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STUDY ON THE DRIVING GAZE SHIFT CHARACTERISTICS OF VISION INTERESTING AREA ON MOUNTAINOUS ROAD

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ABSTRACT

Mountainous road landscape is the main source of driving information. The characteristics of two-lane mountainous road result in real-time dynamic changes in the driver's vision interesting areas. In order to explore the dynamic gaze characteristics, a driving experiment is conducted, and the gaze data of 10 drivers are collected. Markov chain is used to analyze the change process of the gaze. The results show that: (1) when the current gaze point is in the straight front area, different road landscape has no significant impact on the gaze shift probability; (2) when the current gaze point is in the near left area, next gaze will expand the search scope to obtain much more driving information; (3) when the current gaze point is in the near right area, there is a high probability that the driver's next gaze will return to the front area; (4) when the current gaze point is in the far right area, the gaze will move back and forth between the near right and the far right areas; (5) when the current gaze point is in the far left area, there is a high probability that the gaze will remain in current area; (6) the main source of traffic information obtained by the driver in mountainous road landscape is the straight front area in the vision field, and the gaze point constantly shifts between the far ahead and the near ahead. The research results can provide technical reference for the construction of landscape in mountainous two-lane road.

KEYWORDS

Mountainous road, Landscape, Shift of gaze while driving, Vision interesting area, Markov chain

INTRODUCTION

Mountainous roads often have many characteristics, such as complex alignment, many artificial structures, frequent spatial changes, etc. Drivers need to make correct driving operations in time to cope with changes in the driving environment. In addition, the form of traffic safety facilities is often very simple, and the variability of road landscape is often insufficient. These factors will cause the driver to have frequent eye movements when driving. From the perspective of traffic safety, the driver should have excellent driving skills. Drivers should be able to receive and process external information timely and accurately. At the same time, the driver should also get appropriate feedback from the external driving environment, so as to maintain a good attitude, which is conducive to driving operation.

The landscape of mountainous roads can affect the driver's vision interesting area. There are rich landscape resources along mountainous road. Through reasonable landscape construction, the driving visual environment can be improved, and the driving direction can be guided by appropriate visual stimulation to improve the driving safety performance.

LITERATURE REVIEW

During driving, different drivers will have different visual loads due to the influence of environmental changes. Many scholars have studied the relationship between traffic safety and road landscape. A single road landscape is easy to cause negative driving psychology and visual fatigue [1]. XiaoLei Li et al. used simulation software such as UC-WIN to test the impact of road landscape environment color on driver vision, and found that red and yellow in the environment have a significant impact on drivers [2]. Meng YW et al. used the threshold segmentation method to process the visual image, obtained the calculation method of road landscape information, and established the regression relationship between comfort and landscape information [3]. Qin YQ summarized the factors affecting the driver's visual load, and pointed out that the road landscape had a great visual impact on drivers from the relationship between people, car, road and environment [4]. Jeong-Hun Mok et al. conducted statistical analysis of road traffic accidents in Texas, and found that the driver's visual perception was correlated with the road landscape [5]. After landscape improvement of some sections or roadside stops, the quantity of traffic accident significantly decreased.

The vision interesting area is located in the driver's vision field, which is the area with more gaze times and longer gaze time. With the aid of eye movement observation instrument, the distribution of visual gaze points can be obtained. A reasonable and effective division of the vision field helps to find the rules of the gaze points. By dividing the field of vision, the vision field will be divided into several zones. The number of gaze points and gaze time in each zone can be compared to determine where the vision interesting area is located. Therefore, it is important to divide the vision field. At present, there are three main methods to divide the vision field for deciding vision interesting area. (1) The method of statistical analysis for each frame, that is, researchers' playback the driving scene video frame by frame and record the position of the gaze point, and then superimpose the gaze point in the vision field according to the time sequence, so as to obtain the vision interesting area, i.e. the concentration of the gaze points. (2) Default partition method. Its main characteristic is to divide the vision field into several sub-regions before experiment. This method is relatively simple and has been widely used. Shan Bao et al. divided the vision field into 7 sub-regions: far left, near left, far right, near right, straight front, rearview mirror and others. The division of vision field is related to the gaze specific environment [6]. Yamada studies the visual recognition characteristics of drivers by dividing several regions with different weights [7]. (3) Clustering method of gaze points. It firstly selects several gaze point samples as the clustering center, then clusters according to the criteria, and continuously adjusts the clustering center until the clustering result is reasonable. Drusch et al. applied a clustering method based on Hausdorff distance to study the relationship between gaze behavior and body behaviour [8]. Saha Bipin proposes a real-time eye gaze tracking interface based on an active appearance method using a simple web or smartphone camera in an unconstrained environment, where natural head movements have been taken into account [9].

