Clustering of in-Vehicle User Decision-Making Characteristics Based on Density Peak

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Abstract. In this paper, we designed the simulated combat experiment to obtain the decision of the participants. Combining with the characteristics of the decision - making in the combat procedure and combat task, the fuzzy recognition model was established to obtain the model user characteristic matrix. The decision-making characteristics clustering analysis of density peak is the foundation for the design of adaptive in-vehicle user interface based on user decision-making characteristics.

Keywords: Decision-making characteristics · In-vehicle user · Cluster analysis

1 Introduction

In the process of interacting with the vehicle interface and completing the operation task, the display content and mode of the interface play a very important role in the decision-making of the operator's behavior. In order to provide more helpful interface information and interactive mode for the operator's characteristics, the user can efficiently carry out the human-computer interaction, and the vehicle-based adaptive interface is the hotspot of the current research. Adaptive user interface(AUI) can be automatically adjusted according to the user's interactive behavior, thereby changing the interface information display and content, such as changing its layout, structure, style, display content and other elements to meet specific user requirements in a particular environment [1, 2]. AUI can predict user behavior, reduce the burden of human-computer interaction, improve the efficiency of interaction tasks, can adapt to the user, the environment or changing needs [3]. Although many scholars are working on the new vehicle interface adaptive mechanism, few researches on engineering vehicles and military vehicles have been done, especially, the user characteristics modeling are also lack of research in these field.

Without sufficient consideration of user characteristics, the lack of adaptive mechanisms for user characteristics is one of the causes of operator error in human-computer interaction. User modeling is an important part of AUI research. User model includes adaptive information, which can summarize and classify users. (1) In application-based modeling, Dieterich H [4] divides user characteristics into application-related computer experience knowledge and application-independent user

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preferences and learning abilities. (2) In the aspect of cognitive-based modeling, Zuxiang Zhu [6] introduces the user's attention strategies, words and spatial abilities into the user model. (3) In the process of learning based on the user, Jingyun Cheng [7] select user thinking, learning in the understanding, memory and other characteristics of modeling; (4) Based on the number of users, Dieterich H et al. [4] Zhiwei Guan [5] and Xiao Li [8] model individual and user groups, general and special users, respectively.

The study of user classification includes classification criteria and classification methods. (1) In the study of user classification criteria, Dieterich H [4] Anthony F et al. [9] and Schiaffino S et al. [17] classify users both qualitatively and quantitatively. Zhiwei Guan [5] and Anthony F [9] studied the frequency of use, purpose, type of learning and proficiency of users, and develop the standards for classification. (2) In the study of user classification methods, Hongmei Ge et al. [10] carried out two naive Bayesian classifications according to the user's interest vector in all time slices, and got the user classification in the whole time period. LingLuo [11] used the fuzzy c-Means clustering algorithm to cluster the power users according to the load curve of power users. Wei Zheng [12] proposed a Web user clustering method by extracting the user's access behavior and getting the similarity. And use these clusters as the previous empirical data for the artificial neural network, improve the efficiency of user classification.

Decision-making style is a decision-making habits, but also for accepting or reflecting the decision-making tasks personal characteristics [13]. For the type of decision-making style, different scholars according to different standards were classified. Henderson and Nut [14] divide the decision style into Analytic and Heuristic according to the rational way. Driver [15] divides decision styles into five types according to the amount of information used. Scott and Bruce [16] divided decision making into five different styles.

Based on the human-computer interaction task, this paper established a combat simulation experiment based on abstract task content and information. Design experimental tasks and human-computer interaction interface with LabVIEW. The related indexes in the task performance of participants were obtained. The user characteristic matrix in the form of fuzzy recognition model was obtained based on the characteristics of the decision process presented by the participants in the experiment. Cluster based on density peak and the analysis result is the foundation for the design of adaptive in-vehicle UI based on user decision-making characteristics.

2 Method

This experiment is simulated combat experiment, the participants complete the given task as a real user in battlefield.

The experiment was carried out to obtain the decision of the participants in 5 kinds of combat situations.

In order to reduce the participants' unfamiliarity with the effect of the vehicle interface on the experimental results, the participants need to repeat the experiment several times.

The experiment is divided into stage 1 and stage 2.

Stage 1 is user modeling.
Stage 2 is user clustering.

