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Development and Real-Vehicle Validation of an Around View Monitor Evaluation System for Parking Experience

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Abstract: With regard to surround view systems, after they have been broadly applied in mass - produced cars, one must consider them as part of the factors influencing parking safety or satisfaction .Yet at present no full industry evaluation exists — neither theoretical nor practical — that meets driver needs by combining objective data with subjective impressions .The present article is devoted mainly to problems arising in basic parking situations, and by means of user surveys, of the Delphi method, and of hierarchical analysis, a surround-view evaluation plan is proposed—one with four components: viewing angle, activation time, real - scene proportion, and stitching quality .It was applied to 31 common models currently available on the market .The data suggest that stitching quality affects the whole experience more than any other factor .The evaluation idea seems well suited for detecting differences, and it gives carmakers a solid basis for design choices or for standard-setting purposes.

Keywords: Around View Monitor (AVM), real-vehicle testing, activation time, zoom scale, stitching quality.

1. Introduction

With regard to today's developments of technologies applied to intelligent connected vehicles, the Around View Monitor (AVM) system is now regarded as one of the significant features for parking help and is attracting considerable consumer interest .It employs a number of ultra - wide - angle cameras—on the front, on the back, and along the sides—to gather views of all parts of the vehicle and then uses image stitching to form a 360 ° panoramic layout showing the whole area around it .The idea behind it is to fill in the gaps left by ordinary rearview mirrors (such as those near the wheels or along the lower flanks of the car),thus helping the driver to estimate immediately the spatial relation of the car to nearby obstacles when parking or moving slowly.

Among driving scenarios, parking is one in which low - speed accidents—particularly urban ones—occur often .From analyses of police data made by the U . S .Insurance Institute for Highway Safety (IIHS) it is known that using a rearview camera when reversing cuts down on collision rates by almost 16%;if such cameras are paired with parking sensors, the chance of reversing mishaps may be reduced by some 42%.Studies conducted domestically have confirmed a definite preventive role for panoramic cameras in regard to low - speed scrapes .For inexperienced drivers or for people handling big vehicles, AVM technology removes the ' guesswork ' involved in parking by offering visible, precise information —which helps to keep scrapes and minor accidents at bay[1]

The idea of parking assistance is now being pushed forward very quickly, yet it runs into problems in many actual cases .When an underground garage has pillars or three - dimensional barriers, the perception tools may not be able to map all parking areas or to find a full route for maneuvering .Older districts or open lots — lacking marked spots — are hard to handle from this technical standpoint[2].

From the standpoint of vehicle owners, it seems that the system ' s ability to recognize obstacles is very limited in heavy rain or at night — or with low obstacles present .That fact implies a continuing difficulty for parking assistance in adapting to non-standard parking configurations or unusual conditions .With regard to such situations, AVM ' s analysis of the vehicle ' s environment is necessary support and cannot be omitted in parking assistance[3][4].

All such considerations aside, mass - produced AVM systems still run into many practical problems .From the standpoint of actual usage, current systems do not always yield fully satisfactory results for image stitching — proportions of angled views may not match well, or the startup speed may be too slow — which brings down both vehicle safety and passenger comfort .With an eye toward these practical limitations, this paper begins with driver - oriented parking situations to evaluate user needs ， and looks at AVM performance from the user ' s perspective .It proposes a framework of user experience criteria, one that may guide vehicle design or enhancement, and that may help shape emerging industry standards of evaluation .

2. Development of an Evaluation System for Around View Monitor

2.1. Determination of Technical Evaluation Dimensions

If one wishes to create an evaluation of panoramic views that actually represents drivers ' parking experience, it is useful to apply a dual - path method—combining driver interviews with information from industry tech specialists — in order to define criteria that are at once grounded in actual use and in technical reality[5].

2.1.1. Survey on AVM Parking Usage Experience Based on Multidimensional Stratified Sampling

If one wishes to be sure that the samples taken for the survey will help to describe accurately the actual panorama-use habits of various drivers ， it is appropriate to adopt a

structured stratified sampling method, with both web-based and face-to-face data collection, giving 758 valid answers. In terms of age (18 to 55), gender, city of residence (first-, second-, third-tier cities, and others), driving experience, and average daily parking frequency, all five main variables surveyed have been fully processed (see Figure 1). The resulting sample provides a fairly realistic, multidimensional dataset of the overall market users[6].

