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How to Use Self-Attention Mechanism Model to Improve Driving Interface Design and Evaluation Research

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Abstract. The core of the paper is to enhance the handling of the car's central control interface through the Self-Attention mechanism in the Transform model, especially for specific driving groups, which vary greatly between groups, this study targets female drivers, aiming to solve the unique problems faced by women in central control interaction, and will add other groups such as men, the elderly, people with specific diseases, etc. in subsequent research plans. The main process of the study involves analyzing handling data from existing interfaces, using self-attention mechanisms to understand the characteristics of female drivers, and predicting user satisfaction. Studies have shown that improving the design based on the self-attention mechanism is beneficial to interface designers to improve the design, improve the efficiency and safety of female drivers, and ultimately improve the driving experience of specific groups.

Keywords. Self-Attention Mechanism, Model Central, Control, Interface Female, Driving, Interaction Design

The automotive on-board central control is an important interaction hub for new energy vehicles, which directly affects driving comfort and ease of use. Since the current stage of automobile design often draws on the experience of traditional fuel vehicle central control design, cannot meet the driving experience in the field of new energy vehicles, in the driving process of female drivers and male drivers experience is quite different, how to meet women's needs for central control interaction comfort and ease of use, has become a key issue in the design of vehicle central control interactive interface. Therefore, from the perspective of women's psychology and physiology, it is increasingly important to design better interaction ease of use, which is also the key to this research.

To solve the above problems, it is not only necessary to study the psychological and physiological characteristics of women, but also to use AI algorithm tools to better meet women's higher requirements for central control interaction design. Therefore, this paper plans to combine the Self-Attention Mechanism in the latest Transformer model to form a data algorithm by studying the psychological and physiological preferences of female users with driving satisfaction, and then design an interaction design scheme to finally design a vehicle central control interaction system that users are satisfied with.

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1. Theoretical background

1.1. Comparison of the Self-Attention Mechanism and Recurrent Neural Network

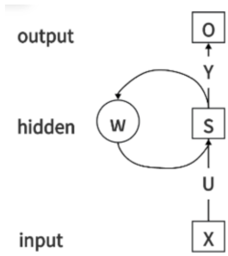


Figure 1. Recurrent neural network (RNN) diagram.

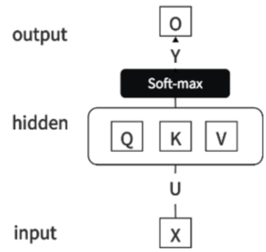


Figure 2. Illustration of the self-attention mechanism.

The Transformer model is a powerful neural network architecture for natural language processing and other sequential data tasks. It was first proposed by researchers at Google in 2017[1] and excels in a variety of NLP tasks, such as translation, text generation, and sentiment analysis.

Traditional sequence models (such as Rerrent Neural Network, RNN) face some problems when processing long text, such as long-term dependencies that are difficult to capture, resulting in information loss. The Transformer solves these problems, making it better able to handle long sequences.

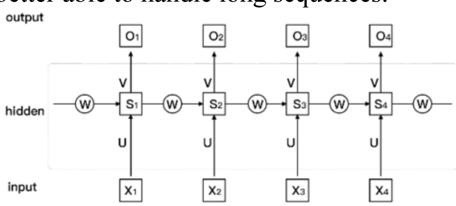


Figure 3. Recurrent neural networks (RNNs) unfold the graph by time.

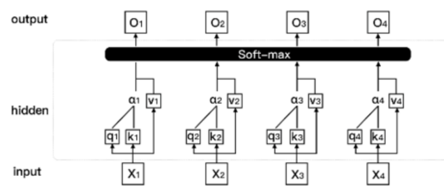


Figure 4. Self-Attention Computational Graph.

Figure 1 shows a basic Recurrent Neural Network (RNN) with input (X), output (O), hidden layer (S), and weight matrix (W) connections (Figure 2). The hidden layer depends on both current and past input (S). RNN struggles with long time series, limiting its ability to capture complex correlations. This limitation is evident when studying intricate female central control behavior, challenging RNN's capabilities.

