Optimization of the position layout of in-vehicle central information display based on genetic algorithm

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Abstract. In-vehicle central information display (CID) has become an essential part in the cockpit. It is of great theoretical significance and application value to optimize the position layout of CID, which help to improve driving safety and operating comfort. In this paper, the ergonomics experiment is designed and the driving simulation test method is used for the experiment. Based on the collected data for genetic algorithm, the fitness function is set, and the process of gene selection, crossover and mutation is simulated to obtain the optimized coordinates of the position layout of the central control screen. According to the results of optimization, ergonomics experiments are carried out again to verify the reliability of the optimization results. This paper has guiding significance for the development of digitalization in the cockpit.

1. Introduction

In the automotive industry, global automobile manufacturers, such as Volkswagen in Germany, Ford in the United States and local brands in China, have been equipped with the touch screen in the cockpit as the main interactive device [1-2]. According to the IHS Markit database, global sales volume of touch screen panels for vehicles were 50 million in 2017, up 11% from 2016 and appearing obvious growth trend. Ergonomics is internationally recognized as a science-based discipline, which combines anatomy, physiology, statistics, psychology and engineering so that design can bring into play human strengths and abilities and avoid human weaknesses as much as possible. [3]

The digitalization and intelligence of automobile cockpit has become an irreversible trend. In the short and medium term, the CID will be the most important hardware to show the digitalization and intelligence of cockpit. While driving, the driver often uses map navigation, music radio, air conditioning settings, communication and social functions through CID [4-5]. Compared with the traditional button operation, the change of this interaction mode will bring additional physiological and psychological loads to the driver [6], thus affecting the driving behaviour. Therefore, based on ergonomics, it is an essential mission for automobile manufacturers to optimize the position layout of in-vehicle CID to meet driving safety and operational comfort, which has high theoretical and practical significance.

When it comes to the ergonomic optimization of in-vehicle CID, the most concerned evaluation dimension is driving safety and operational when driving. With the help of the simulation driving laboratory and CID built in the cockpit, it is easy to set up the experimental environment required for the ergonomics experiment method, and collect rich operational data and environmental data. Based on
rich data, it is significant optimize the position layout of the in-vehicle CID by building a mathematical model.

2. Methods
Genetic algorithms (GA) were originally introduced in literature by John Hollan in the 1970s. GA are based on the mechanics of natural selection and evolution optimization. [7] By simulating the biological evolution mechanism in nature, the algorithm takes the parameters in specific mathematical systems as evolutionary genes to simulate gene selection, replication, crossover and mutation in biological evolution, and optimizes the mathematical system. In the decades after the introduction, genetic algorithm has been developed to improved genetic algorithms, annealing algorithms, and etc., and they are applied to engineering production to optimize the process.

Genetic algorithm includes gene coding, gene selection, gene crossover, and gene variation and so on. In this paper, this process consists of the following five processes. [8]

(1) Gene coding and identification of initial population
This paper uses binary coding. Taking the range of characteristic variables \([U_1, U_2]\) as an example, 2k different codes are generated and the corresponding relation of coding is

\[
\begin{align*}
000\ldots000 &= 0 \\
000\ldots001 &= 1 + \delta \\
000\ldots010 &= 2 + 2\delta \\
\vdots & \quad \vdots \\
111\ldots11 &= 2^k - 1 \rightarrow U_2 \\
\delta &= \frac{U_2 - U_1}{2^k - 1} 
\end{align*}
\]

(2) Gene selection
The father individual is selected for fitness judgment and the child generation is generated. In this paper, roulette algorithm is used to select individuals. The fitness of all individuals makes up a disc. The larger the fitness, the larger the sector area, the higher the probability of inheriting the features to the next generation. Assuming that the fitness of individual i is \(f_i\) and the population number is M, the probability of each individual i being selected is:

\[
P_i = \frac{f_i}{\sum_{k=1}^{M} f_k}
\]

(3) Gene crossover
The process of gene crossover allows the child generation to inherit the different genetic characteristics of the parents. As shown in Fig.1, after the gene coding positions of the two parental individuals are interchanged, two new gene combination are generated. In the genetic algorithm, the probability of gene crossover is generally between 0.25 and 0.75, and it is set to 0.6 in this paper.

![Gene crossover exchange in binary coding](image)
(4) Gene variation
This process simulates gene variation in nature, through which organisms in nature can maintain the diversity of the population and avoid evolving into a single progeny population. In genetic algorithm, gene variation can avoid premature convergence to local optimal solution. As shown in Fig.2, the binary-coded gene variation from 0 to 1, and from 1 to 0. In genetic algorithms, the probability of gene variation usually occurs between 0.01 and 0.1. In order to avoid the premature convergence of the algorithm to the local optimal solution, the probability is 0.15 in this paper.

