

ANALYSIS OF VISUAL FIXATION AREAS AND VISUAL TRANSITION CHARACTERISTICS DURING THE DRIVING PROCESS

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ABSTRACT

Traditional analysis methods used for measuring a driver's visual fixation areas are low in accuracy, so to overcome this problem we used dynamic clustering theory in this paper to observe visual fixation areas and to assess the visual field of a driver throughout the driving process. From this a driver's visual transition characteristics was examined using the Markov chain theory. This information was then used to compare the visual habits of experienced and novice drivers.

The cluster results were divided into 6 areas: left side mirror area, left part of the main visual field, middle part of the main visual field, right part of the main visual field, right side mirror area and dashboard area. Using this method, eye movement data from 15 drivers with different driving experience were analyzed. Then with the application of Markov chain theory, transition probabilities from one area to another and Markov stationary distribution of fixation points in each area were calculated. From this we found the transition characteristics in relation to the driver's visual line. The results show that, drivers need to look at the same object long enough to extract sufficient information. All drivers paid great attention (more than 70% of the time) to frontal objects. After using the right side mirror, experienced drivers tended to transit their

fixation points to the left, but novice drivers were more likely to focus on the front area. Experienced drivers paid more attention to the left and right side mirrors and dashboard than novice drivers.

Keywords: driver; eye moment; fixation areas; visual transition; cluster theory; Markov chain.

INTRODUCTION

In recent years, drivers' visual behavior has been widely studied, mainly including the visual search patterns and visual strategies of novice and experienced drivers, the relationship between driver's visual behaviors and these following areas: age, visual defects, workload, vehicle control and operation, and so on.

Some differences were found between novice and experienced drivers in visual search patterns and visual strategies under different levels of cognitive load imposed by different types of road. Experienced drivers had shorter fixation durations and wider spread of search on roads with more information (dual carriageway) than on roads with less information (rural roads), which was the opposite to novice drivers. The results suggested that experienced drivers select visual strategies according to the complexity of the roadway (Crundall and Underwood, 1998). The reason why novice drivers used a shorter horizontal spread of search was studied. Results showed that novice drivers relied more upon their internal mirror than experienced drivers did, even when lane-changing maneuvers required information about traffic best obtained from the external mirrors (Underwood et al., 2002). After training, a driver would produce shorter fixation durations and greater spread of horizontal search, indicating that training could improve a driver's visual search behavior significantly (Chapman et al., 2002). In a similar study, FALKMER and GREGERSEN (2005) compared visual search strategies between experienced and novice drivers, and found that novice drivers fixed their gaze more often upon in-vehicle objects. They spread their gaze less along the horizontal meridian than on relevant traffic cues, and focused more often on objects classified as potential hazards.

Drivers' visual behavior, in relation to vehicle control and operation, has also been widely studied. On both bending roads and straight roads, great differences were found on travel trajectory, distribution of visual angles and visual anticipation between inexperienced drivers and very experienced drivers (Baujon et al., 2001). Sodhi M. (2002) used a Head mounted Eye-tracking Device (HED) to study the effect of various driving tasks on driver distraction, and found that there were two basic eye movement patterns, one in which glances were made between the roadway and the device (radio, rear view mirror, and odometer) and another where the driver was in a state of static fixation on the center of the road. Dukic et al. (2005) studied the effect of a button's location on a driver's visual behavior and safety perception. They found that the visual time off road increased significantly as the angle increased between the normal line of sight and button location for the buttons placed on the centre stack, and that the button located close to the gear stick produced a shorter visual time off road. A similar study found that when pushing the buttons old drivers spent significantly more visual time off road than young drivers (Dukic et al., 2006).

Research has shown that age is a primary factor in the effect upon a driver's visual behavior. Old drivers had more fixations and shorter saccades than young drivers, although the average fixation durations remained the same. Furthermore, old drivers allocated a larger percentage of their visual scan time to a small subset of areas, whereas young drivers scanned more evenly (Maltz and Shinar, 1993). A study on the visual habits of professional truck drivers was carried out. This included a basic eye examination, assessment of visual fields, adaptation to darkness, contrast sensitivity, color vision and glare sensitivity. It was found that the visual acuity of some drivers was lower than that required for a professional driver's license (Mäntyjärvi et al., 1998). However, some studies revealed that there was a non-significant trend towards older drivers having more accidents per distance driven, which was contrary to the opinion that increasing age would cause higher risk (Hakamies-Blomqvist et al., 2002). Besides, Becic et al. (2008) found that with instruction and minimal practice, older adults could improve search strategies.

