Research on Tactile Interaction Measurement and Evaluation Method of Vehicle Switch

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Abstract. In this paper, the method of vehicle switch-like tactile interaction measurement is explored by using high-degree-of-freedom robot objective test equipment. Besides, this paper also presents a complete set of vehicles switch-like tactile interaction subjective and objective comprehensive test evaluation method. This paper uses this method to evaluate many kinds of vehicles in the market. The results show that the tactile interaction evaluation method, which combines subjective evaluation with robot objective test, can effectively evaluate the vehicle’s tactile interaction performance and provide important theoretical support for quality control of vehicles' interactive parts.

1. Introduction
At present, a huge number of scholars have studied comfort from their own fields, and the research methods and evaluation methods involve many fields such as psychology, physiology, anthropometry, engineering technology, and so on [1]. For a man-machine system, tactile interactive comfort can be defined as the ability to adapt to the physical and mental characteristics of the operator and enable the operator to operate comfortably and efficiently when the operating force is applied to the operating device and its operating state is changed in a certain period. Starting from their research fields, many scholars have carried out certain researches on the tactile human-computer interaction of vehicles. For example, in the study of the comfort of automobile operating lever, Rossi Jeremy et al. recorded 10 palm-side force application data of the operator's fingertips, phalanx, and palm, and studied the relationship between handle diameter and handgrip strength [2]. Adilamu Stahon combined BP neural network with D-S evidence theory to build a comfort evaluation model for automobile joystick [3]. In terms of steering wheel operating comfort, Carina Rislund et al. studied the influence on comfort when the steering wheel of the forklift truck was operated under normal and tilting conditions [4]. Cole et al. studied the influence on driver comfort by establishing the neurodynamic relationship between steering moment feedback and lateral force interference feedback [5]. Besides, from the perspective of ergonomics, some scholars have studied the muscle changes [6,7] and psychological changes of the operator [8]. To sum up, the research on vehicle handling comfort is very important to improve the overall quality of vehicles in China.
In view of the current situation of tactile interaction measurement and evaluation of vehicle switches, this paper explores vehicle tactile interaction measurement methods, establishes a scientific subjective and objective evaluation model, and puts forward a complete set of tactile interaction measurement and evaluation methods of vehicle switches.

2. Introduction of haptic interaction evaluation methods
At present, tactile interaction assessment mostly adopts a subjective evaluation method, which mainly uses people's tactile sense to obtain effective information and give comprehensive judgment on objective objects. The evaluation principle is shown in Figure 1 below.

![Fig. 1 Schematic diagram of subjective evaluation of tactile interaction](image)

The objective evaluation is to evaluate the performance of the vehicle by measuring the physical quantity represented by the test instrument, and then utilizing data analysis, parameter formulation and selection, comparison, and so on. The principle of objective evaluation is shown in Figure 2 below.

![Fig. 2 Schematic diagram of objective evaluation of tactile interaction](image)

3. Evaluation model establishment
Both subjective and objective evaluation methods have advantages and disadvantages when applied to the haptic interaction of vehicles, which are mainly shown in Table 1 below.

| Table 1. Advantages and disadvantages of objective test and subjective evaluation |
|------------------|------------------|------------------|
| Comparison of the content | Objective to test | Subjective evaluation |
| The test method | Physical device | people |
| The test method | The physical method | Physical and psychological feelings |
| The output | The numerical | language |
| Evaluation of error | small | big |
This paper established an evaluation method combining subjective evaluation with an objective evaluation, as shown in Figure 3 below.

**Fig. 3** Schematic diagram of combining subjective and objective evaluation with principle

### 3.1. Establishment of subjective evaluation model
Subjective evaluation in this paper adopts SAE recommended subjective evaluation criteria [9] to classify testers and evaluation levels, as shown in Table 2.

