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Evaluating on flight simulator fidelity based on fuzzy algorithm

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ABSTRACT*: Flight simulator plays more and more important role in the application of training pilots and modifing aircraft. Fidelity is the main index in the evaluation of flight simulator. Definition of fidelity and the traditional evaluation method is introduced briefly in this paper. According to the basic principle of fuzzy evaluation present a practical evaluation method, established the fidelity of the evaluation model, and applied this method to experimental evaluation.*
Keywords: *Fuzzy algorithm; Fidelity; Factors; Weight set*

I. INTRODUCTION

Pilot training heavily relies on the use of flight simulators, by which expenditure and flying time is saved[1]. Fidelity is the main index for evaluation of flight simulator. In many papers, "fidelity" usually refers to the accuracy of the dynamic characteristics of the model. Such explanation about the fidelity is inadequate. Though in practice we found that the aerodynamic characteristics of a model is precise enough for a simulator, the pilot do not satisfy with simulation fidelity, sometimes even feel that it can't manipulate. How to define and evaluate the fidelity has become an important part of the study of flight simulator. Because there are too many factors that influence the fidelity and combine with the uncertainty of the operators there is no precise mathematical description for the evaluation of training effect. On the basis of the pilot-plane control circuit analysis and the comprehensive evaluation method that based on fuzzy set theory to evaluate the fidelity of the simulator is a practical and effective method.

Fidelity is the degree of recurrence of the simulation objects about their external state and motion. Fidelity can be described with a decimal between 0 and 1. As boundary conditions, 0 means that there is no any similarity between target and simulation while 1 means that simulation completely resembles the target and there is no difference between them. During the research, we usually evaluate the fidelity by the fidelity of hardware, software, open loop system, closed-loop system, the subjective of pilots, the task and the experience of simulator, etc.

II. THE EVALUATION METHOD OF FIDELITY

2.1 The Subjective Evaluation Based on Experience of Pilot

Subjective evaluation on fidelity of flight simulator system includes the qualitative function test and quantitative performance test. The purpose of evaluation is testing simulator's ability to simulate the movement of the aircraft. The evaluation result is depend on subjective judgment and given qualitatively by the experts in this field. The advantage of subjective evaluation method is that as soon as setting a target, the experts can give the results of evaluation on the basis of evaluation system. Subjective evaluation method can evaluate fidelity of the whole flight simulator, wide range of application. Despite that the evaluation result is processed by the objective mathematical and is deterministic, from the aspect of specific factors of the evaluation target ,the result of evaluation , in essence, is still subjective evaluation which lead to the result that the result of evaluation is uncertainty.

2.2 The Objective Evaluation That Based on Mathematical Model of Pilot

The characteristics of objective evaluation, compared with the subjective evaluation,is that it apply the mathematical model of pilot. Establish the mathematical model of pilots-planes and pilots-simulator and compare the similarity of two systems by choosing a certainevaluation index,then get the objective evaluating result of fidelity. The selection of evaluation index is restricted by the pilot model. In order to ensure the accuracy of evaluating results we usually choose evaluating indexes depend on different model of pilots.

(1) Cross ModelPilots have the ability of self-regulation which makes thesystem of pilot-aircraft be a feedback control system with good features[2,3]. According to this idea, McRuer put forward a quasi-linear model of pilot in 1957 and after years of research he put forward the cross model of pilot in 1965[4]. The principle of this model is that the behavior of pilot's control can be described with linear function and redundant signal ,in addition ,assuming that the linear behavior of pilotplaysthe main role when close to the point of cross frequency.

(2)Structural ModelIn the mid of 1970sSmith,during the research of the qualities of aircraft manipulation,point out that the operation output rate of pilot is the most important in pilot-aircraft system[5]. Hess explained Smith's point of view and put forward the structure model of pilots.

III. THE EVALUATION INDEX SYSTEM

Flight simulator is general composed of optical display system, motion platform system, computerized image system, control system, network system, auxiliary system, flight simulation software package and cockpit simulation system, etc. Based on the verification of open-loop fidelity, build the evaluation system of simulator fidelity hierarchically, as follows:

First-degree factors:U_1(visual display system),U_2(motion platform system), U_3(pilot's feel about operation), U_4(Cockpit environment).