Eye movements of drivers with visual field defects were also widely studied. The visual search strategies of drivers with cerebral palsy (CP) were less flexible than drivers without CP (Falkmer and Gregersen, 2001). Drivers with peripheral field defects required more fixation points, longer search times and had shorter fixation durations than normal drivers. Drivers with central field defects also performed less well than normal drivers (Coeckelbergh et al., 2002).

Workload affects a driver's visual behavior to some extent. As the visual task becomes more difficult, drivers look at the display for longer periods, and for more varied durations, leading to a decrease in focus upon the centre of the road. Furthermore, average fixation duration on curved sections is significantly shorter than that on straight sections (Victor et al., 2005).

Some research was carried out to study the relationship between a driver's visual fixation area and traffic facilities. Shinoda et al. (2001) tested a driver's ability to detect Stop signs in a virtual environment and found that visibility of the signs required active search, and that the frequency of this search was influenced by learnt knowledge of the probabilistic structure of the environment. A study of a driver's eye movement on motorways revealed that on the whole drivers spend 80% of their time looking into an area in front of them, and on average, looking away from it for around 0.65 of a second at a time. In addition to variations between subjects, factors such as road section were found to contribute to variation. However, no firm dependence on traffic flow was found (Brackstone and Waterson, 2004).

In regard to driver assistance systems, Fletcher et al. (2003) used a CeDAR (Cable Drive Active Vision Robot) head camera and faceLAB cameras to develop a system to help drivers to spot pedestrians, check information in their blind-spot, and to detect traffic signs.

METHOD

Test Road Sections

A 16.19 km long city road section passing a business district, school, scenic site, community and market was selected for the test. The selected section has the typical characteristics of city roads with heavy traffic and many crosswise disturbances by pedestrians and vehicles, including intersections, overpasses, normal city roads and fast trunk roads.

Participants

At present, there is no definite criterion to differentiate between drivers' proficiency levels. Driving experience is represented indirectly by driving distance. In total fifteen participants (13 male and 2 female) from Xi'an city were recruited for this experiment, with driving experience ranging from 2 thousand to 1 million kilometers. Nine subjects whose driving distances covered less than 50 thousand km were classified as novice drivers, and the other six as experienced drivers (see Table 1).

Table 1 Participant number and driving distance

Driver Number	01	02	03	04	05	06	07	08	09
Driving Distances (thousand km)	15	40	10	50	30	12	20	4	2
Driver Number	10	11	12	13	14	15			
Driving Distances (thousand km)	600~1,000	50~100	100~300	50~100	100~300	300~600			

Materials and Apparatus

Eye movements were monitored and collected with a sampling rate of 500 Hz using a head-mounted eye tracking system EyeLink II (SR Research Ltd., Canada). The sample rate of this eye tracker can be set to 250 Hz or 500 Hz, we chose 500 Hz for this experiment. A 7-seater commercial car (JAC Motor, Model Refine, with manual gearbox) was used for the experiments.

Procedure

All participants were fitted with the eye-tracker, after which calibration and validation of the equipment were done using 9 points on the PC monitor. We tried to keep the traffic volume, weather and light intensity the same, and told the participants the experiment routine in advance, and told them to drive as normal.

DETERMINATION OF VISUAL FIXATION AREAS

Traditional Methods

Traditional methods divide the field view rigidly. Underwood et al. (2002) classified field view into nine non-overlapping visual areas. FALKMER and GREGERSEN (2005) divided the driver's visual field roughly into three areas based on right hand drive vehicles. Brackstone and Waterson (2004) classified the visual plane into five regions based around the positions of windshield, side mirrors, rear mirror and dashboard. These were labeled as LEFT, AHEAD, RIGHT, TOP and DOWN. However, Victor et al. (2005) confined the visual plane to a 20° (horizontal) \times 15° (vertical) rectangular area in their study.