The Transformer model's core idea is Self-Attention Mechanism, shown in Figure 3. It processes inputs (X1 to X4) to calculate the hidden layer's output (O) by considering all input data. Figure 4 illustrates the model's calculations, including data vectors, Query,

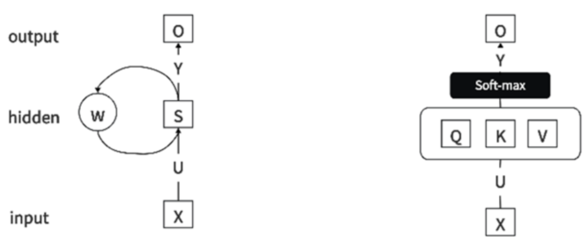


Figure 5. Recurrent neural networks (RNNs) versus Self-Attention patterns1.

Key, Value vectors, weight calculation (α), and final output generation. This allows the model to grasp context across the input sequence simultaneously and maintain positional information through an attention coding mechanism.

Comparing Figure 5: Both RNNs and Self-Attention Mechanism use vector sequences for input and output, processing through hidden layers. In RNN, W is reused for hidden layer processing, while Self-Attention Mechanism parameters are determined

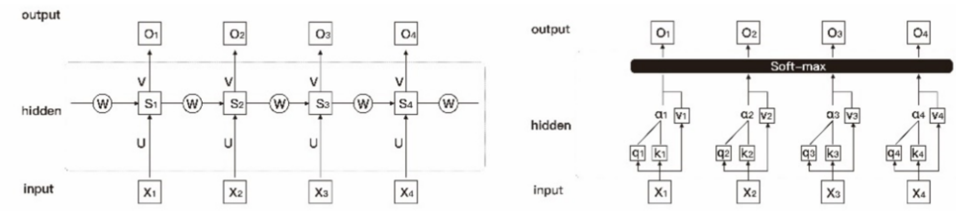


Figure 6. Recurrent neural networks (RNNs) versus Self-Attention patterns2.

through input decoding before output.

Figure 6 shows the difference. In RNN, outputs depend on previous input, but this connection weakens with longer sequences, causing information loss. Self-Attention Mechanism efficiently computes and maintains correlations between input values.

1.2. Behavioral characteristics of the target group

1.2.1. Psychological characteristics of the target group

Female and male driving behaviors differ due to physiological and psychological factors[4]. Emotions, particularly stress, affect female drivers more, increasing the risk of stress-related issues and accidents[5]. Guo Shuang's 2014 study found that women experienced higher anger and nervousness levels than men[6]. Younger women tend to avoid risks[7] and are more conservative regarding violations[8]. Both genders use roads differently, with women preferring lower-grade roads, having a more detailed memory of branch line details[9].

Female drivers and male drivers have a large difference in the hazard seeking index, women have higher sensitivity to danger[10], and the hazard seeking index is closely related to their own driving behavior[11], which reflects why the dangerous behavior of female drivers is much lower than that of men. At the same time, women's risk perception levels are much higher than men's[12].

1.2.2. Physiological characteristics of the target group

Physical Differences: Men and women display natural physiological variations in body shape. Men often have larger bones, a burlier physique, and well-developed muscles, resembling an inverted triangle. Conversely, women usually possess smaller bones, slimmer figures, with fat deposits around the chest and hips. These size differences can affect central control operations and interface design parameters like button size, placement, and interaction levels. This is shown in Figure 7

Motor Skills: Women often exhibit superior precision and flexibility compared to men, especially in activities like gymnastics, traditional crafts, etc. With the rise of intelligent central control screens, the reliance on physical buttons has decreased, and women adapt well to multi-function displays.

Visual Abilities: Studies show women may have slightly lower visual acuity than men, possibly due to their higher education levels and differences in field of vision[13]. This influences driving behaviors and offers insights for interaction design[14].