Secondary factors:

U_1 U_{11}(Detail of scene), U_{12} (scene of heaven and earth, the coordination of target), U_{13}(tracking property of visual), U_{14}(the effect of observation on exterior scene).

U_2U_{21}(Rotating effect), U_{22}(translation effect) ,U_{23}(motion sensitivity of platform), U_{24}(motion stability of platform).

U_3U_{31}(Operating force), U_{32}(operating displacement), U_{33}(simulating fidelity of sound), U_{34}(simulating effect of operating fault), U_{35}(coordination of the whole system) .

U_4U_{41}(Light), U_{42}(temperature), U_{43}(noise), U_{44}(vibration), U_{45}(electromagnetic interference), U_{46} (effect of emergency response).

IV. EVALUATING MODEL

4.1 Mathematical Model

Given: factors set F （$F_1, F_2, F_3 \dots F_m$） , evaluation set E($E_1, E_2, E_3 \dots E_n$),there is a factor U_i corresponds to every fuzzy evaluation $R_i(r_{i1}, r_{i2}, \dots r_{in})$.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}_{mxn} \quad (1)$$

Where R is single factor evaluation matrix, r_{ij} is the membership degree of factor u_i versus the evaluation rating s_j . Because of the different effect of every factor,the weight is different.

Given: weight vector $W = [a_1, a_2, \dots a_n]$,the comprehensive evaluation can be expressed as:

$$D=W◯R \quad (2)$$

Where ◯ represent a suitable fuzzy algorithm, denoted by $M(+, *)$.The commonly used fuzzy operation are:M(∧,∨),M(·,+)[6].

The weighted average method M(·,+) can be described as :

$$W◯R = [b_1, b_2, \dots, b_n]$$

$$b_j = \sum_{i=1}^{m} w_i r_{ij} \quad j = 1,2 \dots n \quad (3)$$

4.2 Weight Set

The weight set $W = [a_1, a_2, \dots a_n], \alpha_j \in [0,1]$, as a fuzzy subset, reflect the importance of event in the system[7]. Suppose that there are h evaluators, according to the degree of importance, every evaluator rank the factors$u_1, u_2, \dots, u_n$, from less important to more important.

$$u_{i_1}, u_{i_2}, \dots u_{i_n} \quad i = 1,2, \dots, h$$

The importance index value ofu_{i_1} is 1 and u_{i_n} is n. We use f_i^k to represent the value of importance index that the nth evaluator evaluating on factoru_i.

Compare the value of $\sum_{k=1}^{h} f_i^k$ $(i = 1,2, \dots n)$, rank these value from small to large. Standardize the sequential values $p_i = \sum_{k=1}^{h} f_i^k$ and take the grade as weight, then we get the weight vector $W = [a_1, a_2, \dots, a_n]$, where $\sum_{i=1}^{n} a_i = 1$

$$a_i = \frac{2p_i}{hn(n+1)} \quad i = 1,2, \dots n \quad (4)$$

V. APPLICATION ON EVALUATION OF ONE SIMULATION

We apply the model above to the evaluation of one simulator.

Grading the factors that effect the fidelity of simulator to 5 levels: higher(E_1), high(E_2), middle(E_3), low（E_4）, lower（E_5）. Then get the evaluation set E= $\{e_1, e_2, e_3, e_4, e_5\}$.

Take the first-degree factors for example. There are 10 evaluators who have evaluated this simulator and the result as below:

Table 1 The evaluation value of importance index on first-degree factors

	1	2	3	4	5	6	7	8	9	10
U_1	4	2	2	1	4	2	2	3	2	3
U_2	1	4	3	1	1	2	1	3	1	2
U_3	3	4	4	3	4	4	3	4	2	4
U_4	3	2	2	2	1	4	2	1	3	1

According to table 1 and equation (4) we can get the weight vector:

$$\mathrm{W} = \left[0.25，0.19，0.35，0.21\right]$$

Similarly, we can get the weight vectors of secondary factors. (Omit the value table of the evaluating of secondary factor)

$$W_1 = \left[0.232，0.211，0.134，0.266，0.157\right]$$

$$W_2 = \left[0.261，0.277，0.282，0.230\right]$$

$$W_3 = \left[0.185，0.137，0.134，0.163，0.120，0.261\right]$$

$$W_4 = \left[0.211，0.103，0.118，0.133，0.123，0.152，0.150\right]$$

10 evaluators, according to evaluation set E, evaluate the secondary factors set $\mathrm{U} = \{u_{11}, u_{12}, u_{13}, \dots u_{47}\}$ about the index of factors, the result as table 2.