The study was based on preset parking scenarios and used structured questions to let drivers share their experiences with the surround view system. From driver feedback, four main issues were summarized: 'incomplete view (only reversing camera)', 'slow startup', 'poor 360° image stitching quality', and 'distorted display'. Based on this, the paper then proposed four technical evaluation points: viewing angle, startup time, actual zoom, and the quality of the stitching.

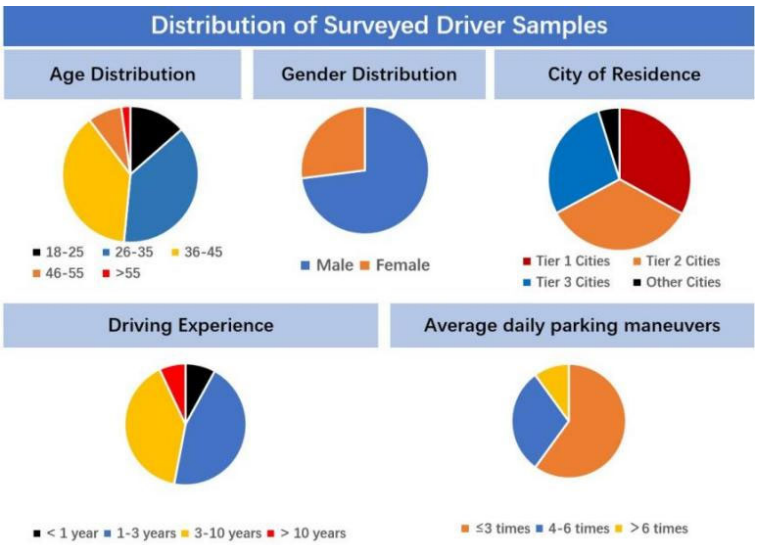


Figure 1. Distribution of the survey sample.

2.1.2. In-Depth Interviews with Automotive Industry Experts Based on the Delphi Method

To ensure that the designed evaluation system meets the necessary technical standards, a fairly detailed survey of industry experts should also be conducted. The companies surveyed include 20 representative firms among independent brands, emerging brands, joint ventures, and Tier 1 suppliers (see Table 1). The interviews covered topics such as panoramic view products, human-machine interaction, and related technologies. The research method used was a two-round Delphi Method, and the implementation steps can be explained as follows:

Table 1. Scope of Enterprise Expert Consultation.

Automaker Type	Enterprises Surveyed
Independent Brands	Beijing Automotive, Avatr, BYD, Dongfeng Motor, Jianghuai Automobile, IM Motors, Great Wall Motors, Seres, Chery
NEV Startups	Xiaomi Automotive, NIO, XPENG Motors, Leapmotor, LEADING IDEAL
Foreign Brands	Volvo, Toyota, BMW, Volkswagen, Tesla
Tier-1 Suppliers	Huawei

First round (semi-structured interviews): Think about the issues from four technical evaluation points—observation perspective, involved time, real-scene zoom and stitching quality (see Table 2 for related data). Experts make freestyle judgments and provide additional comments, gathering the initial opinions to form a draft of the indicators.

Table 2. Evaluation Dimensions of AVM.

Driver Subjective Experience	Objective Evaluation Indicatorz
Incomplete viewing angle (only rearview camera)	Viewing Angle
Slow startup response	Activation Time
Distorted display	Real-Scale Zoom
Poor stitching quality of 360° image	Stitching Quality

The method used in the second round (structured consultation and consensus judgment) was to organize the evaluation indicators from the first round into a questionnaire. Each indicator was rated by experts on a 5-point Likert scale (1 to 5 corresponding to 'not important at all' to 'very important'). The criterion for convergence was: for a given indicator, if the proportion of experts rating it as 'important' (i.e., 4 or above) was ≥ 75%, it was considered that consensus had been reached and the indicator would be kept; if the proportion was less than 75%, further discussion or removal was needed. All the indicators listed here were resolved after just one round of consultation, with no cases requiring multiple rounds due to disagreements[7].

2.2. Evaluation System Development and Weight Allocation

The present article outlines a way of evaluating the user experience of panoramic surround view at daytime parking, with four analysis points—observation angle, activation time,

stitching quality, and real - scene zoom .It does not assign fixed priorities to the indicators but takes account of their genuine relative importance.For 20 industry experts who participated in preliminary surveys (see Table 1), weights were determined using the Analytic Hierarchy Process [13-14], and all related statistics and calculations are explained following this approach.