Spatial Skills: Drivers rely on senses to assess objects, location, and object speed. Women tend to have weaker spatial skills than men during driving.

Figure 7. Diagram of physiological differences between men and women

1.2.3. Research process of target group driving interaction based on Self-Attention mechanism

Female drivers prioritize safety, which affects car central control design. Using the Self-Attention Mechanism and female driver psychology, a model (Figure 8) evaluates existing solutions via user satisfaction and collects user data for input. After encoding, it computes Q, K, V matrices, calculates attention scores with Soft-max, and derives an output matrix O with operation information. This informs a new design compared to the original through user satisfaction assessments.

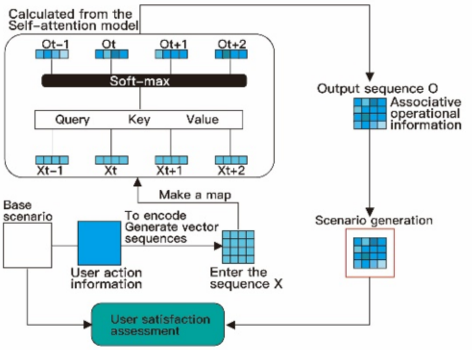


Figure 8. Framework diagram of the interaction of female driving control interface based on self-attention

2. Interaction design method of female central control interface based on Self-Attention Mechanism model

This paper explores vehicle-machine interaction layout design for female users, considering the Self-Attention Mechanism in the Transformer model and female interaction behavior.

Collect female users' interaction data, establish function correlations based on usage order, and optimize the central control interface design within the vehicle screen. Determine function placements based on their associations and conclude the optimized design through data analysis.

2.1. The Self-Attention model fits the target group interaction data

2.1.1. Analysis of the psychological characteristics of the target group

Female drivers, although more safety-conscious and risk-averse than men, often find themselves navigating complex road conditions on lower-level roads. This contradiction between psychological traits and driving behavior poses safety risks. Women can become nervous and make incorrect decisions in intricate road situations.

Figure 9 illustrates the sequential actions of female drivers using the central control screen: starting music, selecting playlists, activating air conditioning, and navigating. We collected interaction data from female drivers, spanning 13 provinces, primarily involving Tesla Model 3 central control interactions. This data, from 136 questionnaires, provides insights into female drivers' habits and experiences. After filtering, we retained 128 valid datasets for analysis.

Figure 9. Female drivers use the central control scene

2.1.2. Data Preprocessing

Data preprocessing involves converting the original female car interaction data into a format suitable for the model. This phase encompasses tasks like word segmentation and encoding.

2.1.2.1. Word Segmentation/Vocabulary Building

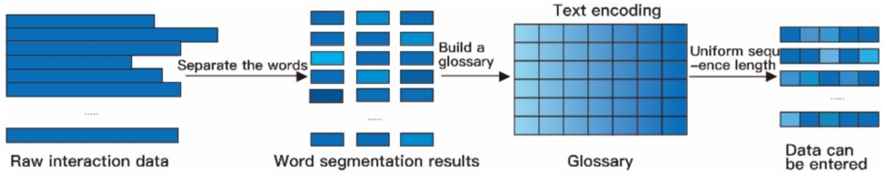


Figure 10. Data preprocessing process.

Word segmentation divides text into sequences of words or phrase, creating discrete tokens. For example, "navigate to downtown" becomes ["navigate", "to", "downtown"] based on questionnaire data.

A vocabulary is established using all text data in the dataset. This vocabulary comprises all possible words or phrase, each assigned a unique integer.

2.1.2.2. Text Encoding

Text encoding transforms segmented text into a format accepted by the model. Typically, we employ vocabulary indices to represent words. For instance, ["Navigation", "To", "Downtown"] might be encoded as [10, 56, 102], where 10, 56, and 102 correspond to vocabulary word indices. Here's the text encoding based on questionnaire outcomes.