| score | Accept the range | evaluators | acceptability | criticality | The vast majority of evaluators | Certain evaluators | Key evaluators | Experience d evaluator | Don’t be detected |
|-------|------------------|------------|---------------|------------|-------------------------------|-------------------|-----------------|------------------------|------------------|
| 1     | unaccept         | All evaluators | severe        | poor       | very poor                    | poor              | Reluctantly      | good                   | good              |
| 2     | unacceptable     | The vast majority of evaluators |        |            |                               |                   |                 | good                   | good              |
| 3     | border           | Certain evaluators | low          | poor        | low                           |                   |                 | very good              | very good         |
| 4     | acceptable       | Key evaluators | good          | good        | good                          |                   |                 | very good              | very good         |
| 5     |                 | Experience d evaluator | excellent    | excellent   | excellent                     |                   |                 | very good              | very good         |
| 6     |                 | Don’t be detected |              |            |                               |                   |                 |                        |                  |
| 7     |                 | All evaluators |              |            |                               |                   |                 |                        |                  |
| 8     |                 | The vast majority of evaluators |              |            |                               |                   |                 |                        |                  |
| 9     |                 | Certain evaluators |              |            |                               |                   |                 |                        |                  |
| 10    |                 | Key evaluators |              |            |                               |                   |                 |                        |                  |
In this paper, SAE subjective evaluation table is used to evaluate vehicle switch interactive tactile perception, and the subjective evaluation parameters can be designed for the following three dimensions:

1) Operation hand feeling: whether the feeling of breaking triggered by the operating part is obvious, and whether there is a procrastination of operation stroke and unclear gear position.

2) Operation force consistency: whether the tactile operation force of a single operating part assembly is in good consistency.

3) Overall coordination: whether the operation force is unified with the operating parts of the regional interior decoration and whether the sense of operation is coordinated.

3.2. Establishment of objective evaluation model

The objective evaluation parameters of vehicle interior tactile interaction need to be established around interaction force/moment, interaction distance/turn angle, and other information. In this paper, the following evaluation model is established for vehicle switch tactile interaction:

Force sense: a physical quantity to measure the change degree of force value,

\[ \text{Feel}_\Delta F = \frac{F_e - F_i}{F_i} \times 100\% \]

The sense of power is the Force of Peak and Force of Trough in the process of button pressing respectively of them all.

The variance of peak force of a single assembly: it describes the consistency of peak force of a single component assembly. The fluctuation degree of peak force commonly used in button class is shown as follows:

\[ s_{F_s}^2 = \frac{1}{n} \sum_{i=1}^{n} (F_{s_i} - \overline{F_s})^2 \]

\[ \overline{F_s} = \frac{1}{n} \sum_{i=1}^{n} F_{s_i} \]

Among them, \( s_{F_s}^2 \) is the variance of key peak force, \( F_{s_i} \) is the peak force of the \( i \)-th button, \( \overline{F_s} \) is the average value of the peak force of all buttons in the assembly, and \( n \) is the number of buttons.

3) The variance of peak force between assembly: describe the fluctuation of the average peak force between the vehicle interior operating parts and the regional assembly.

\[ s_{F_v}^2 = \frac{1}{m} \sum_{j=1}^{m} (F_{v_j} - \overline{F_v})^2 \]

\[ \overline{F_v} = \frac{1}{m} \sum_{j=1}^{m} F_{v_j} \]

Among them, \( s_{F_v}^2 \) is the peak force variance between the assemblies, \( F_{v_j} \) is the average peak force of the JTH assembly, \( \overline{F_v} \) is the average value of the average peak force of buttons for all assemblies, and \( m \) is the number of evaluated assemblies.

3.3. Correlation model of subjective and objective evaluation

In this paper, the dimensions of subjective and objective evaluation are corresponding to each other, and the correlation model of subjective and objective evaluation parameters is established to obtain the comprehensive evaluation results. The principle is shown in Figure 4 below:
Fig. 4 Schematic diagram of correlation of subjective and objective evaluation parameters

4. Subjective and objective evaluation experiments

In this experiment, subjective and objective evaluation methods are respectively used to conduct experiments on vehicles. To fully and comprehensively verify the effectiveness of the method proposed in this paper, the vehicles to be tested cover several mainstream passenger car models in the current market of Europe, the United States, Japan, and China.

4.1. Subjective evaluation experiment

In this experiment, 6 professional subjective evaluators are selected, and the specific evaluators are shown in Table 3 below.

Table 3. Subjective evaluation personnel table

| Personnel Numbers | 1   | 2   | 3   | 4   | 5   | 6   |
|-------------------|-----|-----|-----|-----|-----|-----|
| gender            | male| male| male| female| female| female |
| age               | 35-40| 30-35| 25-30| 35-40| 25-30| 25-30 |
| Been driving range| 10-15| 5-10| 3-5| 10-15| 3-5| 3-5 |
| Economic income range (10,000/year) | 25-30| 15-20| 10-15| 20-25| 15-20| 10-15 |
| Record of formal schooling | Graduate student | Graduate student | Undergraduate degree | Undergraduate degree | Graduate student | Undergraduate degree |

4.2. Objective measurement equipment

In this experiment, the robot tactile measurement system is used to collect the tactile interaction data, which can realize the objective parameter measurement of the operating force/moment, distance/angle, and other operating parts of the air outlet dial and roller, buttons, knobs, tilt plates, dial rods, and other operating parts.