Based on the comprehensive study of the gaze region, it can be found that the research results show that the driver's gaze points are mainly distributed in the middle and far ahead of the vision field, which is consistent with the visual characteristics while driving. With the change of driving, the gaze point will change dynamically.

Visual scanning behaviour can affect the role between attention and information acquisition from the driver's environment [10]. Stephan et al. introduced a new Hidden Markov models. This provides a new approach for the study of vision interesting area [11]. NiIsson introduced a type of gaze concentration effect, which analyzes the impact of cognitive load on driving visual characteristics by analyzing the movement path of gaze during driving. The research results help to understand and predict the safety related effects of cognitive load on car drivers [12]. Meng Y W et al. put forward a quantitative method of comprehensively considering the gaze position, gaze time and gaze times, which can better reflect the driver's gaze intensity on the vision interesting area [13]. He S M et al. analyzed the temporal and spatial characteristics of the driver's gaze behavior when entering the main line and ramp through the diversion region by real vehicle experiment [14]. Ghosal Deepanway et al. propose a transfer learning and attention mechanism based neural network model to predict visual interest & affective dimensions in digital photos. With various experiments they show the effectiveness of the proposed approach [15]. Morales Aythami et al. proposes a new algorithm based on LSTM networks and a fine-grained loss function for saccade landing point prediction in real-world scenarios [16]. For the weighted search area method, Christófano proposes a web application called PlaceProfile to perform visual profiling of city areas based on iconographic visualization and to label areas based on clustering algorithms [17].

Lee YC et al. used the simulating driving method to analyze the driver's gaze shift characteristics, and it pointed out that the short gaze away from the road may cause traffic safety accidents [18]. Shih-Hsuan Huang et al. established a visual attention evaluation framework based on the distribution principle of contribution, and it used the associated logit model to evaluate the driver's gaze shift probability, and it found that there was a wide range of scanning path process between the two fixations [19].

It can be seen that the driver's continuous multiple gaze at the vision interesting area is the guarantee of sufficient information sources. The landscape of two-lane mountainous roads has caused the dynamic shift of driver's attention. In this paper, the driving experiment is used to collect the driver's gaze data. From the perspective of time, the Markov chain is used to analyze the characteristics of dynamic shift and explore the main vision interesting area.

EXPERIMENT PROCESS

In this section, a driving experiment was carried out to explore the dynamic changes of driver's gaze area in two-lane mountainous road. The driving experiment mainly included recording the dynamic image of the road landscape, as well as the driver's visual response and other indexes.

Instruments

In the experiment, the experimental HONDA CR-V car was equipped with a camera. The eye-movement instrument called Dikablis was used to collect the driver's visual characteristic data. The data acquisition frequency is 60Hz. The tracking accuracy of the driver's pupils is 0.05°. The eye-movement instrument is shown in Figure 1. The instrument can record the eye movement trajectory and fixation time of participants. The vehicle-mounted CTM-8C non-contact vehicle speedometer was used to measure the speed and acceleration of the experimental car. The speed measurement range is 0-250km/h, with a baud rate of 9600.

Fig. 1 - Eye movement instrument and on-board data processing equipment

Process of experiment

Chongqing is famous for its mountain city, which has a wide range of mountain terrain, providing a rich site environment for experimental research. A section of road in Chongqing was selected as the experimental mountainous road. This road is located in Ba'nan District, Chongqing,China, and it is the provincial road S102. The geographical plan is shown below.