Table 1. Text encoding

function	encode
Defogging of car windows	[8.27, 71, 37, 22, 6, 0, 0, 0]
air conditioning	[7.56, 36, 38, 38, 16, 6, 2, 0]
Music	[6.97, 21, 29, 38, 28, 15, 4, 1]
Car status	[5.9, 4, 17, 24, 36, 34, 13, 8]
Phone pairing	[4.9, 1, 9, 9, 24, 44, 30, 10]
Front passenger seat adjustment	[3.56, 3, 4, 3, 13, 15, 40, 24]
Main driver seat adjustment	[2.63, 0, 0, 2, 8, 13, 25, 33]
navigation	[1.65, 0, 2, 0, 3, 6, 16, 15]
volume	[0.94, 0, 0, 0, 2, 3, 6, 10]

2.1.3. Application of Self-Attention Mechanism in interface interaction data analysis

The female interaction data input sequence can be obtained by 2.1, assuming a length of N: X=[x1,x2,x3,...,xi,...,xn], where each xi represents the encoding of a word or phrase.

2.1.4. Calculate Q, K, V matrices

First, the input sequence X is passed through a linear map (usually called the embedding layer) to obtain three sets of vectors, representing the query (Q), key (K), and value (V)

$$Q = W^q X \tag{1.}$$

$$K = W^K X \tag{2}$$

$$V = W^V X \tag{3}$$

2.1.5. Calculate attention score

Calculate the dot product between the query vector and the key vector to obtain the attention score (attention weight) A

$$A = softmax\left(\frac{K^T Q}{\sqrt{d_k}}\right) \tag{4}$$

2.1.6. Calculate the output matrix O

Using the weighted sum value of the attention score A weight, the context vector O is obtained:

$$O = VA \tag{5}$$

The Self-Attention Mechanism calculation process, shown above, involves the soft-max function, query, key, and value computation. It establishes meaningful correlations between input sequence locations based on content, aiding in processing women's interaction data.

2.2. Design fitting feedback and female central control interaction design scheme generation

Shih showed the impact of car central control interface layout on user visual retrieval efficiency during driving15 .Taking Tesla as an example, as shown in Figure 11, the central screen size of Model 3 is 15 inches, 1920 x 1200, and the entire interface can be divided into three areas, the driving information area on the left, the content switching area on the right, and the shortcut menu area at the bottom for switching different menus. Driving information area: 508 x 1020, content switching area: 1340 x 1020, shortcut menu area: 1920 x 120.

Designing car screens for women should consider their physiological and psychological characteristics. Women generally have a smaller interpupillary distance (53mm ~ 68mm) compared to men (60mm ~ 73mm), potentially affecting their depth perception. Due to body size differences, female drivers might find the right side of the screen less accessible. Therefore, placing buttons in the middle and left of the screen is advisable. Soft colors should be used to avoid creating a sense of depression. To prevent driver nervousness, concentrate the shortcut menu area at the bottom during driving.

2.2.1. Self-Attention Mechanism data output

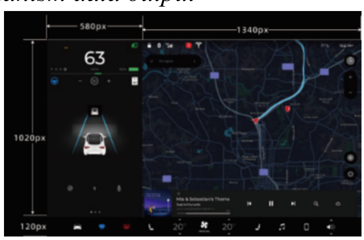


Figure 11. Original interface

Through the analysis of the output results of the Self-Attention Mechanism to guide the generation of design schemes, due to the complex interactive functions of the vehicle-machine central control interface and the large number of layers, this study selects the air conditioning module with the highest frequency of user use as an example for analysis and research. Figure 9 code calculates the sub-attention weight matrix of the relevant air conditioning module.

This study utilizes Self-Attention Mechanism output for design scheme guidance. Given interface complexity and layers, we analyze the frequently used air conditioning module.