The methods discussed above are easy to implement and statistical analysis can be achieved without too much effort, but the results have low accuracy readings and poor credibility. That is because these methods are based on the hypothesis that a driver looks forward during the driving process, with no head rotation. However, a driver always moves his head to fix his gaze upon objects when driving. A driver uses a combination of head rotation and eye movement especially

when looking at objects on both sides. Additionally, the accuracy of readings is also affected by drivers' different visual fixation habits, height of seat and structure of windshield.

Use of Dynamic Clustering

As can be seen in Figure 1, point O is the origin of the coordinates. X-axis is the intersection of horizontal visual plane and vertical visual plane, with right movements resulting in higher horizontal values and downwards movements resulting in greater vertical values. The line between eye and fixation point is defined as visual line. Values α and β are the visual angles on horizontal and vertical axes separately.

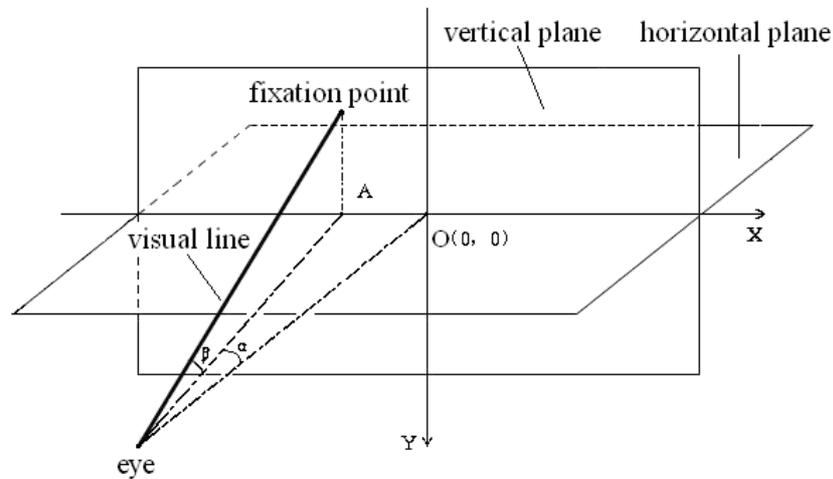


Figure 1 Diagram of eye position in the coordinates

Compared with the methods mentioned above, using the dynamic clustering method to determine visual fixation points is time-saving, has low workload and high accuracy. This method was employed to cluster the fixation points according to their coordinates in the visual field (Yingshi, 2009). The formula of the dynamic clustering method is as follows.

$$d_{ij} = \left[(x_i - x_j)^2 + (y_i - y_j)^2 \right]^{1/2} \quad (1)$$

where:

d_{ij} : the distance between fixation point i and fixation point j

x_i, y_i : the coordinates of fixation point i in the visual plane

Eye movement data is complex and noisy, both in terms of measurement and individual behavior. One of the sources of such problems is the difficulty in deciding on the number of clusters (K). A range of values of K ($K = 5, 6, 7, 8, 9$) were chosen for the dynamic clustering. The 'fastclus' program (SAS statistical software) was employed to execute the dynamic clustering process. Comparison results showed that, when $K = 6$, the clustering results agreed well with the practical conditions. Figure 2 shows the clustering results of one driver as an example. Each number represents a cluster of fixation points, and the same kind of fixation points are presented within the same area.