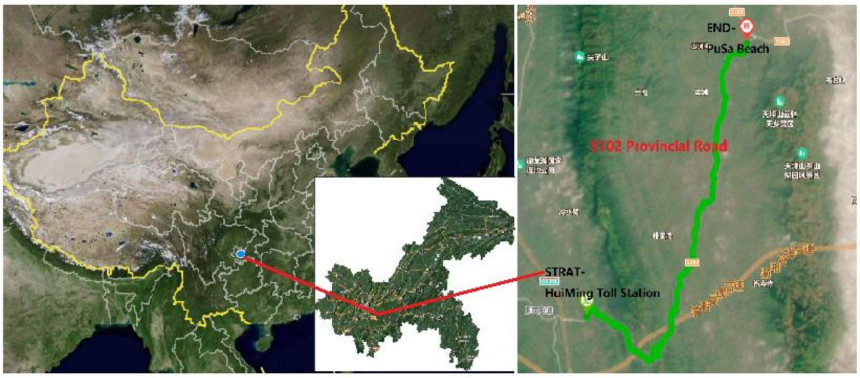

Fig. - 2 Plan of experimental section

The section length is about 25km, and the design speed is 60km/h. The width of the experimental road is 8.5m, of which 7.5m is the carriageway, and there are 0.5m wide hard shoulders on both sides. The pavement is asphalt concrete pavement. The minimum circular curve radius of mountainous roads is 40m, and the maximum longitudinal slope is 5%.

During the driving test, the traffic flow is in a free flow state. The weather is good. During the experiment, there was no obvious direct sunlight on the driver's eyes.

By recruiting online and selecting suitable volunteers, each person will receive 100 RMB and a commemorative cup. Ten subjects were selected as drivers for driving test, who were unfamiliar with the experimental section and had corrected vision above 5.0. Among them, 5 were 20-30 years old and 5 were 30-40 years old. These drivers' occupations include 2 college students, 2 teachers, 1 company employees, and 5 general publics, all with over three years of driving experience. They are not professional drivers. And maintained normal physical condition before the experiment.

According to the acquisition frequency of the eye tracker, a total of 1.8 million pieces of data were collected. The data format includes timestamp files (TXT format), log files (LOG format), and finally imported into Excel for organization. It contains data on the driver's cardiac and physiological changes and the vehicle's movement status. For example, eye shift angle, acceleration, vehicle operating speed, etc.

The experimental process is as follows:

(1) On the experimental road section, the landscape types were selected in advance and marked at the boundary of the different landscape types.

(2) After the camera, eye tracker and other instruments were calibrated, the driver adjusts the height of the driving position. The driving test began. When the speed limit was not exceeded, the test driver could freely choose the driving speed he thinks is comfortable. During the whole process of the test, the tested driver could also adjust the speed according to the traffic conditions. The test driver drove continuously from the beginning of the experimental road section to the end, and the instrument recorded the driver's visual and physiological parameters. A trainman in the car records the range of stake numbers of different road landscapes for verification during data processing. After arriving at the destination, the test driver rested for 3 to 5 minutes to conduct the return test. The content to be recorded was the same.

(3) After a round trip, one test driver was replaced by another test driver, and the above driving test steps were repeated until 10 test drivers completed the whole test. The picture of a driver ready in the experimental car is shown in Figure 3. Figure 4 shows real-time recording of experimental data. Figures 3 and 4 describe the process of the experiment.

Fig.3 - The tested driver in the experimental car and data monitoring

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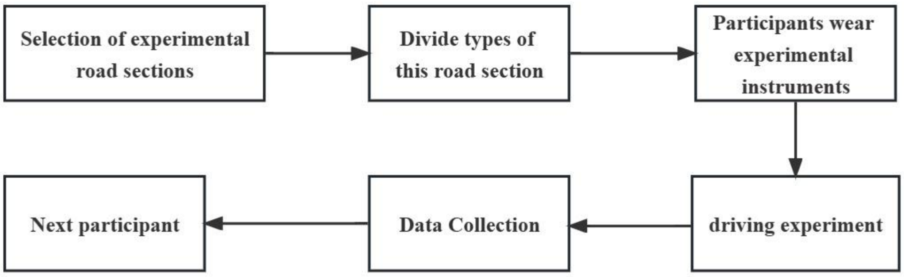


Fig.4 - Experimental process

Analysis model

The existing researchers on vision interesting areas are mainly focused on gaze behavior, including single-factor analysis of gaze indicators, cluster analysis of gaze location, etc. On the basis of the study, the dynamic clustering method is adopted in this paper to analysis the dynamic characteristics of the vision interesting area [20]. The range of driving visual interesting area was determined by the modified weighted search region calculation method.