The sub-attention weight matrix of the relevant air conditioning module is calculated by the following code: Attention weights for air conditioning:

tensor([0.8839, -10.3928, 32.2866, 25.0024, 8.0664, -8.0448, -27.3606,-17.2605, 7.5087, 31.3909, -7.4695, 0.6751, -15.3708, 13.1083,-10.0089, 20.4724])

Calculation results: Window defogging, main driver's seat adjustment, passenger seat adjustment, and navigation have negative weights, suggesting occasional single-function use. Music, car status, mobile phone pairing, and volume exhibit positive weights, indicating a strong correlation with air conditioning, especially music and car status.

2.2.2. *Interface layout optimization*

According to the analysis results of attention weight, the interface layout is optimized. Setting the high-attention section to a more prominent and easy-to-navigate location ensures that users can quickly find and use important features and options. Use attention weight analysis to find out the most important features and options in a particular task. In the air conditioning interface design, these features can be highlighted with a larger, more eye-catching style to direct the user's attention.

The analysis of attention weight optimizes the interface layout, prioritizing high-attention sections for user accessibility. This approach highlights crucial features and options in the air conditioning interface design, making them more prominent and user-friendly.

Based on attention weight analysis, the interface layout is optimized by highlighting high-attention sections for quick and easy access to important features. These significant features in the air conditioning interface design can be emphasized with a larger, more eye-catching style to direct user attention

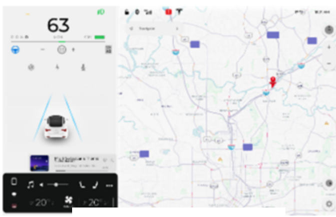


Figure 12. scheme 1

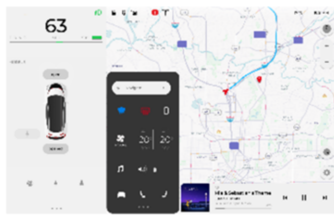


Figure 13. Scheme 2

Conclusions drawn from data prompted interface logic adjustments. Figure 11 shows the original interface, with female user data indicating a strong air conditioning and music module correlation. To accommodate this, the music module was placed near the air conditioning module. Modules for car status, mobile phone pairing, and volume were also positioned nearby for easier access.

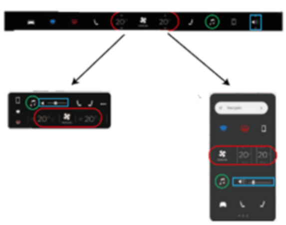


Figure 14. Schematic diagram of functional location adjustments

Figure 15..Illustration of how to adjust the use of the air conditioner

Figure 14 illustrates the relocation of the car air conditioner module based on usage frequency. In scheme 1, the air conditioner was moved to the lower left corner of the screen, facilitating convenient access for female drivers. Scheme 2 positioned the air conditioning module in the center of the driver's line of sight. Additionally, as figure 15 the interaction method was adjusted to include left-right and up-down scrolling with color gradients to guide users.

Music and volume control, highly relevant to the air conditioning module, were streamlined in scheme 1, placing them above the air conditioning module for a more compact layout. Scheme 2 adopted a similar approach for intuitive volume adjustment.

3. Design satisfaction evaluation of the target group's vehicle central control interface generated by the self-attention mechanism

3.1. The target group car central control uses the satisfaction evaluation level construction

In order to obtain the satisfaction evaluation of the in-vehicle central control from the perspective of female users, the following seven indicators were determined by questionnaire method and expert interview method to establish the satisfaction evaluation model, as shown in Figure 16.