2.2.1. Collection and Integration of Enterprise Expert Opinions

The method used in the text is to construct the judgment matrix according to the importance of evaluation indicators and to consult corporate experts. For each indicator, each expert makes independent judgments using Saaty's 1–9 scale (that is, 1 - equally important; 3 - slightly more important; 5 - moderately more important; 7 - very important; 9 - extremely important; 2, 4, 6, 8 are intermediate values). The filled matrix is the judgment matrix, and its format can be seen in Table 3.

Table 3. Expert opinion collection on relative importance of evaluation indicators.

Evaluation Indicator	**a_1**	**a_2**	**a_3**	**a_4**
a_1	a_{11}	a_{12}	a_{13}	a_{14}
a_2	a_{21}	a_{22}	a_{23}	a_{24}
a_3	a_{31}	a_{32}	a_{33}	a_{34}
a_4	a_{41}	a_{42}	a_{43}	a_{44}
Note 1: a_1, a_2, a_3, a_4 denote the four evaluation indicators of viewing angle, activation time, stitching quality, and real-scale zoom, respectively.				

(1) Consistency Check

To check whether the logic behind the experts' judgments is consistent, we first examine each expert's judgment matrix. We calculate the consistency index (CI) using formula (1). Then, using Saaty's random consistency index (RI) values (for n=4, RI=0.90), we calculate the consistency ratio CR (CR = CI/RI). We set the acceptable threshold at CR ≤ 0.1. If an expert's judgment matrix has a CR > 0.1, it is considered logically inconsistent and will be removed[7].

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{1}$$

λ_{max} is the maximum eigenvalue of the matrix, and n is the order of the matrix (here n=4)

Starting with the 20 valid questionnaires collected, a consistency analysis was done, and the conclusion is: the judgment matrices given by the 20 experts all have CR ≤ 0.1, with an average consistency ratio of 0.045, which is obviously lower than 0.1, showing that the judgments used have good internal consistency.

(2) Geometric mean aggregation of expert opinions

This article uses the geometric mean method to integrate and calculate the collected opinions of 20 corporate experts on the relative importance of evaluation indicators according to formula (2), resulting in the consolidated importance data bij (as shown in Table 4).

$$b_{ij} = \left(\prod_{t=1}^{20} a_{ij}^{(t)}\right)^{1/20} \tag{2}$$

a_{ij} represents the importance of evaluation indicator i relative to evaluation indicator j, and t denotes the number of participating enterprise experts (t=20).

Table 4. Aggregated expert judgments on relative importance of evaluation indicators

Evaluation Indicator	**a_1**	**a_2**	**a_3**	**a_4**
a_1	1	1/7	1/6	1/6
a_2	7	1	7/6	7/6
a_3	6	6/7	1	1
a_4	6	6/7	1	1

2.2.2. Indicator Weight Calculation

This article uses the Analytic Hierarchy Process. First, it calculates the geometric mean of the technical indicators according to formula (3), then normalizes the weights of the primary indicators using formula (4), and finally completes the weight allocation for the panoramic view evaluation indicators (as shown in Table 5).

$$M_i = \left(\prod_{j=1}^{4} b_{ij}\right)^{1/4} \tag{3}$$

M_i denotes the geometric mean of the importance of the evaluation indicators.

$$w_i = \frac{M_i}{\sum_{i=1}^{4} M_i} \times 100\% \tag{4}$$

w_i denotes the weight of the evaluation indicators.

Table 5. Weight allocation for AVM evaluation indicators

Evaluation Indicators	**Weight Allocation**
Viewing Angle	5%
Activation Time	35%
Stitching Quality	30%
Real-scale Zoom	30%

2.2.3. Scoring Rule Development

To score the four listed observational perspective indicators using scientific methods, we first need to design the corresponding rules. Right now, we've invited experts from 20 companies that participated in the earlier survey to help develop the rules, and the results are shown in Tables 6 to 9[8].

