Static Driving Comfort Analysis Based on Fuzzy Comprehensive Evaluation

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Abstract. Based on the purpose of the comfort zone of the drivers' body angle and on the basis of evaluation principles in analyzing the human-machine adaption capacity, this paper puts forward the systematic and practical index system for the driving operation comfort evaluation. Facing the uncertain factors in the index system, it utilizes the fuzzy mathematics to evaluate the ability and also sets up the multistage level fuzzy evaluation model.

1. Introduction

In the human-machine system, the machine is always in the control, monitor and use of the people regardless of the level height of the automation machine, and people are always in a dominant position [1]. Therefore, the design of the machine and environmental conditions should match the basic biological structure of the human body, so as to ensure the operators go through a series of operating movements in a comfortable condition, which further improves the efficiency of the system. And the design of the work space is a very important element.

The work space design is in accordance with the operator's operating range, the visual range, and working posture and a series of physiological and psychological factors on the job objects, based of which the machines, equipment, tools are reasonable arranged. It can also contribute to the most suitable job position and job scope for the operation, and create an optimal working condition for the operator [2]. The driving comfort is an index to evaluate the work space design in the normal driving. Because this comfort index is uneasily to defined and quantify, this paper uses fuzzy comprehensive evaluation method to evaluate.

2. The driving comfort evaluation model

Ergonomics experts have observed and measured the comfort angle range of various parts of human body in the comfortable driving conditions, which is shown in Table 1 [3]. Each measuring angle is shown in Figure 1 [4].

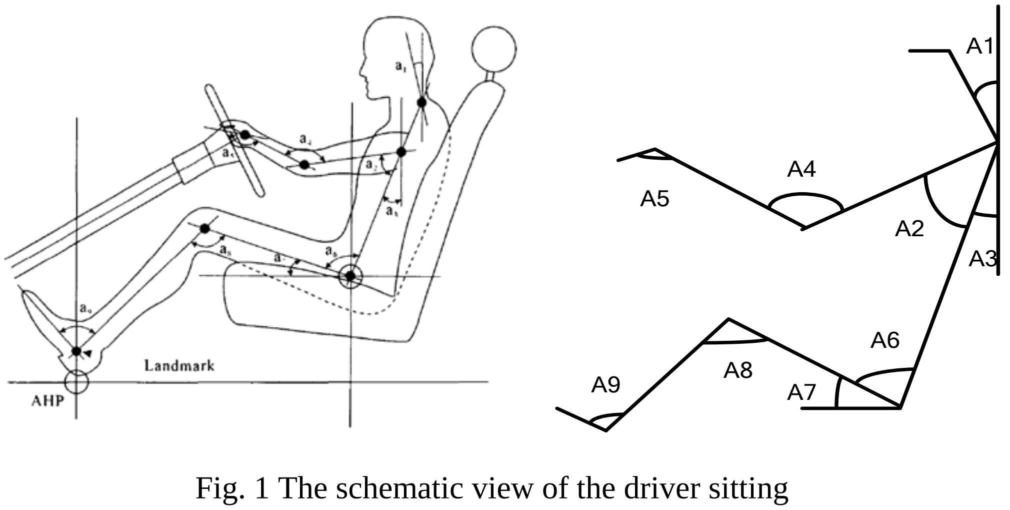

Fig. 1 The schematic view of the driver sitting

The specific meanings are as follows:

- A1 The neck bending angle: the vertical line and the connecting line from seventh cervical vertebrae to the ear canal.
- A2 The upper arm-trunk flexion angle (including the left arm and right arm): the connecting line from shoulder to epicondyle and the connection line from shoulder to thighbone.
- A3 The trunk flexion angle: the vertical line and the connection line from shoulder to thighbone.
- A4 The elbow bending angle (including the left elbow and right elbow): the connection line from palm to ulna and the connection line from ulna to epicondyle.
- A5 The hand-forearm bending angle (including left and right): the connection line from palm to ulnar and the connection line from ulna to epicondyle.
- A6 The trunk-thigh angle (including the left thigh and right thigh): the connection line from shoulder to thighbone and the connection line from lateral epicondyle to thighbone.
- A7 The thigh lift angle (including the left thigh and right thigh): the horizontal line and connection line from thighbone to lateral epicondyle.
- A8 The knee bending angle (including the left knee and right knee): the connection line from thighbone to the lateral epicondyle and the connection line from lateral ankle to lateral condyle.
- A9 The leg-foot angle (including left and right): The connection line from lateral ankle to lateral condyle and the parallel lines of the foot.