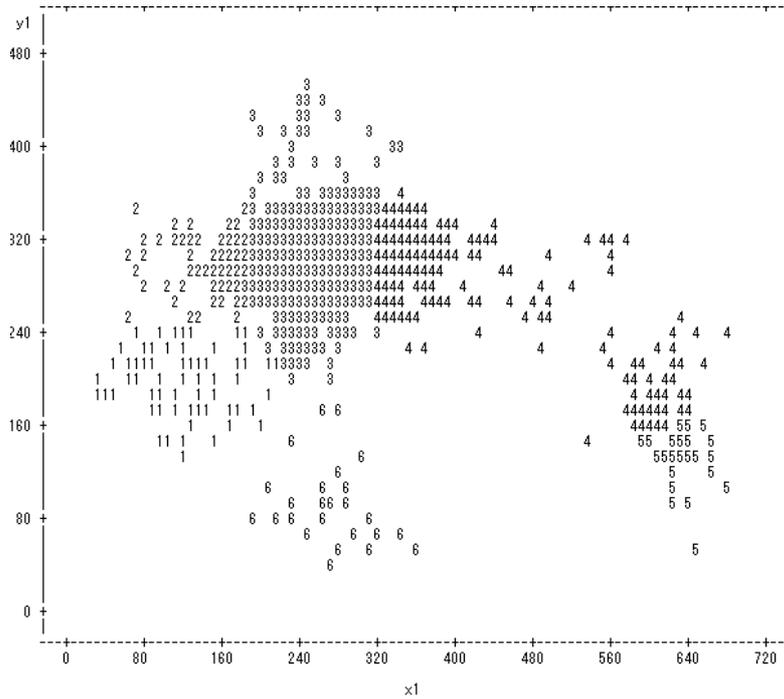


Figure 2 Clustering result of a driver's fixation points ($K=6$)

According to the clustering results, the visual field was divided into six fixation areas, which were area 1 (left side mirror), area 2 (left part of the main visual field), area 3 (middle part of the main visual field), area 4 (right part of the main visual field), area 5 (right side mirror) and area 6 (dashboard area), as can be seen in Figure 3.

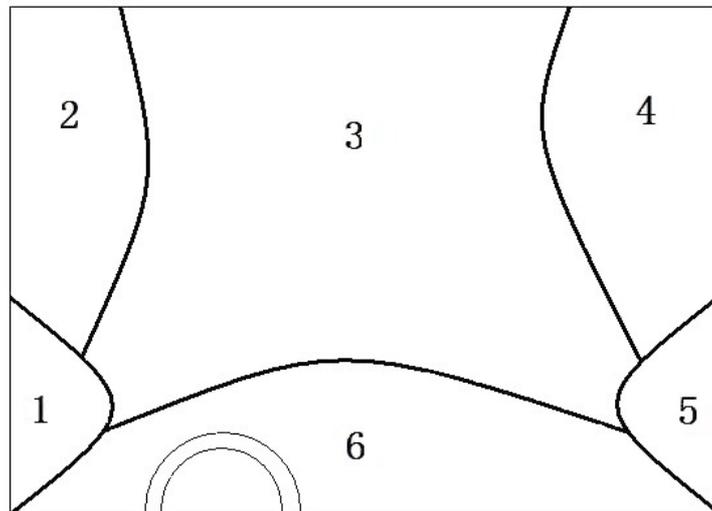


Figure 3 Silhouette plot of dynamic clustering result

To evaluate the accuracy of the clustering results, we counted the fixation objects one by one using video frames from the experiment (see Figure 4), with much workload but high accuracy.

Figure 5 and Figure 6 show the results of counting the fixation objects one by one and the results of dynamic clustering. Comparison of the results indicates that the dynamic clustering method has a relatively high accuracy.

VISUAL TRANSITION

During a driver's visual behavior process, the location of any following fixation point is dependent upon the current fixation point, and has nothing to do with previous fixation points (Yingshi, 2009). Thus, Markov chain theory can be used to solve this problem (Yanan, 2001). The Markov chain, when used for analysis of a driver's fixation points, is discrete in both time and state.

One-step Transition Probabilities

Probability statistics were used to calculate one-step transition probabilities of a driver's fixation points. The basic idea of this method is that the area the fixation points fall in is thought to be a Markov state, and the transition probabilities between each state were calculated.

Value a_{ij} is the transition frequency from area i to area j . For example, a_{11} means the frequency in which both the current and the following fixation points fall into area 1, and a_{13} is the frequency in which the current fixation point in area 1 has its following fixation point in area 3.

Based on the assumption in formula (2), the transition probabilities from area i to area j are shown in formula (3).

$$\sum_{j=1}^n a_{ij} = a_i, (i, j = 1, 2, \dots, n) \quad (2)$$

$$p_{ij} \approx \frac{a_{ij}}{a_i} \quad (3)$$

The average one-step transition probabilities of experienced and novice drivers can be seen in Table 2 and Table 3.