Table 6. Scoring rules for viewing angle

Technical Requirement	Score
The AVM provides a surround-view image , the stitched view supports 3D view display and allows 3D view adjustment.	100
The AVM provides a surround-view image , the stitched view supports 3D view display but does not allow 3D view adjustment.	75
The AVM provides a surround-view image , the stitched view does not support 3D view display (only 2D view available).	50
The AVM does not provide a surround-view image.	0

Table 7. Scoring rules for activation time

Technical Requirement	Score
Activation time ≤ 1.0 s	100
1.0 s < Activation time ≤ 1.5 s	75
1.5 s < Activation time ≤ 2.0 s	50
Activation time ＞1.0 s	0

Table 8. Scoring rules for real-scale zoom

Technical Requirement	Score
Target display size ≥ 20 arc minutes	100
15 arc minutes ≤ Target display size ＜ 20 arc minutes	75
10 arc minutes ≤ Target display size ＜ 15 arc minutes	50
Target display size ＜10 arc minutes	0

Table 9. Scoring rules for real-scale zoom

Technical Requirement	Score
Within the visible area of the planar stitched view: No visible stitching gaps (black, colored, etc.) are present, The actual distance corresponding to any stitching misalignment is ≤ 0.4 m, The total actual area corresponding to stitching ghosting and stitching loss in any four cells arranged in a 2×2 grid pattern is ≤ 0.15 m², and the total proportion of stitching ghosting and stitching loss is ≤ 3%.	100

Table 9. Scoring rules for real-scale zoom(continued)

Technical Requirement	Score
Within the visible area of the planar stitched view: No visible stitching gaps (black, colored, etc.) are present, The actual distance corresponding to any stitching misalignment is ≤ 0.5 m, The total actual area corresponding to stitching ghosting and stitching loss in any four cells arranged in a 2×2 grid pattern is ≤ 0.6 m², and the total proportion of stitching ghosting and stitching loss is ≤ 5%.	75
Within the visible area of the planar stitched view: No visible stitching gaps (black, colored, etc.) are present, The actual distance corresponding to any stitching misalignment is ≤ 0.6 m, The total actual area corresponding to stitching ghosting and stitching loss in any four cells arranged in a 2×2 grid pattern is ≤ 1.0 m², and the total proportion of stitching ghosting and stitching loss is ≤ 10%.	50
Within the visible area of the planar stitched view, ANY of the following conditions is met: Visible stitching gaps (black, colored, etc.) are present, The actual distance corresponding to any stitching misalignment exceeds 0.6 m, The total actual area corresponding to stitching ghosting and stitching loss in any four cells arranged in a 2×2 grid pattern exceeds 1.0 m², and the total proportion of stitching ghosting and stitching loss exceeds 10%.	0

2.3. Score Calculation for AVM System Evaluation

Based on the previously mentioned quantitative scoring rules and indicator weight distribution for the panoramic surround view assessment, after completing the evaluation of the indicator scores, the total score for the panoramic surround view is calculated using a weighted method of technical indicator scores, as shown in Figure 2.

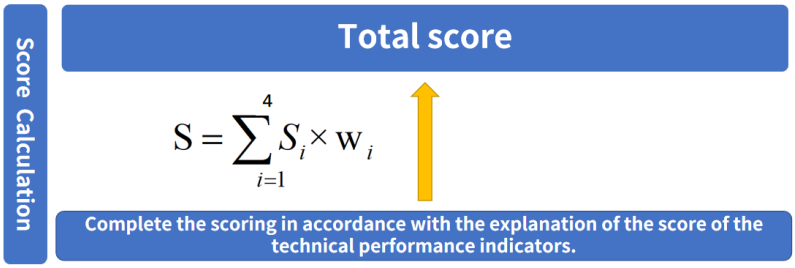


Figure 2. AVM Evaluation Score Calculation.

3. Real-Vehicle Application of the AVM Evaluation System

To reasonably validate the established panoramic view evaluation system, this article takes 31 currently popular car models as the subjects for testing and analysis. The models can be found in Table 10, with prices ranging from about 100,000 to 650,000 yuan, covering mainstream options in the market, including domestic self-owned brands, new domestic players, and joint ventures. After performing panoramic view evaluations on these 31 models using the method described in this article, the obtained scores and experimental facts are summarized, and the analysis results are explained as follows[9].

Table 10. Vehicle models for experimental validation

Brand Category	Selling Prices	Number of Models
Independent automotive enterprises	(100,000 - 200,000)RMB	4
	(200,000 - 350,000)RMB	7
	(350,000 - 650,000)RMB	2
New force vehicle manufacturing enterprises	(100,000 - 200,000)RMB	1
	(200,000 - 350,000)RMB	9
	(350,000 - 650,000)RMB	1
Foreign-funded automakers	(100,000 - 200,000)RMB	4
	(200,000 - 350,000)RMB	2
	(350,000 - 650,000)RMB	1

3.1. Overall Performance Analysis of AVM Evaluation

Looking at the 31 car models from the perspective of Figure 3, their average score for panoramic surround view evaluation is 88.9 points. Among them, 13 models got the highest score (a full score), but 8 models scored below 80. This shows that a considerable number of vehicles still need improvements in parking surround view functions.