2.1 Experiment Design

Interface Design
Vehicle interface is the channel between user and the vehicle to transmit information, including the display and controller. The display design is a vital part of the overall design of the vehicle interface, which directly affects the overall combat effectiveness. In this experiment, the vehicle interface display is designed to provide the user with full consideration of the operating characteristics, allowing vehicles and users to adapt to each other and improve the efficiency of interaction.

In this experiment, we designed the vehicle interface display information and layout.

Information
Combined with specific combat situation, the information provided to the participants included 4 parts.

(1) Map
Including one's own position with the enemy's information, the number of the enemy, the direction of the front.
(2) Description
Description describes the current combat situation, the experiment contains 5 kinds of combat situations.

Situation 1: The enemy is located outside the scope of the attack.
Situation 2: The enemy is located within the scope of the attack.
Emergency of Situation 2: When the enemy is within the attack range, a new enemy is detected.
Situation 3: the enemy is located within the scope of the attack and the enemy has launched an attack.
Emergency of Situation 3: The enemy is located within the attack range and the enemy has launched an attack, a new enemy is detected.

(3) Task information
Including the degree of threat of the enemy, the relative position (distance and height), target types and attack plans.

The relative position includes distance and height difference; the target type is divided into helicopters, tanks and fighters; attack plan contains different enemies equipped with the corresponding attack methods, namely shells, missiles and shells together.

After abstracting and simplifying the combat information, we designed the simulated combat task. The information of the task in 5 cases is shown in Table 1, in which

Table 1. Task information in 5 situations

		Situation 1	Situation 2	Emergency of situation 2	Situation 3	Emergency of situation 3
Threat degree	A	0.929	0.803	0.695	0.004	0.003
	B	0.004	0.018	0.014	0.923	0.979
	C	0.975	0.943	0.948	0.899	0.856
	D			0.629		0.798
Relative position (Distance–Height)	A	30-50	14-20	14-20	14-20	14-20
	B	35-5	8-5	8-5	7.1-100	7.1-100
	C	45-2000	25-1500	25-1500	18.2-2500	18.2-2500
	D			3.1-15		3.1-5
Target type	A	H	H	H	T	T
	B	T	T	T	H	H
	C	F	F	F	F	F
	D			T		T
Attack plan	A	M	M	M	S	S
	B	S	S	S	M	M
	C	M	M & S	M	M	M
	D			S		S

Notes:*H* represents *helicopter*; *T* represents *tank*; *F* represents *fighter*
M represents *missile*; *S* represents *shell*

the threat degree is calculated from the relative position and the target type, and the attack plan is given according to the specific situation.

(4) Feedback
Feedback the operation of the participants.

Layout
According to the requirements of the experiment, the display should include the following five parts: the map area, task information area, description area, feedback information area and control button area. Meng Wang [18] studied the identify performance on the display location information recognition, and the result is 1 (upper left area) > 2 (lower left area) > 3/3' (upper right and lower right areas), as shown in Fig. 1. The user has the highest recognition identify for the information displayed by 1 (upper left area), so that the map area presenting the complex information is arranged at 1 position; Wherein the user has a faster reaction speed and a higher correct rate for the information displayed by the 2 (lower left area), and is suitable for displaying important prompt information, so that the description is arranged at the 2 position; The user has a high accuracy rate for the information displayed at the 3'(lower right area), thus arranging the feedback at the 3' position; The user has a faster response speed to the information displayed by 3 (upper right area), so that the task information area is arranged at the 3 position.

