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Markov reliability model research of monitoring process in digital main control room of nuclear power plant ☆

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ABSTRACT

Monitoring process is an important part in a high safety digital main control room of nuclear power plant (NPP), it is the source extracted information and found abnormal information in time. As the human factors events arisen from monitoring process recently take place more and more frequent, the authors propose a reliability Markov model to effectively decrease these abnormal events. The model mainly analyzes next monitoring object probability in terms of current information and plant state. The authors divide digital human–machine interface into two parts that are referred as logical homogeneous Markov and logical heterogeneous Markov. For the former, a series of methods of probability evaluation are proposed, such as, Markov transition probability with condition, probability distributed function with human factors, system state and alarm; for the latter, the authors propose the calculation of probability of correlation degree between last time and next time and probability calculation methods with multi-father nodes. The methods can effectively estimate the transition probability from a monitoring component to next monitoring component at time t, can effectively analyze which information is more important in next monitoring process and effectively find more useful information in time $t+1$, so that the human factors events in monitoring process can greatly be decreased.

1. Introduction

The monitoring process is an important part in digital human–machine interface, it is referred to as the action (Kim and Seong, 2006) of extracting information from surrounding correctly. The authors mainly research the transition probability of monitoring process in digital human–machine interface. Digital is considered as the flexible ways provided by computer. Digital system has converted the way by common detecting into the method by computer station in control room. From the capability offered and handled information, computer work platforms have tremendous superiorities. On the contrary, computer working consoles bring new challenges to operators. The challenge particularly focuses on the changing of monitoring process. So, in digital system control room, the operators not only monitor the traditional information sources (Vicente et al., 2001) that mainly include shift turnover, testing, control room panels, field operators, other units, log, alarm screens, CRT displays and Field tour, but also monitor that thousands of complex and dynamic information derived from computer. Thus, previous monitoring models and methods have not been adapted for digital system monitoring reliability evaluation in control room. To facilitate monitoring and decrease events, the authors build a monitoring transition probability model and present some functions in this paper. The paper has two prominent contributions that are listed as follows: (1) The model exploited by Markov chain can effectively assess the transition probability of the next monitoring object; (2) The model is formed under certain conditions that include human factors, other relating factors and the specific field of digital human–machine interface in monitoring process; (3) The authors propose many novel methods and dynamic functions.

2. Review of monitoring process researches

In fact, some researchers have proposed many monitoring methods and models toward monitoring tasks in human–machine interface. Such as, in 1980, Sheridan (1980) developed a mathematical model of monitoring behavior for automated systems.

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The model depicted how monitor behavior is allocated in time to multiple task. In 1983, Rasmussen (1983) proposed two basic models in monitoring: the situation model and the mental model. An accurate mental model is viewed as a limited feature of expert judgement, and is reckoned as drive skill-based processing. It provides the capability to predict and reason plant states. The situation model truly reflects the plant actual state, the situation accuracy is related to a function of correlated degree among the operator situation model. In 1990, Hart and Wickens (1990) raised an alternative, closed-loop model, operators can use various available resources for mediate task demands at random time in the model. In 1993, Verwey (1993) came up with the view of an adaptive man–machine interface for the optimal allocation of drivers' attentional resources. In 1994, Raby and Wickens (1994) expressed that cognitive resources can effectively ascertain how to optimally arrange and manage tasks in multiple task situation. In digital nuclear power plants, all functions demanded to confirm nuclear safety need be automatically performed. In order to resolve the phenomenon, in 1998, Stadelmann (1998) proposed a computer-aided system to monitor proper behaviour of NPPs. The system checks sequences of automatic operations for their proper function, in addition, the system makes it possible to search all over the signal message report for certain signals as well as to produce an overview protocol of the current (or a past) status of the Plant. Above studies have some effect on monitoring, but have much shortage. In generally, those methods basically are static, they cannot preferably accommodate to dynamic of monitoring process and cannot consider the effect arising from human factors on monitoring. In fact, in a control room computerized, there are tremendous information that is randomly changing at each time, on the other hand, the operators need to know how the information that they want to display on CRTs brings up. So, digital human–machine interface increases the difficulties of monitoring process for operators. We cannot help thinking whether there is a more adapt method than previous ways on monitoring process for operators.

