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Mirror Effect Based Learning Systems to Predict Human Errors – Application to the Air Traffic Control

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Abstract: Resilience of a human-machine system such as air traffic control relates to the successful control of its instability. This instability can be due to the temporal variability or the magnitude of functional task demands, and this may provoke human error occurrence. The paper proposes an original knowledge based learning approach for human error prediction by taking into account the temporal variability of task demands. The reinforcement of the knowledge base applies the concept of the reffect by considering different feedback strategies to handle the knowledge content. When a sequence of information from the knowledge base is similar to new inputs, this sequence is used for predicting human errors. The vector composed by new inputs and the real observed human error replaces then this sequence or it is considered as a new knowledge. This principle is the mirror effect that consists in mirroring a part or an entire content of a new input vector into the current knowledge base. Algorithms of the proposed mirror effect based learning systems are proposed in order to predict human errors by making correlations between the temporal variability of task demand and the occurrence of human errors. They are applied in air traffic control. The results show that the knowledge based on task demand evolution and its reinforcement by mirror effects are suitable for predicting human error occurrence.

Keywords: task demand, learning system, human error prediction, mirror effect, air traffic control

1. INTRODUCTION

Resilience is mainly considered as the capacity of a human-machine system to successfully control the occurrence or the consequences of undesirable events affecting its stability. Human errors are examples of such undesirable events. The stability of a given system is usually linked with an equilibrium or a sustainable equilibrium of the system functioning and this equilibrium can be interpreted in terms of several criteria such as safety, workload, quality, production, etc. (Zieba et al., 2011). It involves technical factors, human factors and organisational factors.

The more stable a technical system is, the more successful its control is supposed to be. However, a sustainable stability of human workload for instance can affect vigilance or attention, and can lead to the occurrence of human errors (Vanderhaegen, 2010): a sustainable high or low level of workload may affect the cognitive capacity and provoke human errors too. As a matter of fact, the perception and the treatment of the occurrence or the consequences of human errors can affect the human workload when for instance no procedure exist for recovering them or when they are treated too late (Vanderhaegen, Caulier, 2011). Therefore, the stability of a human-machine system depends sometime to the stability of the human behaviour that relates to the variability of the human workload and the relation between this variability and the human error occurrence.

Learning from human errors can be useful for predicting them (Vanderhaegen et al., 2009; 2011). Different knowledge based supports can be used for implementing such a concept. For instance, learning systems aim at merging new data into an existing base with a constant number of knowledge and other systems consider new data as potential new knowledge to be added into the base with an unlimited number of knowledge (Polet et al., 2012; Ouedraogo et al., 2013; Vanderhaegen, Zieba, 2014).

The paper proposes an original way to learn from human errors in order to predict them. It presents mirror effect based learning systems that adapt their knowledge base by reflecting partly or entirely new input vector content into the knowledge base. This input vector contains the variability of task demands related a period of time and a human error parameter. The knowledge base of the learning systems is composed by a limited number of vectors containing different sequences of variability of tasks demands and the associated human error parameters. This, the paper consists in studying the impact on the prediction of human errors related to different mirror effect strategies implemented on learning systems.

The section 2 details the architecture of these mirror effect based learning systems and the section 3 presents a feasibility study of application in air traffic control.

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2. MIRROR EFFECT BASED LEARNING SYSTEMS

2.1. The task demand based knowledge

Workload is usually defined as the level of physical, physiological and cognitive effort to achieve a task. Several researches aim at identifying the impact of workload, task demand or stress on human performance. For instance, they are based on the so-called inverted-U model (Weiner et al., 1984; Hancock, Ganey, 2003). This model supposes that a maximum level of performance occurs when the workload level is over a minimum threshold and under a maximum one. Then, a low level or a high level of workload leads to a possible decreasing of human performance, and to a possible increasing human error occurrence. This hypothesis might be verified for sustainable low or high levels of workload instead of for an intermittent variability of the workload levels.