Table 2 One-step transition probabilities of novice drivers

		Next Fixation Area j					
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6
Current Fixation Area i	Area 1	0.471	0.237	0.238	0.040	0.000	0.013
	Area 2	0.022	0.617	0.317	0.033	0.008	0.001
	Area 3	0.005	0.078	0.873	0.039	0.002	0.003
	Area 4	0.102	0.102	0.272	0.490	0.032	0.001
	Area 5	0.007	0.099	0.397	0.071	0.419	0.000
	Area 6	0.008	0.019	0.374	0.012	0.004	0.584

Table 3 One-step transition probabilities of experienced drivers

		Next Fixation Area j					
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6
Current Fixation Area i	Area 1	0.509	0.240	0.204	0.036	0.012	0.000
	Area 2	0.014	0.618	0.249	0.025	0.096	0.002
	Area 3	0.034	0.230	0.673	0.049	0.012	0.002
	Area 4	0.045	0.164	0.231	0.516	0.045	0.000
	Area 5	0.000	0.562	0.108	0.044	0.266	0.000
	Area 6	0.000	0.128	0.339	0.000	0.000	0.534

Analysis shows that the transition of fixation between visual areas had the following rules:

When $i=j$, probabilities p_{ii} show the frequency in which both the current fixation point and the following fixation point fall into the same area i . As can be seen in Table 2 and Table 3, almost all the p_{ii} are the peak values in the same row, showing that a driver has to look at the same object long enough to extract sufficient information before they transit their gaze to other objects or another area.

When $i=1$, the current fixation area is the left side mirror area, so the driver gets information from the rear left area of the vehicle. Value p_{1j} represents the probabilities of fixation points transiting from area 1 to area j . The sum value of p_{11} , p_{12} and p_{13} reaches as high as 94.9%, indicating that a driver uses the left hand side mirror repeatedly. So, particular attention is paid to the left lane and the front area to guarantee driving safety. Significance testing results show that degree of driving experience only has a significant effect on probability p_{15} .

When $i=2$, the current fixation area is the left part of the main visual field, showing that the driver gets information from the left lane. Value p_{2j} represents the transition probabilities of fixation points transiting from area 2 to area j . Value p_{23} is second only to value p_{22} , indicating that a driver will pay particular attention to the traffic situation in front of the vehicle when fixing their gaze on the left lane. Significance testing results show that degree of driving experience only has a significant effect on probability p_{25} . The transition probabilities p_{25} of experienced and novice drivers are 9.6% and 0.8% respectively, indicating that experienced drivers observe the right side mirror to get information from behind the vehicle in addition to observing the left hand side of the vehicle. However, novice drivers seldom do this.

When $i=3$, the current fixation area is the middle part of the main visual field, showing that a driver gets information from the front area of the vehicle. Value p_{3j} represents the probabilities of fixation points transiting from area 3 to area j . Probabilities p_{33} of experienced and novice drivers are 67.3% and 87.3% respectively, indicating that area 3 is the most important and complex area and needs more fixation points. Significance testing results show that degree of driving experience has a significant effect on probabilities p_{31} , p_{32} and p_{33} . Experienced drivers pay more attention to the left hand side mirror and left lane when observing the area in front of the vehicle.

When $i=4$, the current fixation area is the right part of the main visual field, meaning that the driver gets information from the right lane. Value p_{4j} represents the probabilities of fixation points transiting from area 4 to area j . The values of p_{44} , p_{43} and p_{42} are 49.8%, 26.3% and 12.1% respectively, indicating that the driver gets information from the front of the vehicle and the left

lane in addition to this area. Significance testing results show that degree of driving experience has no significant effect on any area when $i=4$.

When $i=5$, the current fixation area is the right side mirror area, observing information from the areas behind and to the right of the vehicle. Value p_{51} represents the probabilities of fixation points transiting from area 5 to area j . Significance testing results show that degree of driving experience has a significant effect on p_{52} and p_{53} . Values p_{52} of experienced and novice drivers are 56.2% and 9.9% respectively, indicating that experienced drivers need to observe the left lane in addition to the right hand side mirror. However, novice drivers still have much to learn in this respect.

When $i=6$, the current fixation area is the dashboard area. Value p_{6j} represents the probability of fixation points transiting from area 6 to area j . Degree of driving experience has no significant effect on one-step transition probabilities in this area. The value of p_{66} and p_{63} are 57.1% and 36.5% respectively, indicating that the driver fixes their gaze on the area in front of the vehicle when observing in-vehicle objects.

