The Influence of the Directivity of the Speaker in the Car on the Subjective Sound Quality Evaluation

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Abstract. The directivity of the speaker in the car is a key factor affecting the acoustic comfort of the car. This paper reviews the influence of directivity of the speaker in the car on the subjective sound quality evaluation. The subjective sound quality evaluation method, subjective sound quality evaluation model and experimental verification are summarized. The work of the predecessors is summarized, on this basis, the next research prospect is proposed.

Keywords: sound quality; subjective evaluation; the speaker in the car; directivity

1. Introduction

With the popularization of automotive products and the rapid development of automotive-related technologies, users' requirements for the acoustic environment in the interior of automobiles have also begun to diversify. The acoustic environment in the car is mainly divided into two parts: one is the sound field generated by the speakers equipped with the audio and video system in the car.The second is the noise caused by various excitation sources during driving. These two main acoustic environments are key factors affecting the acoustic comfort of a car. At present, on the basis of automobile noise meeting the specified standards[1], automobile manufacturers mainly reduce the noise by avoiding the existence of abnormal noise of the whole vehicle or parts, and actively or passively reduce the way to improve the comfort of the acoustic environment in the car. The acoustic comfort of most car brands has achieved the above goals, but it still fails to meet the growing demand of consumers for the acoustic environment in the car, and less attention is paid to the directivity of the interior speakers.

The development of in-vehicle audio and video systems has led to a strong demand for passengers to expect different audio and video environments to be generated in different areas of the speaker in the car without interfering with each other. This type of demand problem can be boiled down to the problem of sub-region sound field control of the in-vehicle loudspeaker,

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that is, reconstructing the target sound field in a specific area (bright area[2]) while reducing the impact of the target sound field on other areas (dark area[2]). Spatial sub-regional sound field control is divided into two main categories: binaural sound field control using headphones[3] and sound field control using speaker arrays[4]. The binaural sound field reconstruction system using headphones is simple, but its disadvantage is that the physical information of the three-dimensional spatial sound field is lost, and the long-term wearing of headphones is easy to cause fatigue and tingling in the human ear. Sound field control using speaker arrays can avoid this problem, obtain more physical information about the target sound field, and effectively enhance the user's stereo experience.

Blauert gave a clear definition of sound quality[5] in 1994: sound quality is the suitability of sound in the context of a particular technical goal or task. The concept is to evaluate sound from the perspective of people's perception of sound. Automotive sound quality is to meet the requirements of people and the environment, and seek product sound that meets the characteristics of the car. The study of sound quality actually puts forward the concept of modern noise control, which can adjust the directivity influence of the speaker in the car to an ideal state by taking reasonable measures according to the user's subjective sound quality evaluation. In addition to the two major factors of frequency and intensity, the study of sound quality emphasizes the direct impact of psychoacoustic and non-acoustic factors. Therefore, studying the influence of the directivity of the interior speaker on the subjective sound quality evaluation is an innovative idea for the design of the acoustic environment in the car, a new method that can effectively improve the acoustic comfort of the car, and is an important means for automobile manufacturers to improve the competitiveness of their own automobile brands, which has important theoretical significance and clear application prospects.

2. Subjective sound quality evaluation method

The focus of subjective evaluation is not on the analysis of specific objective parameters of sound quality, because what is important for a product is the consumer's perception of it, which is the main part of the meaning of automobile sound quality. In order to truly cater to the needs of the general public, subjective evaluation must be mainly aimed at specific evaluation activities that can be carried out with people who are inexperienced and have no formal listening training, so this excludes many professional traditional psychoacoustic evaluation methods.

Otto and Amman et al. of Ford Company[6] of the United States gave detailed subjective evaluation experimental guidelines from the perspectives of evaluation target design, evaluation sample preparation, evaluation environment selection, evaluation population determination, evaluation method and selection of analysis and treatment methods. CERRATO[7] describes a similar process for studying sound and vibration quality. Otto and Amman et al.[6] summarized four main evaluation methods: rank order, rating scales, paired comparison, and semantic differential. These methods also have their advantages and disadvantages, and the appropriate selection of appropriate methods will improve the accuracy of the data and facilitate more effective conclusions in subsequent data processing.

2.1 Rank order method

The rank order method is a relatively simple subjective evaluation method, which requires reviewers to arrange 1 to several sound samples in order according to some artificially prescribed descriptive criteria of voices, such as preference, annoyance, and certain quantification.