Table 2 The evaluation of secondary factors

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
S_1	4	1	3	2	2	5	4	5	3	5	4	3	4	3	3	4	3	3	3	3	3	3
S_2	3	2	2	2	4	3	3	2	3	3	2	3	2	2	3	2	2	4	2	2	2	2
S_3	3	3	3	3	3	1	1	2	2	2	1	2	2	2	2	2	2	2	2	2	2	3
S_4	1	4	2	3	2	2	2	2	3	0	1	2	0	1	0	3	2	2	2	1	2	2
S_5	2	1	1	0	0	2	1	1	0	0	1	1	0	0	0	1	1	1	0	0	2	0

Now we can get the single factor evaluation matrix of visual display system:

$$R_1 = \begin{bmatrix} 0.3 & 0.2 & 0.2 & 0.2 & 0.1 \\ 0.1 & 0.2 & 0.3 & 0.3 & 0.1 \\ 0.3 & 0.2 & 0.3 & 0.1 & 0.1 \\ 0.3 & 0.2 & 0.3 & 0.2 & 0 \\ 0.2 & 0.4 & 0.3 & 0.1 & 0 \end{bmatrix}$$

The weight $W_1 = \left[0.232，0.211，0.134，0.266，0.157\right]$, so the comprehensive evaluation result of visual display system is :

$$D_1 = W_1 \bigcirc R_1 = [0.2421, 0.2314, 0.276, 0.1920, 0.0577]$$

Similarly, the comprehensive evaluation result of motion platform system is:

$$D_2 = W_2 \bigcirc R_2 = \left[0.3749，0.3，0.1512，0.123，0.509\right]$$

The comprehensive evaluation result of pilot's feel about manipulation is:

$$D_3 = W_3 \bigcirc R_3 = \left[0.4192，0.3026，0.212，0.0391，0.0271\right]$$

The comprehensive evaluation result of cockpit environment is:

$$D_4 = W_4 \bigcirc R_4 = \left[0.3251，0.2123，0.1998，0.1779，0.0849\right]$$

In conclusion, the comprehensive evaluation result of this simulator is:

$$\mathrm{V} = \mathrm{W} \bigcirc \mathrm{D} \quad = \left[0.25，0.19，0.35，0.21\right] \bigcirc \begin{bmatrix} 0.2421 & 0.2314 & 0.2768 & 0.192 & 0.0577 \\ 0.3749 & 0.3 & 0.1512 & 0.123 & 0.0509 \\ 0.4192 & 0.3026 & 0.212 & 0.0391 & 0.0271 \\ 0.3251 & 0.2123 & 0.1998 & 0.1779 & 0.0849 \end{bmatrix}$$

$=[0.3467, 0.2653, 0.2141, 0.1224, 0.0514]$.

In order to be easy of evaluating, we use the hundred percentage system to assign each grades of evaluation, $e_1(100)$、$e_2(85)$、$e_3(70)$、$e_4(60)$、$e_5(50)$[8].Then we can get the comprehensive evaluation score of the fidelity of this simulator.

$\mathrm{H} = [0.3467, 0.2653, 0.2141, 0.1224, 0.0514] \cdot [100, 85, 70, 60, 50]^T$ =82.1302

The result says that this simulator is in upper-middle level.

VI. Conclusion

This paper presents a practical method which based on the fuzzy set theory to evaluate the fidelity of simulator. This method contributes to the optimization of flight simulator, enhance the fidelity of flight simulating and the effect of flight training. However the progress of evaluating the fidelity objectively is very complex and as the different evaluators and evaluating targets, the index and the weight must be adjusted.

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