Computation and Analysis of Stationary Distribution of Fixation Points

Markov stationary distribution is a method for predicting visual probabilities in regard to a stable value after a long time period. To calculate the one-step probability for each driver, an equation with six unknowns can be established, see formula (4).

$$\begin{cases} \left\{ \left[P^T - \text{diag}(1,1,1,1,1,1) \right] \right\} p = 0 \\ \sum_{i=1}^6 p_i = 1 \end{cases} \quad (4)$$

P is the matrix of one-step transition probabilities between different areas, and state space is $E = \{1, 2, \dots\}$. So the following formula is the one-step transition matrix of the system states.

$$P = \begin{bmatrix} p_{11} & p_{12} & \dots & p_{1n} & \dots \\ p_{21} & p_{22} & \dots & p_{2n} & \dots \\ \dots & \dots & \dots & \dots & \dots \end{bmatrix} \quad (5)$$

The 'Iml' program (SAS statistical software) was used in combination with formula (1) to compute stationary distribution vectors of each driver (see Table 4).

As can be seen in Table 4, all drivers are more likely to have over 70% of their fixation points in area 3, which is the central area of the visual field. And significant testing results showed that novice drivers fixed their gaze on this area more than experienced drivers, with significant differences. Experienced and novice drivers had no differences in fixation distribution in area 1 and area 2, but significant differences were found in area 4, showing that experienced drivers pay more attention to observing traffic information on the right hand side. Furthermore, although no statistical differences were found between area 5 and area 6, the value p was fairly small. This

indicated that certain differences existed between these two areas, experienced drivers fixing their gaze in area 5 and area 6 more than novice drivers.

Table 4 Stationary distribution of driver's visual transition

	Driver Number	π_1	π_2	π_3	π_4	π_5	π_6
Novice Driver	01	0.037	0.078	0.816	0.033	0.031	0.004
	02	0.001	0.144	0.787	0.062	0.000	0.006
	03	0.024	0.024	0.818	0.114	0.011	0.009
	04	0.024	0.121	0.804	0.041	0.007	0.003
	05	0.006	0.050	0.882	0.052	0.002	0.007
	06	0.017	0.046	0.859	0.063	0.006	0.011
	07	0.001	0.109	0.812	0.046	0.017	0.004
	08	0.003	0.058	0.868	0.062	0.005	0.004
	09	0.000	0.042	0.864	0.091	0.002	0.000
Experienced Driver	10	0.026	0.062	0.803	0.086	0.015	0.008
	11	0.000	0.075	0.663	0.227	0.022	0.014
	12	0.022	0.173	0.678	0.080	0.033	0.013
	13	0.000	0.089	0.747	0.070	0.020	0.075
	14	0.020	0.029	0.720	0.217	0.014	0.000
	15	0.000	0.024	0.734	0.221	0.006	0.015

CONCLUSIONS

After comparison of the methods used for determining fixation areas, we see that traditional classification methods have a relatively low accuracy although they are simple to implement. Using the dynamic clustering method has high accuracy and high efficiency.

During a driver's eye movement process, the location of the following fixation point is dependent upon the current one, and has nothing to do with previous fixation points. Thus, the Markov chain can be used to deal with this. And the Markov chain of a driver's fixation points is discrete in both time and state.

Analysis of a driver's one-step transition probability shows that a driver can not extract enough information from only one fixation point. Experienced drivers usually observe the traffic situation on the left of the vehicle as well as the front area, to facilitate overtaking or changing lanes. However, novice drivers have few overtaking and lane-changing behaviors, so little attention is paid to the left lane. All drivers pay a lot of attention to observing the area in front of the vehicle, but novice drivers spend much more time doing this than experienced drivers. Thus, experienced drivers are able to observe other objects in addition to the front area. Experienced drivers tend to transit their fixation points to the left part of the driving lane after observing area 5, so as to fully acquire traffic information on both sides. However, novice drivers are more inclined to transit fixation points to the area in front of the vehicle. They seldom transit their gaze to the left part of the driving lane, so they are not able to gain enough information from the left hand side.

Analysis of the drivers' stationary distribution indicates that all drivers are more likely to have over 70% of their fixation points in the middle part of the main visual field, and novice drivers have a higher fixation probability than experienced drivers. Experienced drivers pay more attention to the right lane, right side mirror and dashboard than novice drivers.

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