If we take a closer look at the 31 models based on their market positioning (see Figure 4), we can see that mid-to-high-end models priced between 350,000–650,000 yuan or 200,000–350,000 yuan generally have higher average scores, while economy cars in the 100,000–200,000 yuan range have lower average scores (less than 90). From this, we can conclude that if overall vehicle manufacturing costs are strictly controlled, it's hard for a panoramic surround view system to be fully equipped with hardware and have properly upgraded image processing at the same time. As a result, economy cars lag noticeably behind mid-to-high-end models in overall performance.

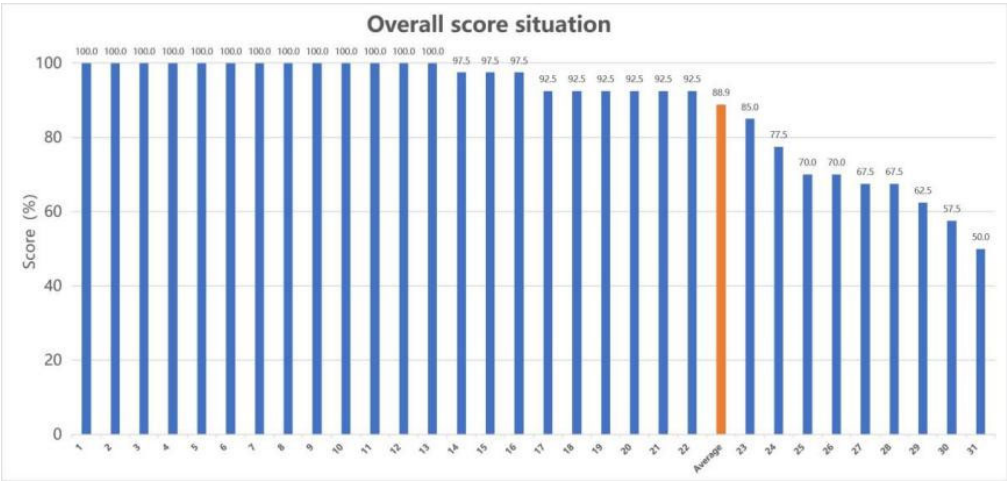


Figure 3. Calculation of AVM evaluation scores.



Figure 4. Distribution of AVM evaluation scores by vehicle price range.

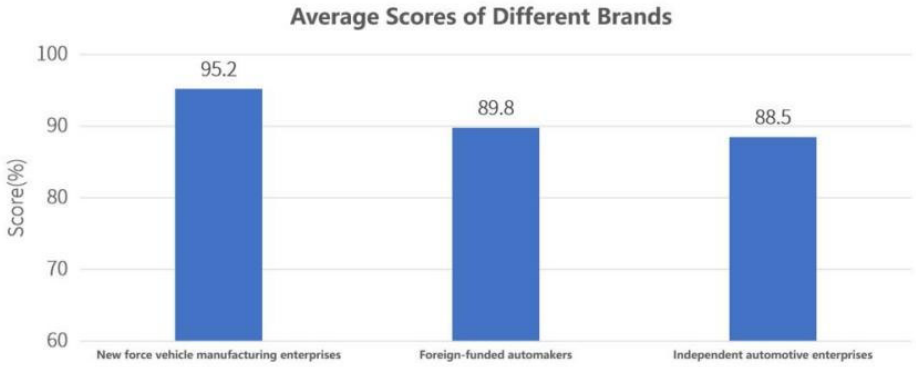


Figure 5. Distribution of AVM evaluation scores across brand categories.

The 31 listed car models can be grouped by brand category, and their performance is illustrated in Figure 5. From the data, the average score of domestic new energy brands is currently slightly better than that of regular domestic brands or joint venture brands. This result roughly aligns with the fact that domestic new energy manufacturers have put more thought into the human-machine interaction involved in panoramic viewing. As a result, their systems start up faster, the stitched images are more complete, and overall, they have a noticeable relative advantage in performance[10].

3.2. Analysis of Technical Indicator Scores

With regard to the four technical indicators mentioned (viewing angle, activation time, real - scene zoom, and stitching quality), it may be stated that the average scores of the first three are all over 90, i.e., the performance is very good .Yet the average score of stitching quality now lies below 80, far lower than for the other three, and this seems to be the central obstacle to an appreciable rating of the panoramic surround system .Below is a breakdown of the scores obtained by various car models on each indicator[11].