Spatial Enclosure

When driving on the mountainous road, the driver's visual axis keeps the same direction with the tangent vector of the vehicle's motion path. At a certain speed, the driver's vision field is a nearly conical area. In landscape engineering, it believes that the driving speed, visual distance and scenery determine the degree of closed feeling brought by the landscape to the driver, which is called the space sense. The driver's space sense is expressed by the degree of space interface enclosure, and the evaluation index is the ratio H/D between the height H of the landscape or structure interface on both road sides and the horizontal distance D from the viewpoint to the roadside landscape or structure, as shown in Figure 5.

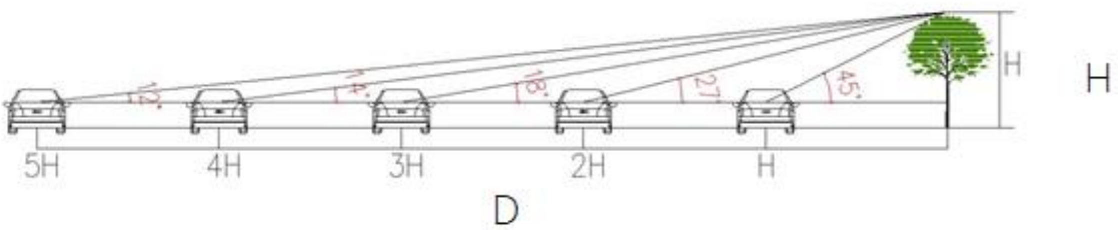


Fig.5 - the calculation of spatial enclosure

The impact of road landscape on driver visual comfort is mainly reflected in its spatial enclosure and color stimulation. In the field of landscape engineering, spatial enclosure is often used to represent the driver's sense of spatial closure, and road landscape is divided into three types—— open, semi-closed, and closed, as shown in Table 1. The space enclosure is different, drivers get different feelings of space. When H/D<1:3, the driver's vision vertical angle is less than 18°, the sight line is less limited, and the vision field is relatively wide, so the driver can obtain an open space sense; when H/D>1:2, the driver's vision vertical angle is greater than 27°, and the vision field is limited, which will produce a more closed space sense [21].

Tab. 1 - Parameters of different landscape types

Type	H/D	Vision vertical angle
Open space	≤1/3	<18°
Semi-closed space	1/3～1/2	18°～27°
Closed space	≥1/2	>27°

Markov chain theory

Set the random sequence $\{X(n),n=0,1,2,\dots,n\}$ and the discrete state space be $E=\{0,1,2,\dots n\}$. If for any m non-negative integers, $n_1,n_2,\dots,n_m$ ($0< n_1< n_2<\dots< n_m$) and natural number k, and any $\{i_1,i_2,\dots,i_m,\},j\in E$. satisfy Equation 1,

$$\begin{aligned} & p\left\{X\left(n_m+k\right)=j \middle| X\left(n_1\right)=i_1, X\left(n_2\right)=i_2,\cdots, X\left(n_m\right)=i_m\right\} \\ & = p\left\{X\left(n_m+k\right)=j \middle| X\left(n_m\right)=i_m\right\} \end{aligned} \tag{1}$$

$\{X(n),n=0,1,2,\dots,n\}$ is called Markov chain.

Markov chain is a typical random process with no aftereffect, that is, the model state at time t is only related to its previous state time $t-1$, and independent from the previous state condition.

The driver's gaze point falls in different areas during driving. The next gaze point falls in which region is only related to the region where the current gaze located, which is a typical homogeneous Markov chain. Therefore, it is appropriate to use this theory to study the driver's gaze shift characteristics. The statistical estimation method is used to solve the driver's one-step shift probability matrix. The basic idea is to take each gaze region as a state of the Markov chain, and then calculate the shift probability between each state.

Set 1, 2, 3, 4 and 5 as the five states of the gaze point, and a_{ij} is the frequency of state i shiftring to state j. For example, a_{11} represents the frequency of the current gaze point in region 1 and the next gaze point still in region 1; a_{13} indicates the frequency of the current gaze point in region 1 and the next gaze point in region 3, and so on.