The advantage of this method is that it is a small amount of work and is suitable for situations where a rough comparison of the results of sound samples is required. The disadvantage is that this method requires comparing one or some different characteristics of the sound samples, and the number of sound samples that can be evaluated is limited. It is precisely because the results of the rank order method cannot correspond well to the objective parameters, so the rank order method is usually used to allow users to do selective design.

2.2 Rating scales method

Rating scales method allows reviewers to score sound samples on a prescribed scale, usually using a numerical score (1 to 10). The advantage of this method is that information on the scale of sample strengths and weaknesses is quickly obtained, which is suitable for situations where the evaluator is experienced. Numerical scoring is familiar to most people, so this form of preventing sound quality evaluation is simple and quick, but rating scales method will be difficult for people who are not trained or have no experience in listening evaluation. Therefore, the listening test experience of the participating reviewers should be fully considered when using.

2.3 Paired comparison method

The paired comparison method, also known as the A/B comparison method, compares two sound samples. After listening to two sound samples, the evaluators made a selection based on one of the subjective properties of the sound. When the paired comparison method is used for subjective evaluation experiments, the evaluators' lack of experience in sound quality evaluation can also obtain more accurate evaluation results, so the paired comparison method is very suitable for inexperienced people. But the use of paired comparison is also somewhat limited by the number of sound samples, because it grows by the square of the sample size. In order to retain the advantages of the paired comparison method and reduce the evaluation workload, the semi-matrix comparison method is widely used at home and abroad[8], which can reduce the workload by nearly half. At the same time, Mao Dongxing et al.[9] proposed a grouped pair-wise comparison method, which mapped the evaluation results of each group to the same scale by setting up associated samples, so as to carry out subsequent analysis. Huang Yu et al.[10] proposed the method of adaptive selection of associated samples, which avoided the situation that the accuracy of evaluation results was low due to improper selection of associated samples.

2.4 Semantic differential method

The paired comparison method typically focuses on only one property of a sound, while semantic differential method focuses on multiple properties of a sound sample at the same time. The disadvantage of this method is that a single playback of the listening sample produces different results without comparison. An attribute is usually described by an adverb of degree, and reviewers only need to make subjective choices about the degree of these attributes. Murata[11] of Mitsubishi Motors Corporation of Japan, Sato[12] of Hino Corporation used dozens of pairs of antonyms (such as smooth-rough, quiet-noisy, etc.) 7-level semantic differential method to study the sound quality of diesel engine trucks idling and gasoline engine passenger cars when driving steady-state respectively, and used factor analysis method or principal component extraction method to classify sound quality semantic words, and found that comfort and stiffness are the main concerns of consumers.

The above four subjective evaluation methods have advantages and disadvantages, which are summarized and compared in Table 1. The method can be chosen to solve the problem according the comparison in Table 1. How to eliminate the improper evaluation results and accurately extract the subjective characteristics of sound quality after the subjective evaluation experimental results are obtained, is another problem that needs to be solved. Correlation analysis[13-14] and cluster analysis[13] are often used to classify similar evaluation data, eliminate improper evaluation results, and avoid the influence of other subjective characteristics. After screening out reasonable subjective evaluation experimental data, there are many quantitative methods for subjective evaluation experimental data using paired comparison method, such as Bradley-Terry model[15], fractional value sorting method[16], mean method[17] and so on. The above quantitative method does not fully consider the ambiguity of human subjective evaluation, but it has important reference significance.

Table 1 Advantage and disadvantage of subjective sound quality evaluation methods

Method	Advantage	Disadvantage
Rank order method	It is a small amount of work and is suitable for situations where a rough comparison of the results of sound samples is required.	This method requires comparing one or some different characteristics of the sound samples, and the number of sound samples that can be evaluated is limited.
Rating scales method	Information on the scale of sample strengths and weaknesses is quickly obtained, which is suitable for situations where the evaluator is experienced.	It is difficult for people who are not trained or have no experience in listening evaluation.
Paired comparison method	It is suitable for inexperienced people.	It is limited by the quantity of the sample.
Semantic differential method	It is easy to understand.	A single playback of the listening sample produces different results without comparison.