Several methods for assessing such a workload level exist (Vanderhaegen, 1997, 1999a; 2010; Djokic et al., 2010). Task demand assessment is a fair indicator of human workload. Indeed, task demand assessment based approaches calculate the physical, the cognitive or the temporal constraints of the tasks that human operators are achieving. Instead of treating the instantaneous value of this task demand regarding maximum and minimum thresholds, the approach developed in this paper consists in associating a sequence of variability of the task demands with the occurrence or the consequences of human errors. The proposed task demand assessment relates to the functional complexity of the situation a human operator has to control. Three classes of situation are identified: 1) the complexity to control independent situations noted *IS*, 2) the complexity to control dependent situations noted *DS*, and 3) the complexity to control the global situation noted *GS*. A weight of complexity has to be defined for each class of situation and for each unit of time *t* from the *T* set, the task demand assessment consists in calculating the input *I(t)* from the set *I* in order to identify the entire weight of complexity of the current situation by applying the *D(t, IS, DS, GS)* function:

$$
\begin{aligned}
D:\ & T \rightarrow I \\
& t \rightarrow I(t) = D(t, IS, DS, GS), \\
& \quad I(t) = \sum Weight(IS(t)) + \\
& \qquad \sum Weight(DS(t)) + \\
& \qquad \sum Weight(GS(t))
\end{aligned}
\qquad (1)
$$

A sequence of the task demand variability is then obtained by the *D(t, j)* function in order to assess the vector I_p that contains the current complexity level and the previous ones:

$$
\begin{aligned}
D:\ & T \rightarrow I^{j} \\
& t \rightarrow I_p = D(t, j),\ t > j, \\
& \quad I_p = (D(t-j, IS, DS, GS) \cup \\
& \qquad D(t-j-1, IS, DS, GS) \cup \dots \cup \\
& \qquad D(t, IS, DS, GS))
\end{aligned}
\qquad (2)
$$

The variable *t* corresponds to a unit of time that is superior to *j* in order to make possible the assessment of *D(t-j, IS, DS, GS)*.

The knowledge noted K_{HO} of a human operator *HO* is then a matrix that contains the real relationships between the evolution of the sequences of the inputs *I* related to the task demand assessment upon the time units, and the associated future outputs *O* related to the human error occurrence:

$$
K_{HO} = \begin{bmatrix}
I_1(t_1) & I_1(t_2) & \dots & I_1(t_j) & O_1(t_{j+1}) \\
I_2(t_2) & I_2(t_3) & \dots & I_2(t_{j+1}) & O_2(t_{j+2}) \\
 & & \dots & & \\
I_k(t_k) & I_k(t_{k+1}) & \dots & I_k(t_{k+j}) & O_k(t_{k+j+1})
\end{bmatrix}
\qquad (3)
$$

The number of lines of the matrix K_{HO} of a given human operator can differ from the matrix of another human operator because the number of lines of a matrix depends on the experience duration of the human operators. However, the structure of each matrix of knowledge is the same. Each line *p* of the matrix represents the successive input values I_p for *j* units of time and the last value of a line relates to the occurrence of human errors O_p at the next unit of time *j+1*. Therefore, the matrices of knowledge K_{HO} are composed by *j+1* columns and the inputs I_p is a vector obtained by using the *D(t, j)* function. The global knowledge that gathers the matrices of a group of human operators is noted *K*, and K_n corresponds the line *n* of this global matrix.

2.2. The mirror effect based prediction and reinforcement

The mirror effect based learning systems are reinforced iterative processes that take into account a knowledge base noted *K*, Figure 1.

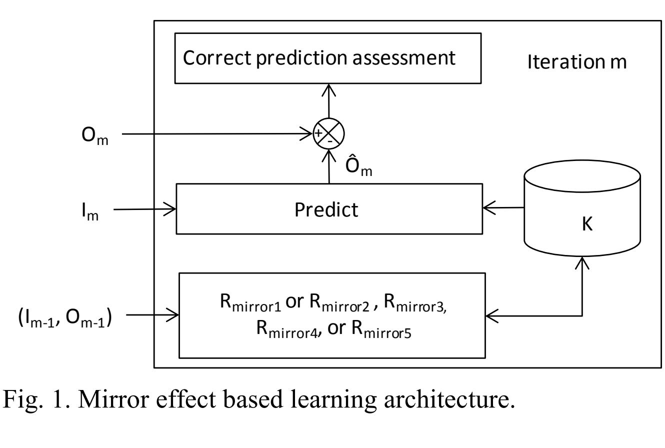

Fig. 1. Mirror effect based learning architecture.

The knowledge is a matrix that contains a predefined number of lines and each line has *j+1* columns. Regarding an input vector I_m, the prediction process consists in founding the future corresponding outputs $\hat{O}_m$ by using the function *Predict*. The knowledge reinforcement is done by the functions $R_{mirror1}$, $R_{mirror2}$, $R_{mirror3}$, and $R_{mirror4}$ regarding the real inputs and outputs of the previous iteration.