4.2.1 Introduction of objective measurement system
The robot tactile measurement system is mainly composed of high-precision force/torque sensor, multi-degree-of freedom robot and special measurement software, etc. The whole system is shown in Figure 5 below, and the specific parameters are shown in Table 4.

![Composition of robot tactile measurement system](image)

**Fig. 5** Composition of robot tactile measurement system

**Table 4.** Parameter table of robot tactile measurement system

| designation                          | value of number |
|--------------------------------------|-----------------|
| Number of robot joints               | 6               |
| Robot arm span (mm)                  | 713             |
| Maximum moving speed of robot (mm/s) | 9300            |
| Repeated Positioning Accuracy of Robot (mm) | ±0.02         |
| Force sensor measuring range         |                 |
| Force (N)                            | 0-240           |
| Torque (N.m)                         | 0-5             |
| Accuracy of force transducer         |                 |
| Force (N)                            | 0.025           |
| Torque (N.m)                         | 0.00075         |

4.2.2 Introduction to objective measurement methods

Firstly, test trajectory planning is carried out for various switches, and parameters such as running speed and trajectory travel of robots and sensors are adjusted to complete anthropomorphic tests for different switch types, such as linear press, curve lift, and arc toggle. In the process of moving, the data were continuously collected and recorded, and the tactile "limit" was detected by setting the sensor threshold. Secondly, the tactile interaction information collected is analyzed. This process mainly eliminates invalid data and extracts data key values. Finally, the objective evaluation model described in Section 2.2 was used for calculation.

5. Experimental results analysis

Through the above experimental methods, two mainstream models of different brands in the market of Europe, the United States, Japan, and China were evaluated respectively, and an SUV model and one sedan were selected from each brand, with a small price difference and basically belonging to the same class of vehicles. The model selection is shown in Table 5 below:

**Table 5.** Models to be evaluated

| cars | The vehicle number | year | models | Guided price range (ten thousand) |
|------|--------------------|------|--------|----------------------------------|
Subjective evaluators in this experiment successively evaluated switches at the same parts of the above vehicles in terms of total units. Subjective evaluation scores were implemented from three dimensions of operation feel, consistency of operation force, and overall coordination. The scoring results are shown in Table 6 below.

**Table 6. Subjective evaluation results**

| cars        | Vehicle number | Evaluation item                  | Rater No. / Score (10-point scale) |
|-------------|----------------|----------------------------------|-----------------------------------|
|             |                |                                  | 1  | 2  | 3  | 4  | 5  | 6  | average |
| European    | 1              | handle                           | 9  | 8  | 8  | 9  | 9  | 9  | 8.67     |
|             |                | Operating force consistency      | 9  | 10 | 9  | 9  | 8  | 9  | 9.00     |
|             |                | Global coordination              | 8  | 9  | 7  | 8  | 9  | 7  | 8.00     |
|             |                | handle                           | 9  | 10 | 9  | 9  | 8  | 9  | 9.00     |
|             | 2              | Operating force consistency      | 9  | 10 | 9  | 9  | 8  | 9  | 9.33     |
|             |                | Global coordination              | 8  | 9  | 8  | 9  | 9  | 9  | 8.83     |
|             |                | handle                           | 8  | 9  | 8  | 9  | 8  | 8  | 8.33     |
|             | 1              | Operating force consistency      | 8  | 8  | 8  | 8  | 8  | 8  | 8.33     |
|             |                | Global coordination              | 9  | 9  | 8  | 9  | 9  | 9  | 8.83     |
|             |                | handle                           | 7  | 8  | 7  | 8  | 7  | 7  | 7.33     |
|             | 2              | Operating force consistency      | 8  | 8  | 7  | 7  | 8  | 7  | 7.50     |
|             |                | Global coordination              | 9  | 9  | 8  | 7  | 8  | 8  | 8.17     |
|             |                | handle                           | 9  | 9  | 9  | 10 | 9  | 9  | 9.17     |
|             | 1              | Operating force consistency      | 9  | 10 | 9  | 9  | 10 | 9  | 9.33     |
|             |                | Global coordination              | 9  | 9  | 10 | 9  | 9  | 9  | 9.33     |
|             |                | handle                           | 7  | 8  | 7  | 8  | 7  | 7  | 7.33     |
| Japanese    | 2              | Operating force consistency      | 7  | 7  | 7  | 8  | 7  | 6  | 7.00     |
The robot tactile measurement system and measurement method introduced in 3.2 above were also taken as the total unit to conduct objective measurement and evaluation of vehicle switches. The evaluation model established in Section 2.2 was adopted for analysis, and the objective analysis results were shown in Table 7 below.