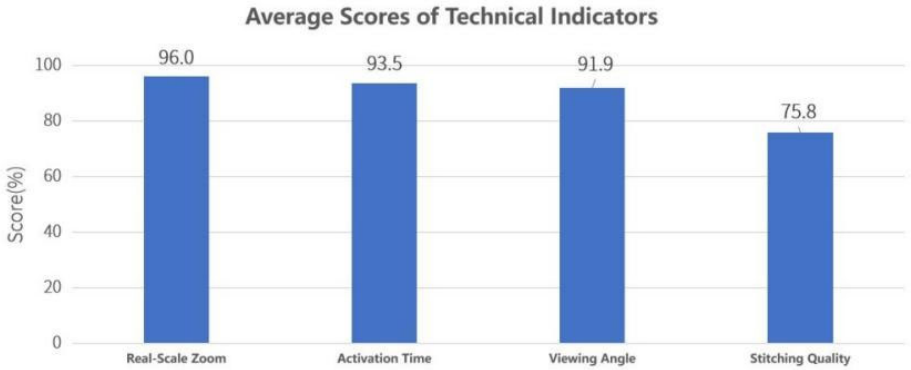


Figure 6. Average scores of AVM technical indicators.

3.2.1. Score Analysis for Viewing Angle

If we consider the given list of car models with regard to the observation indicators (see Fig .7), 26 of the 31 tested vehicles achieved full marks .All of them now make use of 360 ° panoramic cameras and of variable 3D views, which are quite adequate for helping drivers to locate themselves and to park safely .Yet for some models it is possible to look at every angle in 360 ° without being able to apply the 3D aid. Such a

design complicates the estimation of spatial positions, with an accompanying reduction in parking safety .Now it is necessary to encourage progress on HMI ， especially with regard to 3D presentation of data and to the handling (switching, adjusting) of angles .That kind of progress would clarify — for the driver — obstacle size and location, and go far toward eliminating low - speed impacts or near-misses.

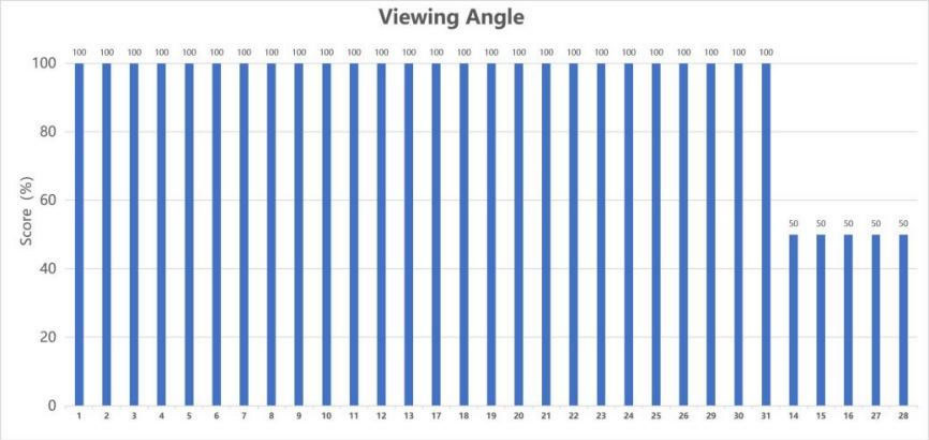


Figure 7. Distribution of viewing angle evaluation scores.

3.2.2. Score Analysis for Activation Time

If one actually tests real - car activation behavior against the time indicators given (see Figure 8), then of the 31 models tested 29 meet all the criteria fully .Their panoramic surround - view systems responded — on average — within 1 . 0 seconds, which is a very convenient speed for visual help when parking or maneuvering closely[12] .Yet there were also models with systems whose delays stood out noticeably, activation times of 2 . 0 seconds or more are involved .Such delays mean that drivers have to wait longer for the whole panoramic view to become available, which is not satisfactory for them .With today's technology, the problems outlined above should be handled jointly by means of software and of hardware: software-wise, make the start - up and the control of cameras less complicated so as not to waste time;hardware-wise, apply image-processing units or multi - tasking system chips to cut down the cumulative delay between request and final panorama, bringing the total time to under 1 . 0 second, thus meeting the expectation of drivers regarding immediate visual feedback during parking[13].