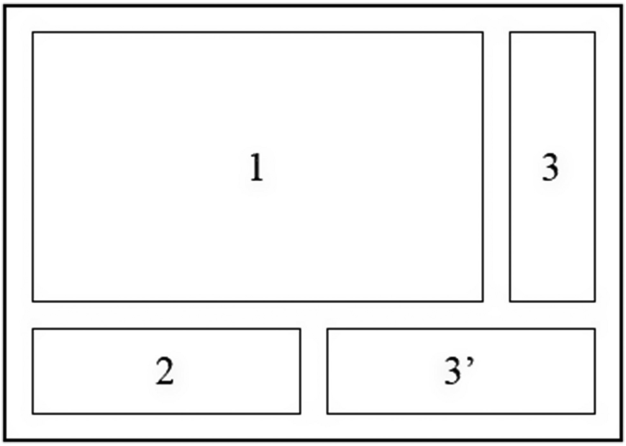

Fig. 1. The sorting of identifying performance of display parts

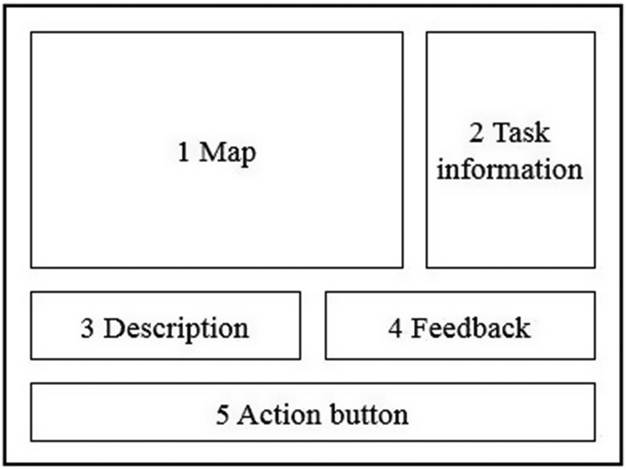

Fig. 2. Vehicle man - machine interface layout

After taking into account the above information and the actual design of the display, we determine the final layout of the display shown in Fig. 2.

Task Procedure

In order to reduce the risk and the difference between operators in manipulating complex controllers, the participants were asked to use a mouse to perform the experiment tasks.

In this experiment, participants need to follow the instructions, according to the battle map and task information and make decisions (attack, defend, escape) in the control button area, the decision will be given feedback. Participants need to make

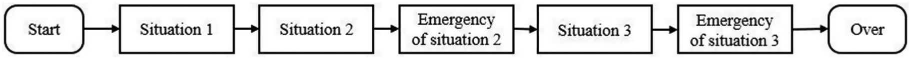

Fig. 3. Experimental flow chart

decisions in 5 situations in turn, and the experimental flow of a simulated combat mission is shown in Fig. 3.

Data Collection

In this experiment, LabVIEW was as the software environment background. The program recorded the decision under different experimental conditions and the number of experiments.

A total of 41 undergraduates, graduate students and doctoral students from Beijing Institute of Technology (including 29 males and 12 females) participated in the experiment. They are between the ages of 20–29 years of age, visual acuity and corrected visual acuity were normal, and has not participated in the test of such experiments. Taking into account the effect of fatigue on the experimental results, the experiment time should not exceed 45 min.

2.2 Stage 1: Modeling of User Decision-Making Characteristics

Select 10 participants, and 10 combat tasks were repeated. Combining with the combat process and combat task, a fuzzy recognition model of user characteristics are established, which can identify the interaction characteristics of the user through the interaction behavior. Analyze the convergence of the user model as the number of user experiments increases.

User Model

Combining with the experimental background of the armored vehicle combat and the behavioral characteristics exhibited by the participants, this study proposed the characteristics of "conservative", "calm" and "risk" to measure the user's decision style. Each of the user's decisions are reflected in these three characteristics.

In this study, the fuzzy comprehensive evaluation method is used to identify the user's decision making [19]. This method is based on the evaluation results of the single factor related to the evaluation object. Finally, the evaluation results are obtained by using the weight factor of each factor.

$X = \{ x_1, x, \ldots, x_n\}$ is a set of evaluation factors, and $Y = \{ y_1, y_2, \ldots, y_n\}$ is a set of evaluation indexes. Each user is determined a fuzzy relation R from X to Y, R is the evaluation matrix of the user, in which the various factors of r_{ij} in R mean evaluation object factor of x_i which belongs to the y_j membership of evaluation grade ($i = 1, 2, \ldots, n$; $j = 1, 2, \ldots, m$).

Λ is a fuzzy subset of X, indicating that the degree of importance of the evaluation factors, e.g. weight, $\Lambda = \{\lambda 1, \lambda 2, \ldots, \lambda n\}$, where $\lambda i \geq 0$ and $\sum \lambda_i = 1$.

C means user evaluation, $C = \Lambda \times R$.

In this paper, $X = \{x_1, x_2, x_3, x_4, x_5\}$, $Y = \{y_1, y_2, y_3\}$.

The x_1, x_2, x_3, x_4, and x_5 respectively indicate the decision in the situation 1, situation 2, emergency of situation 2, situation 3 and emergency of situation 3. y_1 y_2, y_3 is characteristic value of risk, calm, and conservative. A fuzzy relationship from X to Y is as follows:

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \\ r_{41} & r_{42} & r_{43} \\ r_{51} & r_{52} & r_{53} \end{bmatrix}$$

In this experiment, five situations have the same influence on user behavior, so $\Lambda = [0.2, 0.2, 0.2, 0.2, 0.2]$ is taken.