Table 1 The chart of sitting comfort angle

Measurement Content	Comfort Angle	
	Average	Range
The neck bending angle (A1)	8.45	4~20
The left upper arm-trunk flexion angle (L-A2)	31.5	23~50
The right upper arm-trunk flexion angle (R-A2)	15	5~28
The trunk flexion angle (A3)	21.1	13~28
The left elbow bending angle (L-A4)	117.3	92~153
The right elbow bending angle (R-A4)	107.1	80~129
The left hand-forearm bending angle (L-A5)	163.4	140~173
The right hand-forearm bending angle (R-A5)	161	150~171
The trunk-thigh angle (A6)	105.9	99~115
The thigh lift angle (A7)	10.6	6~16
The left knee bending angle (L-A8)	126	112~139
The right knee bending angle (R-A8)	118.6	111~134
The left leg-foot angle (L-A9) The right leg-foot angle (R-A9)	108.4	92~125

2.1 The determination of Membership Function

Since the evaluation mode of the sitting comfort is to judge if the given angle is in the middle of a comfort range, if so, it is determined that the comfort. When another range, the farther off-center, the more uncomfortable, which is not linear. So the method to determine the membership function coincides with the F-distribution method in a parabolic distribution at intermediate type. So the paper uses this method.

$$\tilde{A}(\mathrm{x}) = \begin{cases} 0, x < a \\ [(\mathrm{x}-\mathrm{a})/(\mathrm{b}-\mathrm{a})]^k, \mathrm{a} \le x < b \\ 1, \mathrm{b} \le x < c \\ [(\mathrm{d}-\mathrm{x})/(\mathrm{d}-\mathrm{c})]^k, \mathrm{c} \le x < d \\ 0, \mathrm{x} > d \end{cases} \quad (1)$$

Such as the neck bending angle, when it is in an angular range from 4 to 20, the human body is in a comfortable state. So the parameters are determined, b = 4, c = 20. Since the design of the car seat does not appear to the phenomenon that the neck keep back of the normal state, so a = 0. While neck blending down 60 degrees is extremely uncomfortable, so c = 60, and the membership function is obtained.

$$\tilde{R}(x) = \begin{cases} 0, x < 0 \\ (x/4)^2, 0 \le x < 4 \\ 1, 4 \le x < 25 \\ [(60-x)/35]^2, 25 \le x < 60 \\ 0, x > 60 \end{cases} \quad (2)$$

The distribution diagram is as follows:

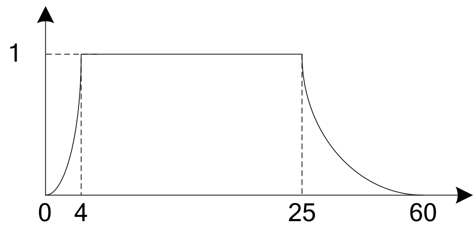

Fig. 2 The distribution diagram

The other projects to determine membership functions use the same method to get.

2.2 Fuzzy Comprehensive Evaluation

Based on the analysis above, the comfort evaluation system is shown in Table 2 by the investigation.

Table 2 The comfort evaluation system

First Level	Second Level	Third Level	Weight
The Comfort	X1 The neck bending angle（0.218）		0.218
	X2 The arm-trunk angle（0.057）	X21 The left arm-trunk angle	0.425
		X22 The right arm-trunk angle	0.575
	X3 The trunk flexion angle（0.119）		0.119
	X4 The elbow bending angle（0.084）	X41 The left elbow bending angle	0.455
		X42 The right elbow bending angle	0.545
	X5 The hand-forearm bending angle（0.163）	X51 The left hand-forearm bending angle	0.412
		X52 The right hand-forearm bending angle	0.588
	X6 The trunk-thigh angle（0.052）		0.052
	X7 The thigh lift angle（0.097）		0.097
	X8 The knee bending angle（0.152）	X81 The left knee bending angle	0.453
		X82 The right knee bending angle	0.547
	X9 The leg-foot angle（0.058）	X91 The left leg-foot angle	0.477
		X92 The right leg-foot angle	0.523

The model is multi-level fuzzy comprehensive evaluation problem and the following steps should be analyzed.

(1) The factors are divided into nine subsets according to the relevant parts of human body.

$$X = \bigcup_{j=1}^{9} X_j \quad (3)$$

And $X_j = \{X_{j1}, X_{j2}, \cdots, X_{jt}\}$ (j = 1, 2 ... 9).

(2) Conducting the single-level fuzzy comprehensive evaluation for each X_j. The reviews of the issue are set to be one, so that is on the "excellent" level membership. The fuzzy weight vector in

the X_j for each factor is $W_j = (\omega_{j1}, \omega_{j2}, \cdots, \omega_{jt})$, and $\sum_{k=1}^{t} \omega_{jk} = 1$. The single-factor evaluation results of X_j is $\tilde{R}_j$ (t row, 1 line).

$$\tilde{R}_j = \begin{bmatrix} \tilde{R}_j \left| X_{j1} \right. \\ \tilde{R}_j \left| X_{j2} \right. \\ \vdots \\ \tilde{R}_j \left| X_{jt} \right. \end{bmatrix} = \begin{bmatrix} r_1^{\ j} \\ r_1^{\ j} \\ \vdots \\ r_1^{\ j} \end{bmatrix}_{t\times 1} \quad (4)$$

The single-factor evaluation model [5]:

$$W_j \circ \tilde{R}_j = (\omega_{j1}, \omega_{j2}, \cdots, \omega_{jt}) \circ \begin{bmatrix} r_1^{\ j} \\ r_1^{\ j} \\ \vdots \\ r_1^{\ j} \end{bmatrix}_{t\times 1} \quad (5)$$

(Note: the °use the model M (·, +) to calculate)

(3) X_j is thought as a combination of factors, it uses $\tilde{B}_j$ as a single-factor evaluation results, so the affiliation matrix can be obtained.

$$\tilde{R} = \begin{bmatrix} \tilde{B}_1 \\ \tilde{B}_2 \\ \vdots \\ \tilde{B}_9 \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_9 \end{bmatrix}_{9\times 1} = \begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_9 \end{bmatrix}_{9\times 1} \quad (6)$$

(Note: if a secondary indicators does not follow third indicators, $bs = Xs$)

If the fuzzy weight vector of a combination factors X_j (j = 1, 2 … 9) is $W = (\omega_1, \omega_2, \cdots, \omega_s)$, the secondary fuzzy comprehensive evaluation model is as follows.

$$B = W \circ \tilde{R} = (\omega_1, \omega_2, \cdots, \omega_9) \circ \begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_9 \end{bmatrix}_{9\times 1} = b \quad (7)$$

The relative size of B means the relative comfort of the evaluated object, so the evaluation system b can be used to sort the objects directly.

3. The Study of Application Case

According to the cockpit comfort evaluation system established in this paper, the comfort of a type of car between three different models can be judged using the fuzzy comprehensive evaluation method above. After the measurement, the statistics of each data are shown in Table 3.

Table 3 The statistics of each index

Index	Car A	Car B	Car C
X1	16	18	7
X21	41	29	22
X22	19	25	16
X3	12	13	27
X41	141	80	104
X42	109	92	122
X51	130	156	186
X52	156	169	141
X6	113	90	101
X7	15	20	17
X81	142	129	141
X82	127	109	120
X91	110	111	124
X92	85	113	139

The indexes are substituted into the corresponding membership function and the membership is obtained as shown in Table 4.

Table 4 The index membership tables

Index	A	B	C
X1	1	1	1
X21	1	1	1
X22	1	1	1
X3	0.98	1	1
X41	1	0.91	1
X42	1	1	1
X51	1	1	0.87
X52	1	1	196
X6	1	0.89	1
X7	1	0.93	0.97
X81	0.94	1	0.95
X82	1	0.99	1
X91	1	1	1
X92	0.98	1	0.91

The car A is analysed as followed:

(1) The comprehensive judgment according to the hierarchy

$$B1=X1=1$$

$$B2=W2\circ R2=(0.425,0.575)\circ\begin{bmatrix}1\\1\end{bmatrix}=1$$

$$B3=X3=0.98$$

$$B4=W4\circ R4=(0.455,\ 0.545)\circ\begin{bmatrix}1\\1\end{bmatrix}=1$$

$$B5=W5\circ R5=(0.412,\ 0.588)\circ\begin{bmatrix}1\\1\end{bmatrix}=1$$

$$B6=X6=1$$

$$B7=X7=1$$

$$B8=W8°R8=(0.453, 0.547)\,°\begin{bmatrix}0.94\\1\end{bmatrix}=0.973$$

$$B9=W9°R9=(0.477, 0.523)\,°\begin{bmatrix}1\\0.98\end{bmatrix}=0.989$$

(2) The high-level comprehensive judgment

$$B=W°B_j=(0.218, 0.057, 0.119, 0.084, 0.163, 0.052, 0.097, 0.152, 0.058)\,°\begin{bmatrix}1\\1\\0.98\\1\\1\\1\\1\\0.973\\0.989\end{bmatrix}=0.993$$

Therefore, the driving comfort of the car A is 0.993, similarly, the driving comfort of the car B is 0.956, the driving comfort of the car C is 0.941. So the fuzzy comprehensive evaluation results show, driving comfort A> B> C.

4. Summary

It is a very complex task to conduct static comfort evaluation for car cockpit, which involves many fuzzy factors that are difficult to quantify. But the fuzzy comprehensive evaluation is a qualitative and quantitative effective method, the method takes given object fuzzy factors into consideration. This paper establishes the evaluation index system and three-level fuzzy comprehensive evaluation model for the cabin comfort. The model is important for scientific comfort evaluation of the static drivers and can guide cockpit design.

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