Set up

$$\sum_{j=1}^{n} a_{ij} = a_i \quad \left(i、j=1,2,\cdots,n\right) \tag{2}$$

then the shift probability from state i to state j is shown in Equation (3).

$$f_{ij}=\frac{a_{ij}}{a_i}, \quad (i=1,2,\cdots,n) \tag{3}$$

From the probability theory, when the theoretical distribution of state probability is unknown, if the sample capacity is large enough, the theoretical distribution of state can be approximately described by the sample distribution. The amount of data obtained in this vehicle test is large enough. Therefore, for the unknown gaze shift probability, the frequency can be used to approximate the shift probability. Therefore, the estimated value of shift probability from gaze region i to j is:

$$p_{ij} = \frac{a_{ij}}{a_i} \tag{4}$$

From this analysis, the shift probability matrix of the driver's gaze can be obtained by using the Markov chain.

SHIFT MODE OF DRIVING GAZE AREA

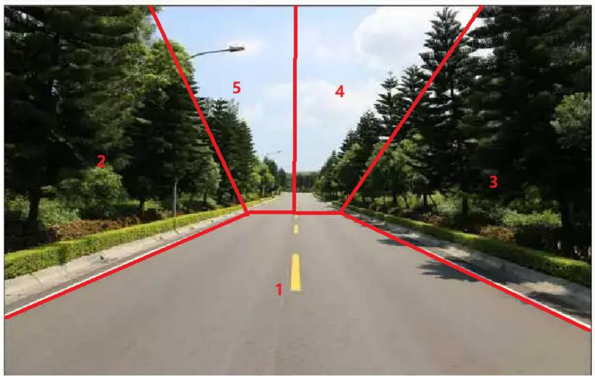
The driver's visual response characteristics are affected by the road landscape. When the road landscape is simple, the driver can easily obtain the information and have the ability to perceive the detailed landscape. When the road landscape is too complex, the driver's perception decreases, and the perception range decreases, which may ignore some important traffic information, and even cause traffic safety hazards. The driver's gaze feature is the visual psychological expression of the dynamic response to the road landscape. After screening the collected data, about 1.75 million pieces of valid data are retained for the analysis of the gaze shift characteristics of the driver's visual interesting area.

Division of driver's gaze region

Before studying the gaze shift characteristics, division of the gaze regions is needed. There are many ways to divide the gaze region of driver's vision field. In this paper, the dynamic clustering method is used to cluster the analytical coordinates of the gaze point location in the vision field. Through the analysis of the final clustering results, it is found that the distribution of driver's gaze points presents a certain clustering distribution rule. In the three types of road landscape, the distribution of gaze points is shown in Figure 5, which is placed in a two-dimensional coordinate system for quantitative analysis. It can be seen that the driver's gaze points are mainly concentrated in five regions. For each kind of road landscape, the range of the gaze point is calculated, as shown in Table 2.

a) Open space *b) Semi-closed space*

Fig.6 - Vision interesting areas



c) Closed space

Fig.6 - Vision interesting areas

Tab. 2 - Division of vision interesting areas

Number	Names for vision interesting areas	Coordinate range
1	Straight Front	-12.36≦X≦5.42, -28.53≦Y≦ -12.36
2	Near Left	-42.62≦X≦ -25.81, -28.56≦Y≦ -7.43
3	Near Right	35.54≦X≦52.61, -28.46≦Y≦ -12.38
4	Far Right	0.52X≦17.47, -10.88≦Y≦2.42
5	Far Left	-16.40≦X≦ -2.14, -11.37≦Y≦ -3.72

The gaze data of 10 drivers in this experiment were selected for clustering and one-step Markov chain shift matrix solution. The following analyses the characteristics of gaze shift in the next step when the gaze is located in different regions.

(1) Current gaze point being in Region 1

Region 1 refers to the straight front of the driver's vision field. By analyzing the calculated data, it is found that if the driver's current gaze point is in Region 1, the probability of the next gaze point continuing to be in region 1 is the highest, and the probability of the open, semi-closed and closed landscapes is 0.829, 0.837 and 0.807 respectively, as shown in Table 3. The probability value of the next gaze point in Region 1 in the three kinds of landscapes is 0.824 on average, which means that no matter what kind of road landscape the driver drives in, most of his attention is in the straight front of the vision field, which also reflects that the straight front in the vision field is the main vision interesting area.

By comparing the probability of gaze shift in different road landscapes, it can be seen that when the current gaze is located in Region 1, different road landscape has no significant impact on the shift probability.