The evaluation object factor x_i belongs to the y_j membership of evaluation characteristic which is determined by the membership function [20], getting the membership function of the user under different decision by the expert evaluation method [21, 22], adopted by the linear membership function distribution [23, 24], the membership function of user characteristics under different behavior is shown in Fig. 4:

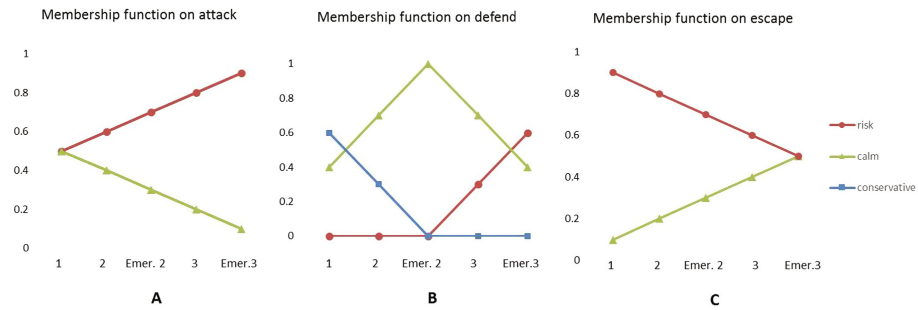

Fig. 4. The membership function of user characteristics under different behaviors

Result and Analysis

According to the user model in 2.2.1, we obtain the user evaluation matrix of 10 participants in stage 1. The changes of user characteristics in 10 experiments and the corresponding number of participants are shown in Table 2.

For example, in the case 1, the evaluation result of a user is always [0.42,0.36,0.22], the decision-making characteristic is stable and the risk characteristic is obvious; The evaluation results of a user in Case 3 are shown in Table 3, and the results of the evaluation have been changed in the first 6 trials. From the 7th trial, the results of evaluation tend to be stable, and the calm characteristics of this user are obvious. We argued that the user model stabilized after the 7th time of trial.

According to the current results, we only make a general analysis of the user's decision-making characteristics, the conclusions are not necessarily applicable, we will further analysis user characteristics in stage2.

Table 2. User characteristics of the changes in stage1

	Characteristic	Number/percentage
Case 1	There were no changes in 10 experiments.	2/20%
Case 2	Changes in the pre-period, no more changes after 6 experiments.	5/50%
Case 3	The characteristic has been changing and tends to be stable after 7 experiments.	3/30%

Table 3. User evaluation in stage1

Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10
0.28	0.32	0.12	0.24	0.12	0.24	0.42	0.42	0.42	0.40
0.52	0.44	0.58	0.46	0.44	0.52	0.40	0.52	0.52	0.48
0.20	0.24	0.30	0.30	0.44	0.24	0.18	0.06	0.06	0.12

2.3 Stage 2: Clustering of User Decision-Making Characteristics

The other 31 participants performed the trial for 7 times. According to the comprehensive evaluation of the user and the corresponding three evaluation indicators, the corresponding points in the 3-dimensional space are obtained. Cluster analysis based on density peak, and the decision-making characteristics of users in each cluster are analyzed to determine the decision-making style.

Result and Cluster Methods

At present, clustering methods are based on partitioning method, hierarchical method, density-based method and so on. In this paper, a method of fast search and find of density peaks (referred to as DPC) introduced by Alex Rodríguez and Alessandro Laio is used for clustering. The DPC algorithm is based on the idea that cluster centers are defined by having a higher density than their neighbors or at a relatively large distance from points with higher densities.

The clustering method defines two variables for each data point: its local density ρ_i and its distance δ_i from points of higher density. Both these quantities depend only on the distances between data points.

The local density ρ_i is defined as

$$\rho_i = \sum \chi(d_{ij} - d_c)$$

where $\chi(x) = 1$ if $x < 0$ and $\chi(x) = 0$ otherwise, and dc is a cutoff distance.ρ_i is equivalent to the number of dots whose distance to point i is less than dc. As a rule of thumb and the number of data points in this experiment, we can choose dc so that the average number of neighbors is around 5% to 8% of the total number of points in the data set.

