control room systems in the standard included the human-machine interface, the control room operators, the operational regulations, the training outline and the relative facilities. In 2008, an optimal layout of the human-machine interface was presented (Jin et al.), the research included the knowledge notation and oriented-object method, established an optimization inference model and the inference system by fuzzy method. In 2009, the relationship between interface layout and comfort level was discussed (Haynes), the study shows that performance of input function and comfort level for human-machine interface is influenced by optimization result. In 2011, an interface between computer and

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human was designed by visual theory (Yan), the design idea was based on the human standpoint in order to make interface design become more simple and intuitive. In a random process, component structure layout optimization of human-machine interface was proposed (Zhang et al., 2012). In 2013, Avola et al. Proposed human-computer interface framework design supporting real-time vision-based gesture recognition and virtual environments for fast prototyping of customized exercises for rehabilitation purposes, this research mainly involved gesture recognition and virtual environments. The same year, an optimization research for topological structure and layout and shape of component of human-computer interface was presented (Xia et al., 2013; Sørensen et al., 2013). The two studies utilized finite unit web idea, simulated functions, and conflicting and detecting algorithm to optimize a layout of components. A computationally-efficient systematic procedure to design an Optimal Type-2 Fuzzy Logic Controller is presented. The main purpose is to optimize the gains of the controller using Particle Swarm Optimization (PSO), optimize only two parameters per type-2 membership function using Genetic Algorithm (GA) (Fayek et al., 2013). In 2014, the design of human-machine interface (HMI) were developed to ensure the safety and availability of the two-modular high-temperature gas-cooled reactor nuclear power plant in China (Jia et al.), the study mainly focused on the layout of large display panels, control consoles and a verification platform for HMI design. A high-lighting design method was proposed for human-machine interface of automatic systems of nuclear power plant (Anuar and Kim, 2014), the purpose is to decrease working intensity of all operators, reduce the time to search information and is easier to obtain parameters. A method is proposed to consider human-related factors, except machine-related factors, in machine failure analysis, which makes the model possible for using the expected uptime and the probability of failure, given the operator skill level and working conditions, to calculate the expected revenue associated with each intervention method (Dovgan et al., 2014). 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 behaviour modes, and that underlined the human factor played an important role and the failure of a human being could lead to safety risk (2015). To make nuclear power plants become more safety, the interface design of a digital alarm system by analyzing the diagnosing process of operating information was proposed. The study focused on the layout planning of alarm windows and considered proximity compatibility principle and nuclear human-system interface design review guidelines to improve the human-system interface (Liu et al., 2016).

In this paper the authors take three important factors including alarm (seen as some components that can give some voice prompts when the situation of plan is abnormal), parameter (regarded as some values that reflect if some situations of a plant are normal at a time) and information (mainly including some symbols, text, curves etc) of digital human-computer interface in a NPP for experimental sample. By calculating human reliability for each fuzzy segment of component quantity, the most suitable fuzzy segments of each kind of factor are obtained. This research has three distinct points compared with the aforementioned studies: (1) The object of study is based on digital human-computer interface of a NPP; (2) the optimization design criteria of human-computer interface is based upon human reliability; and (3) the optimal design methods are quick convergence search method for fuzzy segment and affinity error probability mapping function that are used to select each fuzzy segment from all segments of component quantity and calculate human error probabilities, respectively.

2. Optimization process

An optimization process needs to be established before component quantity is optimized. This paper proposes a quantitative optimization process in which optimization criterion is based on human reliability in monitoring process. The optimization process mainly emphasizes two methods including a quick convergence search method that uses to how to select an appropriate one of segments divided by quantity of components and an affinity error probability mapping function method that uses to obtain human error probabilities of each segment formed by the number of components in monitoring process for digital human-computer interface in a NPP. The proposed process is shown in Fig. 1.

3. Method systems

3.1. Divide fuzzy segments for component quantity of the same factor

A division of fuzzy segment for quantity of components in this paper utilized fuzzy theory that is mainly used to make fuzzy object become clearer (WANG and GUO, 2008). Quantity of components of the same factor of digital human-computer interface needs to be divided into some segments by fuzzy method. A division of fuzzy segment for quantity of components is a two steps process; firstly, respectively gives two ranges including quantity of components of each factor and quantity of fuzzy segments of corresponding component; secondly, divides quantity of components of each factor into some fuzzy segments. For example, if the range of component quantity of a factor is between 1 and 50 and the range of fuzzy segments quantity is five, then the component quantity of the factor can be divided into five fuzzy segments, namely, 1–10, 11–20, 21–30, 31–40, 41–50.

3.2. A quick convergence search method to find an optimal fuzzy segment

If an order to visit all fuzzy segments is appropriate, iterations will greatly be decreased. The search method for fuzzy segments main resolves how to quickly find an optimal segment from all fuzzy segments.

Traditional optimization methods have good accuracy and quick convergence for small-scale or middle-scale objects. But in most cases, they cannot be applied to real optimization problems, because non-dimension problems of some research objects will be generated. In order to solve the problem the authors in this paper propose a quick convergence search method to visit all fuzzy segments. The description of quick convergence search method is shown in Fig. 2.

The following notations are used through the description of the quick convergence search algorithm.

Q1:a queue
Q2: a queue
e: save a segment come from Q1
s: quantity of segments divided by e
z: save segments divided by e
n: a minimal value of cycle times
HEP: human error probability
y: save human error probability
m: save middle segment
c: a value that represent less difficult among HEP.

The pseudo code of the quick convergence search algorithm is written as: