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Study on Adaptive Aiding for Plant Operation

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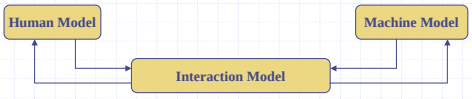
Research Background

- Plant Control System becomes complex.
- Human errors easily occur because of limitations of human information processing.
- Some support system may actually be a burden or harmful to plant operation.
- Computers should know human mental and physical information for effective supports.

Research Objectives

- Human modeling and simulation
  - To analyze human performance by using computational models and simulation.
  - To evaluate the effect of operation supports.
- Prototype system for adaptive aiding

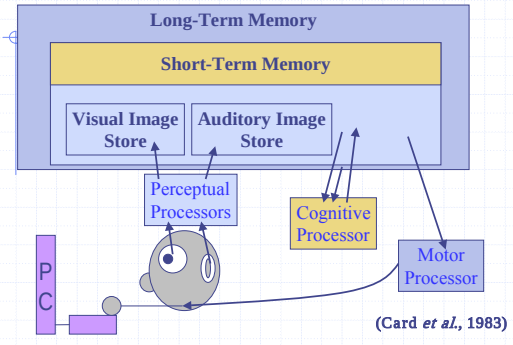
General Architecture of HCI Model



(Cacciabue, Piero, C., 1998)

We use a boiler simulator as a machine model, and build both interaction model and human model.

Model Human Processor

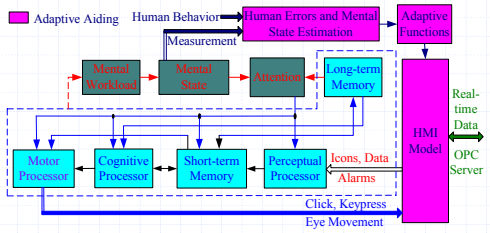


(Card *et al.*, 1983)

Human Model

- Perceptual processor, memory (long-term and short-term), cognitive processor and motor processor constitute a human information-processing system.
- Perceptual processor captures visual and audio information from user panels.
- Short-term memory codes, holds and transfers data for perceptual and cognitive processor.
- Cognitive processor diagnoses failure cause for a plant control system based on the information from memories, and informs the corresponding countermeasures to motor processor.
- Long-term memory stores declarative and procedural knowledge.
- Motor processor executes procedures by manipulating devices on HMI.

Framework of Adaptive Aiding



Mental State

- Mental state can be categorized into three states: confidence, inference, and confusion (Kurooka et al., 2001) .
- Mental state is determined from mental workload in this study.
- Mental state affects the total amount of available attention resources.

Attention

- "Attention" is used to present the cognitive limitation of human in cognitive psychological research.
- We use "selective attention" and "attention resources allocation" in the human model (Treisman, 1960, 1964; Deutsch, 1963; Kahneman, 1973).
- During the coding stage of short-term memory, selective attention can keep abnormal data but reject other normal ones.
- The total amount of attention resources is limited and can be increased or decreased by the mental state. The attention resources are allocated to perceptual, cognitive, and motor processors and memories for information processing, and the assigned attention resource affects the performance of each component of the information processing system.

Fault Diagnosis

- A state vector Y includes all available process variables. An operator monitors which variables are abnormal according to experience and understanding of the plant system.

$$Y=[Y_1, Y_2, Y_3, \ldots Y_k, \ldots, Y_m],$$

Where $Y_k=[yh_k, yl_k]$, (k=1, 2, 3, …, m)

m: number of available process variables.

Y_k: a vector including two discrete variables to represent abnormality.

Fault Diagnosis

Probability of the 2nd failure cause

Probability when the kth variable is abnormal

$$E=\begin{bmatrix} P_{1,1} & P_{1,2} & \cdots & \cdots & \cdots & P_{1,n} \\ P_{2,1} & P_{2,2} & \cdots & \cdots & \cdots & P_{2,n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ P_{k,1} & P_{k,2} & \cdots & P_{k,j} & \cdots & P_{k,n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ P_{m,1} & P_{m,2} & \cdots & \cdots & \cdots & P_{m,n} \end{bmatrix}$$

E: evaluation matrix of failure probability (mental model),

n: number of failure causes,

$P_{k,j}$: probability of jth failure cause when the current value of Y_k has an abnormal value.

Fault Diagnosis

$J = Y \times E = [P_1, P_2, \ldots P_j, \ldots, P_n]$,

$P_r = \text{Max}(P_j)$,

$P_s = A_c \times P_r$,

If $P_s > \theta_c$, the failure cause is identified,

A_c: cognitive attention level,

θ_c: cognitive threshold.

Whether the judgment is correct depends on the mental model (matrix E) of an operator. The identified failure cause is called acceptable result for the operator.