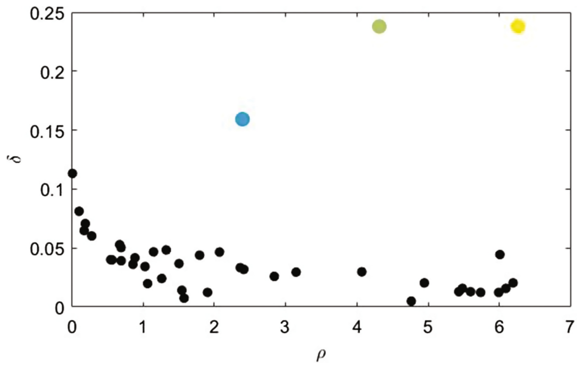

Fig. 5. Decision diagram (Color figure online)

δ_i is measured by computing the minimum distance between the point i and any other point with higher density:

$$\delta_i = \min_{j:\rho_j > \rho_i} (d_{ij})$$

The points with higher ρ_i and δ_i are considered to be clustering centers, and the remaining points are assigned to the clusters with higher density nearest to the point, and the clustering results are obtained.

Cluster Analysis

According to the calculation method in 2.3.1, calculate the ρi and δi of each data point, and the decision diagram is shown in Fig. 5.

It can be concluded from the Fig. 5 that the decision styles presented in this experiment can be divided into three categories, the cluster centers are three points of yellow (1), green (2) and blue (3). The number and percentage of users per cluster are shown in Table 4.

Table 4. Clustering results

Cluster	Number/percentage
1	19/46.34%
2	14/34.15%
3	8/19.51%

Results of cluster analysis are shown in Fig. 6A–D respectively. In the 3-dimensional space composed of three characteristics, the polygons formed by each cluster are not coincident. Users within each cluster have some common features that can be described by the users' 3 decision characteristics.

Figure 6A is a representation of the clustering of user characteristics in 3-dimensional space, and Fig. 6B–D are representations of two of the three properties in two dimensions respectively.

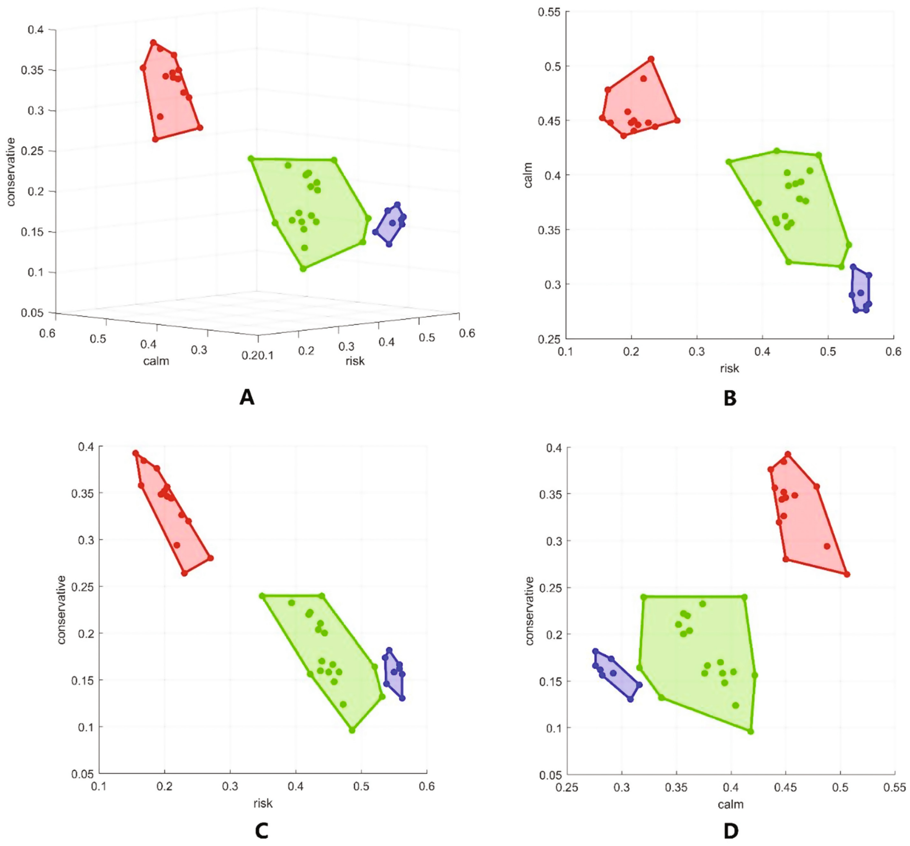

Fig. 6. The clustering results of user decision characteristics Notes: "●"represents cluster 1, "●"represents cluster 2, "●"represents cluster 3 (Color figure online)