![Gene variation in binary coding](image)

**Figure 2.** Gene variation in binary coding

(5) According to the fitness function, it is judged whether the generated child conforms to the optimization condition, and if not, the algorithm repeats the above process until the end condition is satisfied.

3. Experiment
The simulation driving experiment platform for ergonomics experiment is mainly composed of simulation cockpit, simulation driving environment and data acquisition system. The cockpit is refitted from the 2015 Citroen DS5. The power assembly system and the in-vehicle CID system of the original car have been removed and connected with additional steering system sensors, accelerator pedal and brake pedal sensors, which can simulate the movement of the vehicle. The simulated driving environment includes a variety of driving scenarios, including urban, suburban, high-speed and crowded roads, which is controlled by the input of the vehicle's motion system in the cockpit. The data acquisition system is based on the central computer storing the vehicle data and completing the subtask storage.

In this paper, the cylindrical coordinate system is used to construct the screen features. As shown in Fig.3, the three-dimensional coordinates of CID are expressed by x, θ and r, where x represents the translation distance along the axis of the wheel and relative to the center of the eye ellipse, θ represents the rotation angle around the x axis, and r represents the distance away from the x axis. After the gene expression of the CID is expressed in the cylindrical coordinate system, the positional layout of the CID can be transformed into x, θ and r in the cylindrical coordinates. These three points are used as the characteristics of the genetic algorithm. Variable. Based on the definition of manual interface in ergonomics and the current situation of position layout in automobile market, the position characteristics of CID are limited:

- $200\text{mm} < x < 550\text{mm}$
- $450\text{mm} < r < 800\text{mm}$
- $\theta < -6^\circ$
Figure 3. The three-dimensional coordinates of CID

Based on the study of mental load in the fields of ergonomics and automotive engineering, the evaluation method of mental load is refined into manipulative performance indicators, psychophysiological signal indicators and subjective scoring indicators.

Driving on the suburban road of the simulation driving experiment platform, the driver completes the sub-task while maintaining the speed of 60 km/h. Simulation driving experiment platform can help collect the manipulative performance indicators. Eye tracker can collect psychophysiological signal indicators of testers. Subjective questionnaire can collect subjective scoring indicators. 16 testers are selected from the subjects, which included age, gender, driving age, body size and visual acuity. And each tester needs to complete 7 driving tasks at 32 sampling points of the position of CID. The design of the driving task simulates the interaction process of the in-vehicle CID.

4. Results and analysis

In the process of optimizing the position layout of the CID, the population number of each generation is 400, and the maximum genetic algebra is set to 40 generations.

In this paper, the fitness function is determined by six optimization indicators, and the sub-individuals need to meet the target value set by each optimization indicators. Because the screening results of the six evaluation indicators for the best position of the CID are different, when searching for the best solution, the demands cannot be met at the same time. Therefore, in the process of selecting the optimization objectives of the six evaluation indicators, it is necessary to reduce the optimization objectives appropriately, as long as the threshold of certain optimization indicators is reached. The longitudinal target speed deviation and lateral road deviation in driving performance, the number of gaze times and the duration of road gaze in eye movement signals is four indicators, whose optimization goal is determined by the data of non-sub-task driving and the data of the best performance of sub-task driving. The difference between the optimization indicators value and non-sub-task driving value is allowed to increase by 10% compared with the difference between the optimal value and non-sub-task driving:

$$\frac{f_T-f_N}{f_B-f_N} - 1 < 10\%$$  (4)

Where $f_T$ refers to the optimal target value, $f_B$ refers to the optimal performance when driving with sub-tasks, and $f_N$ refers to the value when driving without sub-tasks.
For the two indicators of single screen gaze duration and subjective scoring in eye movement signals, the objective of optimization is determined by past research experience. Relevant studies have shown that [9], the driver's gaze does not exceed 1s each time he moves away from the road, which is a safe value. Therefore, the optimization target of single screen gaze duration is set to be less than 1s. For the subjective score of pressure value, some studies have shown that [10], when the driver is at a high level of pressure load, it is easy to cause accidents, and when he is at a low level, he is also prone to sleepiness or distraction, which is not conducive to normal driving. Therefore, the objective of subjective score optimization is set at less than 35 points, indicating that some efforts are needed to complete the task.

As shown in Fig. 4, it is the deviation ratio between the optimal solution and the optimal goal in each generation's individuals in the iterative process of genetic algorithm. It can be seen that after 10 generations, the deviation value has become stable, and the deviation value between the optimal solution and the optimization objective is close to zero. And the difference between the average solution and the optimal solution of the total sample is also rapidly reduced from several times to 0.5-1 times. Because of the large variation probability set by genetic algorithm, even when the optimal solution has become stable, the average solution of the total sample will pull up the value of the average solution due to the emergence of the variation individuals, and will never reach the optimal solution.