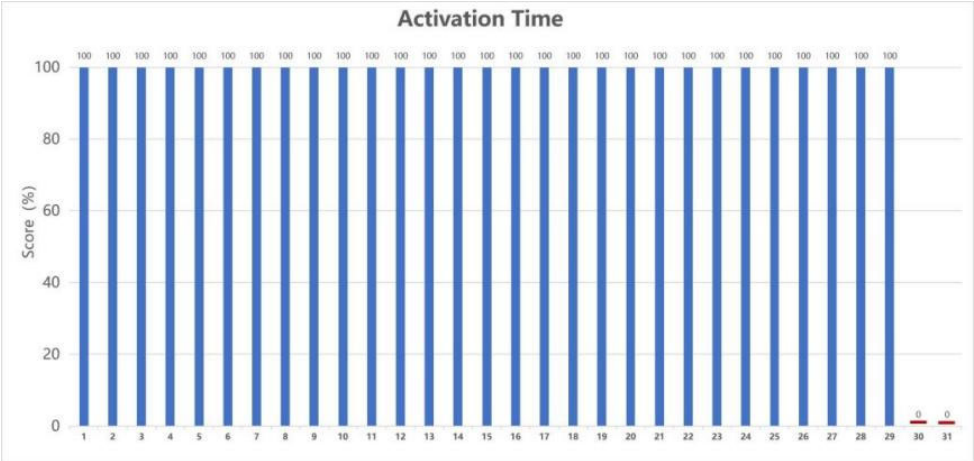


Figure 8. Activation time evaluation scores.

3.2.3. Score Analysis for Real-Scale Zoom

With regard to the real - scene scaling index, the test object taken is an ideal cylinder of 0 . 8 m height and 0 . 3 m diameter .It has to be located at a distance of 3 . 5 m ahead of or behind the test vehicle (with its center lying along the vehicle axis). The apparent size of the object—within the field of view—is obtained from the surround - view camera data (in terms of angles), and this value helps to decide if the sensed scale comes close to that of the actual physical situation .

For real-car evaluations of the real-scene scaling index (see Figure 9), out of 31 tested models, 22 scored full marks, while the remaining nine lost points to varying degrees. The loss of points is generally due to the imaging system used in the surround-view camera not correctly showing the actual size of objects, resulting in distorted images and mismatched proportions. From this point of view, drivers often fail to estimate accurately the size and distance of obstacles .To remedy this, car models would profit from improvements—both in the imaging system and in the way data are shown:in the case of algorithm - driven imaging, it is important to calibrate the camera and to eliminate distortions (so that proportions of targets at various distances correspond to real

- life conditions);with regard to display - based methods, the inclusion of scales or of distance indicators helps to fix the obstacle's actual size and location more clearly, thereby raising both the precision of spatial analysis and the feeling of safety while parking[14].

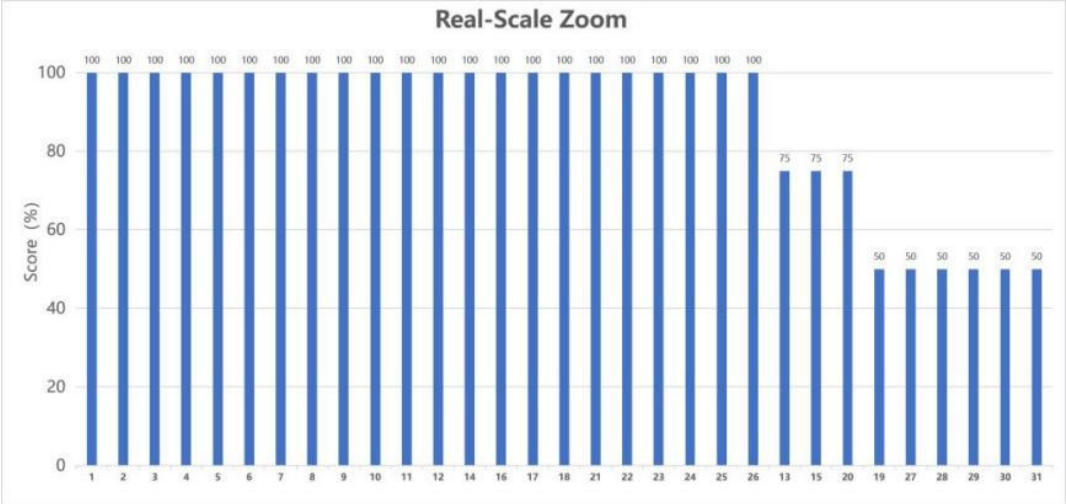


Figure 9. Real-scale zoom evaluation scores.