In reliability study, Bayesian networks is widely applied to many fields (Sahin et al., 2007; Doguc and Ramirez-Marquez, 2009); on the other hand, Markov approach also is diffusely applied to reliability fields (Bucci et al., 2008; Tai et al., 2009; Guo and Yang, 2008). The paper will explores a Markov monitoring transition reliability model in digital human–machine interface. Digital human–machine interface takes on the characteristics of dynamic behavior prediction and multi-task, experience shows that Markov chain can effectively reflect the dynamic behavior (Ma and Trivedi, 1999) and compatibly suit to forecast long time and continual transformation object (Qian and Liu, 2008). So, in this paper, the authors adopt Markov method to develop a monitoring transition probability reliability model in digital human–machine interface. Just as I know, no research to explore a Markov monitoring transition probability reliability model in digital human–machine interface is conducted. The authors intend to try to develop a Markov reliability model of monitoring transition process in digital human–machine interface, so that we can effectively monitor human–machine interface, effectively estimate transition probability and decrease accidents in monitoring process.

3. Markov model description of monitoring process in digital main control room of nuclear power plant

3.1. The description of model

In reliability analysis, we may well say that the study considering human factors and other relating factors in monitoring digital human–machine interface is a blank yet. In this paper, the authors fill a vacancy in the field.

In this paper, the authors propose the logical partition theory that refers as that if the components belong to the same category, we will divide them into a block, otherwise, we will divide them into an other block. For digital human–machine interface, there are thousands of devices and based-computer huge information, if divide same class component or information into a block, we can facilitate to transfer our attention from a certain component belonged to a block to another component belonged to another block. The theory about logical partitioned model is an innovation point in this paper. On the other hand, the authors define that the components belonged to the same block is viewed as homogeneous Markov chain, otherwise, is called heterogeneous Markov chain. The monitoring process from a component to another component belonged to same or different block can be viewed as dynamic process and continuous changing process. Each node of Markov model represents a logical block. The paper mainly highlights the dynamic changing process in monitoring and transition reliability considering three important factors performance that include system state, human factors and alarms, neglects the creating or extracting strategies. The authors mainly consider eight different monitoring objects in this paper. Each monitoring object has *n* parts. In terms of Vicente et al. (1997) and O'Hara and Brown (2002), the objects mainly consist of Computer-based panel, Computer-based CRT Display, Equipment test, Communicate with Field operators, Computer-based Alarm Screen, Computer-based Log/Record, Computer console, Computer-based Navigation System and other parts. The paper mainly assesses the monitoring objects transition probability called homogeneous and heterogeneous Markov chain under the condition of human factors, system states and alarms. The model is shown in Fig. 1.

3.2. Notations

Some notations are listed as below:

Sn: number of system-states.
An: number of alarm system-states.
Hn: number of human-states.
$S_j(t)$: system-state number j with $j = 0, 1$ at time t.
H_i: human-states number i with $i = 0, 1$ at time t.
$A_k(t)$: alarm system-states number k with $k = 0, 1, 2$ at time t.
Ns_i: number of elementary monitoring block in each system-states i, human-states number j, alarm system-states number k.
B_j^i: monitoring jth component of ith block in each system-states i, human-states number j, alarm system-states number k.
T_j^i: jth component of ith block at time t.
STjk^i: kth state of jth component about ith block at time t with $k = 0, 1, 2$.
TR_{ij}^k: transition probability from ith component of kth block to jth component of kth block with each system-states i, human-states number j, alarm system-states number k.
λ_{jk}^{im}: transition failure probability from mth component of ith block to kth component of jth block with each system-states i, human-states number j, alarm system-states number k at time t.
$q_i(t)$: weight coefficient of monitoring block i at a time, it is related to the correlation of previous state, each system-states i, human-states number j and alarm system-states number k.
$\Omega_i(t)$: probability to monitor ith block with each system-states i, human-states number j, alarm system-states number k at time t.
W_h: weight factors of H_i at time.
W_s: weigh factors of S_j at time.
W_A: weigh factors of A_k at time t.
W_c: common weigh load factors of H_i and S_j and A_k at time t, with $W_c = W_h + W_s + W_a$.
$H_{ran\text{-}inp}$: degree of input variables for human at time t.