Tab. 3 - Probability of gaze region following current being in Region 1

	p_{11}	p_{12}	p_{13}	p_{14}	p_{15}
p	0.777	0.255	0.765	0.715	0.551
Open landscape(Average)	0.829	0.037	0.030	0.071	0.033
Semi-closed space(Average)	0.837	0.026	0.040	0.056	0.041
Closed space(Average)	0.807	0.050	0.040	0.052	0.051
Overall	0.824	0.038	0.037	0.060	0.042

(2) Current gaze point being in Region 2

Region 2 refers to the near left of the driver's vision field. Table 4 lists the results of the probability of gaze region following current gaze point being in Region 2 for three types of road landscape.

Tab 4 - Probability of gaze region following current being in Region 2.

	p_{21}	p_{22}	p_{23}	p_{24}	p_{25}
p	0.636	0.057	0.048	0.036	0.755
Open landscape(Average)	0.361	0.368	0.006	0.114	0.151
Semi-closed space(Average)	0.292	0.478	0.031	0.078	0.121
Closed space(Average)	0.288	0.564	0.013	0.048	0.138
Overall	0.314	0.470	0.017	0.080	0.137

From the Table 4, it is found that if the driver's current gaze point is in Region 2, the probability of the next gaze point is still in Region 2, and the probability of the open, semi-closed and closed landscape is 0.368, 0.478 and 0.564 respectively, with an average probability value of 0.470. If it considers the probability value of the next gaze point shifting to Region 1 (that is, p_{21}+p_{22}), the sum of probabilities from Region 2 to remaining and Region 1 is 0.784, the next gaze point is still basically located in straight front and near left, indicating that the driver pays more attention to the left and straight front in different road landscapes.

The one-way ANOVA of the gaze shift probability of three road landscapes was conducted, as shown in *p* (average value) of Table 4. It can be found that when the gaze point is located in region 2, the next gaze point is shifted to region 3 and region 4 with significant difference (p_{23}=0.048<0.05, p_{24}=0.036<0.05). For the case that the next gaze region is still in region 2, although the significance value is 0.057, it is very close to the significance level of 0.05. It can be considered that there are differences in the three types of road landscape. No matter what type of road landscape, when the current focus is in Region 2, for Region 5, that is, far from the left, the next gaze is very few, and the most focus is Region 1. The probability of gazing at Region 2, 3 and 4 next time will vary according to the landscape type. The probability of continuing to gaze on Region 2 in the closed landscape is the highest, the probability of shifting to Region 3 in the semi-closed landscape is the highest, and the probability of shifting to Region 4 in the open landscape is the highest. When located in Region 2, the driver will expand the search vision range to obtain various information beneficial to driving.

(3) Current gaze point being in Region 3

Region 3 refers to the near right of the driver's vision field. The results are shown as Table 5.

Tab. 5 - Probability of gaze region following current being in Region 3

	p_{31}	p_{32}	p_{33}	p_{34}	p_{35}
p	0.109	0.048	0.801	0.388	0.732
Open landscape(Average)	0.259	0.025	0.428	0.144	0.144
Semi-closed space(Average)	0.116	0.078	0.435	0.179	0.192
Closed space(Average)	0.127	0.107	0.407	0.201	0.158
Overall	0.167	0.070	0.423	0.175	0.165

From Table 5, it is found that if the driver's current gaze point is in Region 3, the probability of the next gaze point continuing to be in Region 3 is the highest, and the probability of the open, semi-closed and closed landscape is 0.428, 0.435 and 0.407 respectively, with an average value of 0.423. It indicates that the driver needs to repeatedly gaze on this region to obtain sufficient visual traffic information. If it considers the probability of the next gaze point shifting to Region 1, 4 and 5 ($p_{31}+p_{34}+p_{35}$), the average of the total probability sum in the three road landscape spaces is 0.507, indicating that the driver's gaze point will have a high probability of returning to the straight front after staying near right. It is verified that the driver's vision interesting area is mainly in the front region of the vision field.

The one-way ANOVA of the gaze shift probability of three road landscapes shows that when the gaze point is located in Region 3, there is a significant difference between the three landscapes when the next gaze point is shifted to Region 2 (p_{32}=0.048<0.05), that is, the dynamic attention of different landscapes on the left and right sides is different, and the next gaze point is shifted to other regions in different road landscape has no significant difference.