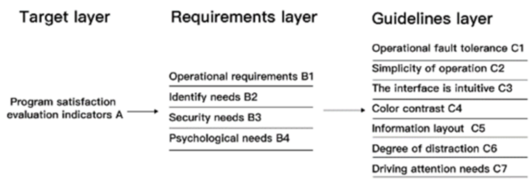


Figure 16. Program satisfaction evaluation indicators

3.2. Satisfaction level weight calculation

Table 2. Benchmark layer weights

Guidelines layer	Original scenario	Scheme1	Scheme2	CR	Consistency check
Operation compatibility C1	0.157	0.594	0.249	0.051	Pass
Operational simplicity C2	0.2	0.6	0.2	0	Pass
Interface intuitiveness C3	0.136	0.625	0.238	0.017	Pass
Color contrast ratio C4	0.167	0.667	0.167	0	Pass
Information layout C5	0.105	0.637	0.258	0.037	Pass
Distraction C6	0.614	0.117	0.268	0.07	Pass
Driving attention requirement C7	0.54	0.163	0.297	0.009	Pass

By constructing a good satisfaction evaluation hierarchy model, the factors in it are compared in pairs, and a judgment matrix is established:

$$\boldsymbol{Z} = \left(z_{ij}\right)_{m\times n} = \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1n} \\ z_{21} & z_{22} & \cdots & z_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ z_{m1} & z_{m2} & \cdots & z_{mn} \end{bmatrix} \tag{6}$$

where z_{ij} represents the relative importance of factor i to factor j, satisfying $z_{ij} = \frac{1}{z_{ji}}$. Using the above judgment matrix, according to the basic principles of analytic hierarchy method, the square root method is used to calculate the weight value of the criterion layer of the new scheme generated by the Self-Attention Mechanism in this study, as shown in Table 2.

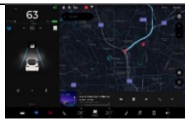
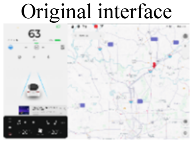
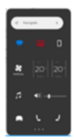
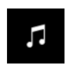
3.3. Scheme selection and determination

Based on the scenario summary results, the ranking of the three scenarios is obtained. Option 1 scored the highest in the analysis, with a quantitative score of 2.143, so this study was based on Scenario 1 for in-depth design.

Through comparative analysis, the functional scores of air conditioning, music, window defogging and main driver seat adjustment are relatively high, and through design optimization, users have higher recognition of the optimized interactive interface, while the functions of car status, passenger seat adjustment and navigation have lower scores. This may mean that when designing a central control interface, focus on those features that score low to improve the user experience.

3.4. Evaluation results and design satisfaction evaluation

Table 3. Comparison of old and new solutions

Overall effect	Navigation bar	Music	Air Conditioning	volume
 Original interface				
 Scheme 1				
 Scheme 2				

Data analysis indicates that air conditioning, music, window defogging, and main driver seat adjustment have higher functional scores post-optimization. Conversely, car status, passenger seat adjustment, and navigation received lower scores, highlighting the need for focused design improvement. Table 4 compares the three scenarios.

The Transformer model's Self-Attention Mechanism improvement enhances female-centric vehicle central control interface design. It assesses user behavior to uncover vital methods for intelligent interaction design, enhancing female user satisfaction. This informs user-centric central control interaction system design.

4. Conclusion

This research aims to improve car central control interactions for female drivers by enhancing the Transformer model's Self-Attention mechanism. It involves analyzing driving interface data, predicting user satisfaction, and creating new interfaces based on feedback from female users to address gender-specific attention differences.

The results indicate that the Self-Attention mechanism improvement method in the Transformer model offers crucial techniques for automotive interaction designers, enabling intelligent generation and interaction design. Additionally, our research enhances the overall driving experience for female drivers in terms of central control interface efficiency and safety. This not only innovates automotive interface design but also provides valuable insights into addressing gender-related impacts on interaction design.

Due to the conditions, there are many details that have not yet been perfected. The target group of this study is female drivers, and in the follow-up research, other groups will be used as the target groups such as men, the elderly, and groups with special diseases, etc., through the research methods and paths explored in this study, to improve the driving experience for other groups and solve the problems that may be encountered in the use of the central control platform. In future research, it is hoped that interested scholars can conduct detailed research according to these directions.

Acknowledgment

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