Cluster 1 includes the largest number of points as well as the largest range, followed by cluster 2, and cluster 3 includes the smallest number of points as well as the smallest range. According to Fig. 6B and C, compared with cluster 2, the "risk" values of cluster 1 and cluster 3 are higher, and there are certain differences between cluster 1 and cluster 3. According to Fig. 6B and D, the "clam" values of cluster 2 are on high level, and the "clam" values of cluster 1 are on middle level, and the "clam" values of cluster 2 are on low level; besides, the "clam" values of the three clusters are continuously distributed, without significant differences between two adjacent clusters. It can be seen from Fig. 6C and D that the "conservative" values of cluster 2 are on high level, and the "conservative" values of cluster 1 and cluster 3 are on middle level, but the range of the "conservative" values of cluster 1 is higher than that of cluster 3.

3 Discussion

3.1 Stage 1

According to the user model and the experimental results in 2.2, we summarize all the user categories into 5 types, divided into 2 categories.

Category 1: The users with any decision-making character much higher than the other two characteristics in the evaluation result are the users of the characteristic, i.e., the risk type users, the clam type users or the conservative type users.

Category 2: The users with relatively high values of two adjacent decision-making characteristics but not an apparently higher one, i.e., the users with relatively high risk characteristic and clam characteristic as well as with relatively high clam characteristic and conservative characteristic in this experiment, are defined as partial risk users and partial conservative users, respectively.

3.2 Stage 2

According to Table 4, cluster 1 includes the largest number of participants, accounting for about half of the total number. Most of the “risk” values of users in cluster 1 are within the range of 0.4–0.5, accounting for about half of the whole proportion, and some users are lower than 50%. Most of the “clam” values of users in cluster 1 are within the range of 0.35–0.4, with little difference with the range of “risk” values. Comparing with the ranges of “risk” and “clam” values, “conservative” values have a wider range of 0.1–0.25, as the minimum values of the three characteristics. The users of cluster 1 have moderate risks and clams and low conservatives during decision-making, and they are partial-risk users.

Most of the “clam” values of users in cluster 2 are within the range of 0.43–0.5, accounting for about half of the whole proportion, and most users are lower than 50%. Most of the “conservative” values are within the range of 0.28–0.38, with larger range than the “clam” values. The “risk” values are the minimum ones in the three characteristics, within the range of 0.15–0.25. Although there is no significant difference between the “clam” values and the “conservative” values of the users in cluster 2, all the “clam” values are larger than the “conservative” values; therefore, the users in cluster 2 are conservative type users.

Cluster 3 includes the least participants, less than 20% of the total number. All the “risk” values in cluster 3 are about 0.55, more than half of the whole proportion. Both the “clam” values and the “conservative” values are relatively small, in which the “clam” values are larger. The “risk” values of users in cluster 3 are apparently the largest; with tendency of higher risks, the users in cluster 3 are risk type users.

Through the analysis of cluster 1, cluster 2 and cluster 3, we find that the user decision-making style is more risk and calm, and less conservative. The reason may be that it is difficult for the participants to have a more realistic experience of the urgency and danger in the experiment. So more decisions are attack and defense, less escape. Although there is a gap between the experimental situation in the experiment and the situation in the real battlefield, but the simulated combat task has been able to achieve the user decision-making characteristic.

4 Conclusion

The main purpose of this paper is to classify the user based on the decision-making characteristics for the design of in-vehicle AUI. The paper is also the foundation for the future research of AUI design in special vehicle application.

In summary, the clustering based on density peak could be a practical way to research the in-vehicle user decision-making characteristics. In the 3-dimensions of "risk", "clam" and "conservative", the users of each cluster have different characteristics. The results of user decision-making cluster analysis are as follows.

(1) According to decision-making style, users are divided into three categories, partial risk-type users is about half, and the rest for the users of calm and users of risk.
(2) The partial-risk users show high risk and moderate calm as well as less conservative in decision - making. Users of calm show slightly greater calm and moderate conservative in decision making; Users of risk show greater risk and less calm and conservative in decision making.

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