(4) Current gaze point being in Region 4

Region 4 refers to the far right of the driver's vision field. The results are shown as Table 6.

Tab. 6: Probability of gaze region following current being in Region 4

	p_{41}	p_{42}	p_{43}	p_{44}	p_{45}
P	0.589	0.010	0.678	0.039	0.567
Open landscape(Average)	0.290	0.155	0.053	0.348	0.154
Semi-closed space(Average)	0.216	0.200	0.035	0.379	0.170
Closed space(Average)	0.205	0.087	0.078	0.440	0.190
Overall	0.237	0.147	0.055	0.389	0.171

By comparing and analyzing the data in Table 6, it is found that if the driver's current gaze point is in Region 4, the probability of the next gaze point is still in Region 4 of the open, semi-closed and closed landscapes is 0.348, 0.379 and 0.440 respectively, with an average value of 0.389. If the probability values of the next gaze point shift to Regions 1, 4 and 5 are added ($p_{41}+p_{44}+p_{45}$), the average value of the sum of the probabilities is close to 0.8. It shows that the main source for drivers to obtain traffic information in the mountainous road landscape is the region in front of the vision field, and the gaze constantly shifts dynamically between the far ahead and the near ahead to obtain the required traffic information.

When the gaze point is located in Region 4, there are significant differences in the three landscapes while the next gaze point shifts to Region 2 and 4 (p_{42}=0.010<0.05, p_{44}=0.039<0.05).

When representing different landscape types, the dynamic attention to the central region is different. There is no significant difference in different landscape types when the next gaze shifts to other regions.

(5) Current gaze point being in Region 5

Region 5 refers to the far left of the driver's vision field. Table 7 lists the results of the difference experiment analysis of the three types of road landscape.

Tab. 7 - Probability of gaze region following current being in Region 5

	p_{51}	p_{52}	p_{53}	p_{54}	p_{55}
p	0.748	0.879	0.205	0.045	0.692
Open landscape(Average)	0.300	0.004	0.004	0.057	0.635
Semi-closed space(Average)	0.288	0.007	0.000	0.102	0.603
Closed space(Average)	0.246	0.013	0.031	0.178	0.532
Overall	0.278	0.008	0.012	0.112	0.590

If the driver's current gaze point is in Region 5, the probability of the next gaze point still in region 5 is the highest, and the probability of the open, semi-closed and closed landscapes is 0.635, 0.603 and 0.532 respectively, with an average value of 0.590. If the probability value (p_{51}+p_{54}+p_{55}) of the next gaze point moving to Regions 1, 4 and 5, the mean value of the probabilities sum in the three types of landscapes is 0.90, which shows that the probability of gaze shifting from the far ahead to the near left and right sides is small, indicating that the driver pays less attention to the roadside vision when driving normally.

The gaze shift probability of three type landscapes is analyzed by one-way ANOVA. From the test results, it can be found that when the gaze point is located in the Region 5, there is a significant difference in the three type landscapes when the next gaze point is shifted to the Region 4 ($p=0.045<0.05$), indicating that the dynamic adjustment of the gaze point in front of the vision field is different in different landscape. In the closed landscape, the probability of the next gaze region in Region 4 is the largest, which indicates that in the more depressed closed mountainous road landscape, the driver continues to seek useful driving information in the far left and the far right directions, reflecting the driver's desire to escape from this closed landscape.

ANALYSIS OF GAZE STATIONARY DISTRIBUTION

The driver's gaze moves back and forth between different vision interesting areas, and there is a time stay in each vision interesting region. So how to calculate the probability of stay in each region is also a quantitative content to determine the overall distribution. Therefore, the method of Markov stationary distribution is proposed.

Markov stationary distribution is a prediction method. It refers to that after a long time, the probability of gaze points assigned to each region can reach a stable value. After the gaze probability of each region is obtained by using the Markov chain, it is more convenient to calculate the stationary distribution vector of gaze shift according to the probability matrix and other data, so as to obtain the gaze probability of each region.