![Figure 4. Optimization process curve of GA](image)

After 20 iterations, the optimal solution of the coordinate value of CID is as follows:

\[
x = 311.045 \text{mm} \\
r = 585.469 \text{mm} \\
\theta = -20.094^\circ
\]

As shown in Fig.5, it is the location diagram of the optimal solution in the coordinate system (including 45° view, top view and side view):
Figure 5. Schematic diagram of the optimal solution of position layout CID

As shown in Table 1, it is the predicted value of six evaluation indicators corresponding to the optimized solution coordinates of the CID given by the genetic algorithm after 20 iterations.

Table 1. Comparison between the predicted value of the evaluation indicators corresponding to the optimized solution and the optimized objective

| Indicator type       | Indicators                             | Predicted value | Optimized objective |
|----------------------|----------------------------------------|-----------------|---------------------|
| Driving performance  | Longitudinal target speed deviation (m/s) | 1.597           | <1.623              |
|                      | Lateral road deviation (m)              | 0.246           | <0.251              |
| Eye movement         | Number of fixation                     | 14.173          | >13.706             |
|                      | Proportion of road gaze time (%)        | 44.785          | >44.201             |
|                      | Single screen gaze duration(s)          | 954.122         | <1000               |
| Subjective scoring   | RSME scoring                            | 29.346          | <35                 |

As shown in Figure 6, it is the box-plot comparison of driving performance indicators of non-sub-task driving, 32 samples of sub-task driving, predicted value of optimal solution and optimized target value.
The optimal solution from genetic algorithm can make the longitudinal target speed deviation and lateral road deviation reach the last 20-25% of the level when driving without a sub-task, approaching the state when driving without a sub-task, which is a relatively ideal optimization result.

As shown in Figure 7, it is the box-plot comparison of eye movement indicators of non-sub-task driving, 32 samples of sub-task driving, predicted value of optimal solution and optimized target value.
For the indicator of single screen gaze duration, most of the positions of sampling points cannot meet the requirement that the single screen gaze duration is less than 1000ms, and only a few CIDs with appropriate positions can do it.
The optimal solution from genetic algorithm can make the number of fixation and proportion of road gaze time reach the last 10% of the level of non-sub-task driving, and reach the first 10% of 32 sampling points, which is an ideal optimization result.

As shown in Figure 8, it is the box-plot comparison of subjective scoring indicators of non-sub-task driving, 32 samples of sub-task driving, predicted value of optimal solution and optimized target value.

![Figure 8. Comparison of predicted value of optimized solution with non-sub-task value and sampling value](image)

The optimal solution from the genetic algorithm for the proportion of proportion of road gaze time can reach the top 10% of the 32 sampling points' subjective scores, "only a little effort" can complete the main task and sub-task of driving, which is a relatively ideal optimization result.

5. Discussion
In order to verify the accuracy of the optimization results, 16 testers were invited again at the end of the research. The operation test of the optimized position of the CID was carried out under the simulated driving simulation environment.

After the data is derived from the simulation driving platform and the eye tracker, the data segment is divided. Then the abnormal values are eliminated according to the method of pauta criterion. Compared with the predicted values, the experimental values of each indicators under the position layout of the CID are obtained, as shown in table 2.

Among the six indicators, except lateral road deviation is slightly higher than the optimization objective and the predicted value, the other five indicators are not much different from the expected value, meeting the optimization objective. The reason for the high lateral road deviation may be that the data collected by the platform fluctuates greatly. Compared with the previous sampling experiments, it can be seen that the lateral road deviation indicators index has a larger fluctuation range than the other five indicators. Therefore, it can be considered that lateral road deviation can meet the objective of optimization.
Table 2. Comparison between predicted values of evaluation indicators corresponding to optimized solution and experimental test

| Indicator type       | Indicators                              | Predicted value | Optimized objective | Experimental value |
|----------------------|-----------------------------------------|-----------------|---------------------|--------------------|
| Driving performance  | Longitudinal target speed deviation (m/s) | 1.597           | <1.623              | 1.470              |
|                      | Lateral road deviation (m)              | 0.246           | <0.251              | 0.256              |
| Eye movement         | Number of fixation                      | 14.173          | >13.706             | 14.0625            |
|                      | Proportion of road gaze time (%)        | 44.785          | >44.201             | 48.7375            |
|                      | Single screen gaze duration(s)          | 954.122         | <1000               | 924.952            |
| Subjective scoring   | RSME scoring                            | 29.346          | <35                 | 24.375             |

According to the optimization results from genetic algorithm, the ergonomic experiments are carried out to verify the reliability of the optimization results.

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