3. Subjective sound quality evaluation model and experimental verification

3.1 Determination of objective parameters of subjective sound quality evaluation

The results of subjective evaluation experiments can visually describe the various properties of sound, but a subjective evaluation experiment requires a lot of manpower, financial resources and material resources. If the objective parameters of sound samples closely related to subjective perception can be extracted, the subjective quality characteristics of sound samples can be predicted to a certain extent without subjective evaluation experiments, which is of great practical value.

At present, commonly used objective parameters include psychoacoustic parameters, sound pressure level, frequency band characteristics, etc. Fastl and Zwicker[18] combined the inherent properties of sound with the masking effect of human hearing, and proposed multiple psychoacoustic parameters: Loudness, Sharpness, Roughness, Fluctuation Strength, Tonality, and Articulation Index. When selecting appropriate evaluation program source, the correlation between subjective and objective evaluation results of nonlinear distortion can reach more than 0.84, and the influence of frequency response curve on sound quality is also extremely important. If the size of peak and valley is the same (that is, the width, height and depth are the same), then the subjective parameters caused by the peak are relatively large, that is, the peak is more important than the valley. The relationship between perceived cepstrum distance and frequency response curve on sound quality is studied, and it is proved that perceived cepstrum distance can not only reflect the impact of nonlinear distortion on sound quality, but also reflect the impact of frequency response curve on sound quality[19].Liu [20] applied the improved gray correlation analysis method to the sound quality evaluation, which determined the correlation degree between various concert halls by comparing and analyzing a series of objective acoustic indicators of several concert halls, and then gave the sound quality evaluation of concert halls.He[21] used the analytic hierarchy process to build the electronic music sound quality evaluation index system structure, taking the electronic music sound quality evaluation as the target layer, taking the sound source characteristics, sound equipment signal characteristics, sound field characteristics, auditory characteristics and stereo sense as the criteria layer, and taking 16 sound quality evaluation elements as the scheme layer, Construct the judgment matrix of electronic music sound quality. Obtain the influence weight of each electronic music sound quality evaluation element on the sound quality, and obtain accurate electronic music sound quality evaluation results.

3.2 Establishment and analysis of subjective sound quality evaluation model

After the subjective characteristics of directivity of interior speakers is obtained, the ultimate goal of sound quality research is to establish an analysis model of sound quality, obtain the influence of directivity of interior speakers on subjective sound quality evaluation, and propose feasible sound quality personalized design directions and improvement methods. Algorithms commonly used to build sound quality prediction models include Multivariable Linear Regression, artificial neural networks, and Support Vector Machines.

The multivariable linear regression algorithm is simple and suitable for model establishment of linear problems. Su Lili [22] pointed out that the multivariable linear regression algorithm is not suitable for modeling nonlinear problems such as sound quality evaluation, and the prediction error is large, but the algorithm is more applicable when the number of sound samples and objective parameters is small and the correlation between objective parameters and subjective evaluation results is strong. For example, Gao Yinhan et al. [23] selected 6 samples of accelerated sound to study sound quality preference, and concluded that loudness and roughness had a significant impact on the subjective preference of accelerated sound quality, and a multivariable linear regression algorithm was used to establish a prediction model for subjective preference of accelerated sound quality.

The artificial neural network algorithm is suitable for model establishment of large-sample nonlinear complex problems, and the prediction accuracy is good. Lee and Kim et al.[24-26] summarized the work of Hatano [27], Terazawa [28], pointing out that roar and rumble are the main characteristics of acceleration sound, and the roar has a strong correlation with the loudness and sharpness in the 200Hz band of the sound sample, while the loudness and roughness in the 200Hz~500Hz band have a significant impact on the rumble, and the ANN algorithm is used to establish a prediction model of roar and rumble index. Shin et al.[29] proposed a quantitative measure of roar intensity to measure roar level. Similar algorithms are also used in the sound quality prediction model of the literature[30]. In order to solve the shortcomings of ANN algorithm such as local extremes, Tang Rongjiang[13] introduced optimization methods such as genetic algorithm into the ANN algorithm. This paper expounds the basic principle and specific implementation method of the multi seed adaptive component pair comparison method, gives the calculation formula for selecting seeds by the multi seed adaptive component pair comparison method (MAGPC), and verifies the effectiveness and reliability of the proposed method by designing two subjective evaluation experiments and comparing it with the traditional pair comparison method (PC) and the adaptive component pair comparison method (AGPC)[31]. He used the sound quality evaluation method of the sound radiation system of the perception model to test whether it is suitable for the sound quality evaluation of indirect radiation speakers. He considered classic sound quality evaluation parameters from different perspectives, such as roughness, sharpness and tone, and applied the parameters obtained from the perception model proposed by Moore. It shows that the method has good correlation with Rnonlin value [32].