**Table 7. Objective analysis results**

| cars | vehicle number | Model item | value               |
|------|----------------|------------|---------------------|
|      | 1              | Force sensation (%) | 34.4-43.5 |
|      | 1              | Variance of peak force in a single assembly | 0.014-0.069 |
|      | 1              | Variance of peak force between assemblies | 0.268 |
|      | 2              | Force sensation (%) | 39.47-43.32 |
|      | 2              | Variance of peak force in a single assembly | 0.02-0.032 |
|      | 2              | Variance of peak force between assemblies | 0.002 |
|      | 1              | Force sensation (%) | 36.82-40.74 |
|      | 1              | Variance of peak force in a single assembly | 0.006-0.034 |
|      | 1              | Variance of peak force between assemblies | 0.01 |
| European | 1 | Force sensation (%) | 30.2-41.94 |
| U.S. | 2 | Variance of peak force in a single assembly | 0.065-0.101 |
|      | 2 | Variance of peak force between assemblies | 0.011 |
|      | 2 | Force sensation (%) | 43.81-43.99 |
| Japanese | 1 | Variance of peak force in a single assembly | 0.018-0.033 |
|      | 1 | Variance of peak force between assemblies | 0.1 |
|    | Force sensation (%) | Variance of peak force in a single assembly | Variance of peak force between assemblies | Force sensation (%) | Variance of peak force in a single assembly | Variance of peak force between assemblies |
|----|---------------------|-------------------------------------------|----------------------------------------|---------------------|-------------------------------------------|----------------------------------------|
| 1  |                     |                                           |                                        | China               |                                           |                                        |
|    | 26.93-46.17         | 0.042-0.163                               |                                        |                     |                                           |                                        |
| 2  |                     |                                           |                                        |                     |                                           |                                        |
|    | 42.42-54.12         | 0.01-0.039                                |                                        |                     |                                           |                                        |
| 2  |                     |                                           |                                        |                     |                                           |                                        |
|    | 50.99-56.08         | 0.039-0.125                               |                                        |                     |                                           |                                        |

In order to explore the correlation between subjective evaluation and objective evaluation results, force perception, single assembly peak force variance, and inter-assembly peak force variance are shown in Figure 6-8 below.

![Figure 6](image1.png)

**Fig. 6** Subjective and objective evaluation results of force perception

![Figure 7](image2.png)

**Fig. 7** Subjective and objective evaluation results of consistency of peak force of a single assembly
Subjective and objective evaluation results of inter-assembly consistency

As can be seen from Figure 6, when the subjective evaluator’s hand sense score is greater than 7.5 points, the corresponding force sense value is between 38-50%, and within this range, the fluctuation law of the score value is roughly consistent with that of the force sense value. The objective evaluation method can provide a necessary but not sufficient basis for the evaluation, and the specific evaluation needs a combination of subjective and objective methods. As can be seen from Fig. 7, in terms of consistency of peak force of a single assembly, when the average score of subjective evaluation is more than 8 points, the mean of objective consistency variance concentrates below 0.04, showing obvious regularity. Therefore, subjective and objective evaluation has a significant correlation in terms of consistency of evaluation. It can be seen from Fig. 8 that, similar to the consistency of a single assembly, the value of consistency of peak force between assemblies is relatively small for models with a subjective evaluation score of 8 or above, and there is a significant correlation between subjective and objective methods.

6. Conclusions

In this article, a tactile measurement method based on the multi-degree-of-freedom robot is proposed, and a tactile analysis model is established, which is combined with subjective evaluation, the corresponding relations between subjective and objective parameters are proposed, and the proposed method is verified in detail by using multi-vehicle switch-like tactile interaction as an object. The experiment shows the effectiveness of the subjective and objective evaluation model and methods proposed in this paper and prove that there is a certain correlation between the subjective and objective evaluation methods. The objective evaluation method can provide a necessary but not sufficient basis for comprehensive evaluation. Specifically, it is necessary to conduct targeted analysis according to different evaluation concerns and develop a reasonable subjective and objective evaluation correlation model.

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