Mental Model

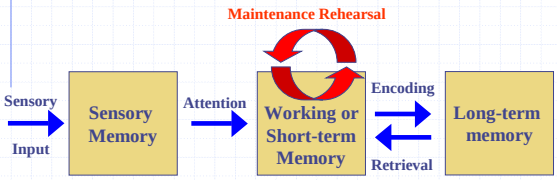
Matrix E for simulation

Failure cause	State	P203. PV	P203. MV	A201. PV	A202. PV	F204. PV	F204. MV	P205. PV	F202. PV	P204. PV	R080. CPV	F203. PV
FDF Capacity Down	High	-1*	0	0	0.4	0	0.5	0.2	0	0	0	0
	Low	0.6	0.6	0.4	0	0.5	0	0	0.2	0.2	0.6	0.5
IDF Trip	High	1.8	1.8	0	0.3	0.4	0.1	0	0	0	0	0
	Low	-1*	0	0.3	0	0	0	0	0	0	0.1	0

*Exclusive method

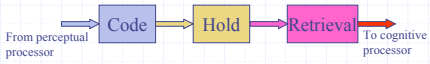
Through this table, cognitive processor can detect two failure causes.

Modal Model of Memories



(Shiffrin, Atkinson, 1969)

Short-term Memory



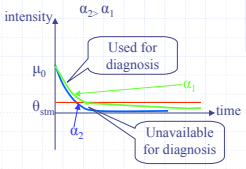
Code: Selectively stores data into chunks. Every variable has a intensity value.

Hold: All data decay exponentially with time.

Retrieval: A variable cannot be read out for diagnosis, If its intensity less than memory threshold.

Memory Decay

$$\mu = \mu_0 e^{\frac{-\alpha(t-t_0)}{A_{stm}}}$$



(Peterson & Peterson, 1959)

μ: memory intensity,

μ_0: initial intensity decided by the long-term memory and perceptual processor,

α: loss factor,

t: current time,

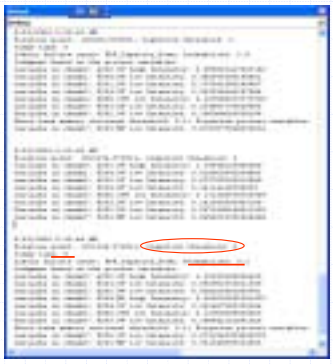
t_0: time when the variable is firstly coded,

A_{stm}: short-term memory's attention level,

θ_{stm}: short-term memory's retrieval threshold

Simulation Experiments

Simulation Experiments



When the probability of a failure cause is bigger than the cognitive threshold, a fault diagnosis is completed.

Simulation Experiments

- When an operator finds abnormal variables during a gaze, A judgment is launched. Total number of judgments for an acceptable result is used to evaluate cognitive performance. This table indicates that the smaller the cognitive threshold is, the quicker a judgment is made, but there is no guarantee of a correct judgment.
  - An incautious operator has a low cognitive threshold.
  - A conservative operator has a high cognitive threshold.

Effect of cognitive threshold on judgment*

Cognitive threshold	1.0	1.5	2.0	2.5	3.0	3.5
Number of judgment	2	3	4	5	5	6
Last failure probability	1.4	1.6	2.3	3.4	3.4	3.9

*Experimental condition: memory retrieval threshold is 0; failure cause is FDF Capacity Down

Simulation Experiments

Effective rehearsal is helpful to hold data for a long while, i.e, to decrease the loss factor α. For operators with the same skill level (cognitive threshold), a small α can complement human's memory deficiency (big retrieval threshold).

Effect of short-term memory retrieval threshold on judgment*

Retrieval threshold	0.05	0.10	0.15	0.20	0.25	0.30	0.35	Condition
Number of judgment	5	5	5	5	5	5	-**	α =0.4
	5	5	5	5	5	-	-	α =0.5
	5	5	5	5	-	-	-	α =0.6

*Experimental condition: cognitive threshold is 2.5; failure cause is FDF Capacity Down

**Failure cause cannot be detected.

Adaptive Aiding Examples for Fault Diagnosis

(a) When some important process variables are abnormal, the system should provide timely alarm information. (for rehearsal)

(b) If the mental state is confusion, the system should supply a list of likely failure causes and their probability (decreasing cognitive threshold).

(c) If there are some abnormal variables on the panel, a memorandum function should record them (for rehearsal).

(d) A help function should be used to complement operator's long-term memory (knowledge complement for mental model).

Summary

- A framework of cognitive information-processing model incorporating with mental sate and attention was proposed.
- Human's cognitive and memory performance was simulated quantitatively.
- Adaptive aiding examples were proposed for monitoring and fault diagnosis.

Future Work

- To improve the fidelity of simulation.
- To validate the influences of human mental state and attention on human performance.
- To evaluate the effect of adaptive aiding.
- To design prototype adaptive aiding systems.