3.2.4. Score Analysis for Stitching Quality

When the listed car models were tested in relation to stitching quality (see Figure 10), a total of 31 vehicles were considered and 14 were found to score less than 80 — i.e., about 45 . 2%.Among them, 4 models had no points at all for this category, so the present panoramic view systems seem to suffer greatly from poor stitching of images .The principal source of point loss lies in difficulty with real - time stitching of front - facing images ,rear, left, and right cameras—i.e., either the stitching algorithm or the camera calibration—do not yield sufficient accuracy in some cases, so that the stitched image may have gaps, ghosting, or distortion .All such problems lead to partial visual coverage of the vehicle's surroundings, with difficulty in spotting nearby obstacles and an increased chance of low - speed scrapes, as well as a rough, poor-quality panorama that fails to look smooth or elegant, and so does not really match the intelligent design of the car.



Figure 10. Real-scale zoom evaluation scores.

Among the issues listed, some are best treated by means of both algorithm optimization and of hardware improvement: algorithm – wise, one needs to match and to fuse feature points in a number of images more precisely (so that stitching holds up against many lighting or texture situations) and to handle seam pixels without producing ghosts or offsets .As far as hardware is concerned, camera modules of low distortion a better field of view may be used without any drop in theprocessing efficiency of the image signal processor (the real - time computation still fits high precision needs) .With regard to system design, one must take into account—along with objective facts—subjective stitching quality, possible image distortions under various parking conditions, and hence the best imaging method for the panorama, which helps to improve the user ' s practical experience.

4. Conclusions

What is discussed here refers to the real-life problems and needs of drivers concerning parking .It makes use of survey data, of Delphi-style expert views, and of the Analytic Hierarchy Process to suggest a general system of indices relating to user experience .Such an index is tested against 31 known present-day car models (i . e . , real vehicle

trials) .The central conclusions are:

(1) Of the four technical items—viewing angles, activation time, real - scene zoom, and stitching quality—it is proposed to make a systematic summary, with the idea that the various indices need separate weights.Delphi surveys were conducted with 758 actual users and experts from 20 major car manufacturers/suppliers (over 200 valid responses). The four basic problems drivers mentioned—'incomplete viewing angles', 'slow startup response', 'distorted display', and 'poor stitching quality'—were transformed into clear technical indicators. Using AHP to weigh them, activation time had the greatest weight (35%), followed by stitching quality and real-scene zoom (each 30%), and viewing angles had the smallest share (5%).

(2) The real-vehicle tests on 31 models demonstrated the differentiation and effectiveness of the index system. Currently, the most obvious issue for users with panoramic view systems is stitching quality. According to the evaluation results, the 31 models had an average score of 88.9 points, 13 models reached the maximum score, but 8 models scored below 80. Looking at the four technical indicators individually, the average scores for viewing angles, activation time, and real-scene zoom were all above 90, which is basically satisfactory. However, the average score for stitching quality was below 80, worse than all the other indicators, and 45.2% of models scored under 80 in this category, with 4 models not scoring at all. This shows that stitching quality is the main obstacle affecting the panoramic view experience.

(3) The evaluation results listed in the text serve as the basis for proposing product improvement plans. For obvious score losses in stitching quality, an overall analysis should be performed, considering improvements from both algorithm and hardware perspectives. To achieve better results one should improve the matching of features across images and their fusion, smooth out the pixels adjacent to stitching lines, use more accurate cameras, and speed up the image processors — while also drawing on both subjective judgment of stitching quality and factual data to decide upon internal product standards .With regard to specific difficulties affecting a given car model (for example, angles of view, time responses, or scaling in practice), remedies are offered:3D views or controls to adjust perspective, an efficient startup procedure, hardware upgrades, correction of camera settings, or use of auxiliary scales to show real size.

Briefly speaking, the panoramic view evaluation method described here is one that may be used to assess effectively the parking assistance of many car models .The results it yields — whether theoretical or practical — help to indicate how an automotive firm might develop, test, or revise its panoramic view technology, as well as how such standards should be drawn up or modified by the industry. Looking ahead, future work should expand the evaluation conditions beyond the current norm (like considering night scenes, rain, etc.) and think about how to better integrate subjective user experience with the technical parameters involved for a more complete and reasonable assessment.

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