Markov chain stationary distribution

Set $\{X_n, n\geq 0\}$ be a homogeneous Markov chain, the state space is E, the shift probability is P_{ij}, and there exist probability distribution is $\{\pi_i, j\in E\}$, if Equation (5) is satisfied.

$$\begin{cases} \sum_{i\in E} \pi_j = 1, \ \pi_j \geq 0 \\ \pi_j = \sum_{i\in E} \pi_i p_{ij} \end{cases} \tag{5}$$

Then, $\{\pi_i, j\in E\}$ is the stationary distribution of the Markov chain.

Set Markov chain $\{X_n, n\geq 0\}$, finite state space $E=\{1,2,\ldots,s\}$, if there is a positive integer n_0, so that there is P_{ij}^{n0} for all $i, j\in E$, then the Markov chain is ergodic. At this point, there is Equation (6).

$$\lim_{n\to\infty} p_{ij}^{n_0} = \delta_j \tag{6}$$

The ergodicity of the Markov chain shows that after a period of time, the system reaches a stable state, that is, for a certain state, the Markov chain starts from i at the initial time, and the probability of reaching j is close to δ_j through a long time shift.

According to the nature of the Markov chain, the Markov chain established for the gaze shift of 10 drivers in the driving experiment in this paper is irreducible and non-periodic, so its Markov chain has a stable distribution.

Solution of gaze stationary distribution

According to the definition of the stationary distribution of the Markov chain, the six-variable linear equation system can be established for the one-step shift probability matrix of each driver's gaze, as shown in Equation (7).

$$\begin{cases} \left\{\left[P^T - diag\left(1,1,1,1,1,\right)\right]\right\} \pi = 0 \\ \sum_{i=1} \pi_i = 1 \end{cases} \tag{7}$$

Using the IML program of SAS statistics, it can solve the stationary distribution vector of gaze shift of drivers in different road landscapes. SPSS was used to conduct one-way ANOVA on the stationary distribution of gaze shift in three landscape types, as shown in Table 8.

Tab. 8 - Difference test of stationary distribution of gaze shift

	δ_1	δ_2	δ_3	δ_4	δ_5
p	0.099	0.527	0.280	0.002	0.438
Open landscape(Average)	0.447	0.100	0.112	0.150	0.191
Semi-closed space(Average)	0.418	0.093	0.105	0.189	0.195
Closed space(Average)	0.426	0.122	0.073	0.176	0.203
Overall	0.430	0.105	0.097	0.172	0.196

From the test results, it can be found that all drivers have the highest gaze probability in Region 1, that is, straight front of the vision field. The probability of open, semi-closed and closed landscapes is 0.447, 0.418 and 0.426 respectively, with an average value of 0.430. If the probability values of gaze distribution in Region 1, 4 and 5 are considered at the same time, the average value of the sum of probability in the three landscapes types is close to 0.80, indicating that the main source of traffic information obtained by drivers in the mountainous road landscape is the area in front of the vision field. The gaze constantly shifts between the far ahead and the near ahead to search for traffic information.

When the gaze points are distributed in Region 4, there is significant differences among the three landscapes. The different landscape of the mountainous road affects the driver's gaze on the far right. There was no significant difference in the gaze point distribution of drivers in other regions.

CONCLUSION

The driver's gaze parameters in the mountainous two-lane road landscape are collected in driving experiments. Through the analysis of gaze dynamic shift, the following conclusions are obtained.

(1) When the gaze point is in the straight front, the average probability of no gaze shift in the open, semi-closed and closed landscapes is 0.824, which means that the driver's attention is mostly near the straight front of the vision field no matter what kind of landscape he drives in. This also reflects that the straight front of the driver's vision field is the main vision interesting area.

(2) If the driver's current gaze point is located in near left, the next gaze point is still basically located in straight front and near left, which means that the driver pays more attention to the left and straight front in different mountainous road landscapes.

(3) After the driver's gaze stays near right, the probability of returning to the straight front is high, which verifies that the driver's vision interesting area is mainly in the area in front of the vision field, and that the dynamic attention of the left and right sides in different road landscape is different. The gaze constantly shifts dynamically between the far ahead and the near ahead to obtain the required traffic information.

(4) The open landscape has the highest gaze probability for the straight front area and the near right area. The closed landscape has the highest gaze probability for the near left area and the far left area, while the semi-closed landscape has the highest gaze probability for the far right area. The different landscape types in the mountainous road area affect the driver's gaze on the far right.

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