Support vector regression algorithm has strong generalization, global convergence, and high prediction accuracy, making it suitable for modeling small sample nonlinear problems. Xu Zhongming et al.[33] optimized the parameter of support vector machines by particle swarm optimization, and established acoustic prediction model of vehicle acceleration subjective preference with psychoacoustics parameters as objective parameters. The subjective sound quality evaluation models are compared and presented in Table 2. The determination of the method depends on the problem itself.

Table 2 Comparison of subjective sound quality evaluation models

Method	Description
Multivariable linear regression algorithm	Simple and suitable for modeling of linear problems
Artificial neural network algorithm	Suitable for model establishment of large-sample nonlinear complex problems, and the prediction accuracy is good
Support vector regression algorithm	Strong generalization, global convergence, and high prediction accuracy, making it suitable for modeling small sample nonlinear problems

3.3 Test verification of subjective sound quality evaluation

The subjective evaluation test includes selecting a model, selecting a test template, completing the test, and selecting a model to select a car model that needs to participate in the evaluation. The test template is chosen to decide which experiment to participate in this model and what kind of test to do.

In the speaker array playback system, the sub-frequency band to realize the sub-regional sound field control of the front and rear areas of the car includes two types: 4 speakers placed at the four doors that can realize the regional sound field control of the front and rear areas of the car in the 20Hz~200Hz frequency band[34],a roof symmetrical speaker array containing 8 speakers that can realize regional sound field control in the front and rear areas of the car in the 200Hz~10kHz frequency band. In the microphone array signal acquisition system, the human ear area of the driver's seat and the passenger seat is used as the front area, and the human ear area near the passenger seat of the left and right rear doors is used as the rear area, and the area between the driver's seat and the passenger seat and the area in the middle passenger seat of the rear seat are not considered in the actual vehicle test.

The electroacoustic transfer function measurement of the control system adopts the comb scanning measurement method[35], which can measure the electroacoustic transfer function of multiple speakers in different frequency bands at the same time, which has a high signal-to-noise ratio, and also improves the measurement efficiency, and the electroacoustic transfer function of the control system can be accurately obtained. In subjective evaluation, various factors must be integrated to obtain satisfactory evaluation results. Fuzzy mathematics theory is used to conduct subjective comprehensive evaluation of the sound quality of a concert hall's nine indicator systems, and the subjective effect of the sound quality of the concert hall in opera performances is obtained[36].Shi Jun [37] applied the gray system weighted correlation analysis method to make a comparative analysis of the Pingtan International Performing Arts Center Grand Theater and the 14 theaters that have been rated internationally, thus reaching the conclusion that the sound quality effect of the Pingtan International Performing Arts Center Grand Theater is the closest to the sound quality effect of the New York Metropolitan Opera House with high evaluation

4. Conclusion and prospect

The directivity of the speaker in the car is a key factor affecting the acoustic comfort of the car. This paper reviews the influence of directivity of the speaker in the car on the subjective sound quality evaluation. The subjective sound quality evaluation method, subjective sound quality evaluation model and experimental verification are summarized and the methods are comprehensively compared. Future work can be carried out in the following ways.

a) This article makes a preliminary summary of the directivity of the speaker in the car, the implementation of the subjective sound quality evaluation results experiment and the processing and analysis methods of the evaluation results. The advantage and disadvantage of subjective sound quality evaluation methods are summarized and provided. Subjective sound quality evaluation models are also compared and presented. With the deepening of the research, it is believed that a simpler and easier evaluation method will be proposed, which is also one of the focuses of the directivity of the speaker in the car on the subjective sound quality evaluation results.

b) The subjective evaluation object is for a fixed population and a specific noise progress, so whether the experimental results are applicable to other working conditions of other models remains to be studied. In the future, several models and random groups of people can be selected to analyze different models under the same working condition and different working conditions of the same model, so that the directivity of the speaker in the car is more meaningful to the subjective sound quality evaluation results.

c) Further research on the characteristics of subjective sound quality evaluation results is carried out, and attempts to include all characteristics of subjective sound quality evaluation results. It is helpful to establish an evaluation vocabulary system in the Chinese language environment.

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