Adaptive Positioning on Windshield for Information Display

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ABSTRACT

We propose a method for adaptive positioning of information windows on the windshield of a vehicle for the safe display of information to the driver. The method is proposed for a device that can display information on a windshield. We have conducted a preliminary experiment and the results show that our method can locate the information window at appropriate positions that are less obstructive and easier for the driver to see. The position of the information window changes adaptively as the road scene changes.

KEYWORDS
driver assistance, HUD, information window, windshield

1. INTRODUCTION

The windshield is a good place to show various types of useful information to a driver. The driver can look at information displayed on the windshield with little eye movement and without needing to look at other devices in the vehicle. A head-up display (HUD) is used for this purpose [1]. Some vehicles already have an HUD installed. In addition, applications that assist drivers using the HUD are also being developed [2]. Although HUDs are generally small, some use the whole windshield as a display [3]. However, as the majority of the windshield should be transparent to allow the driver to safely control the vehicle, it is important to consider the position of displayed information. Information placed on the windshield without any consideration to position may disturb the driver. Moreover, the position of the information should be estimated adaptively as the driving situation changes. This study was performed to develop an information display system that does not disturb driving and also realizes visual support for the driver. The adaptive position of the displayed information is estimated based on three criteria: user factors, legal restrictions, and road conditions. We examined the effectiveness of the adaptive positioning system using a driving simulator.

2. ADAPTIVE POSITIONING OF INFORMATION DISPLAY

Figure 1 shows an overview of our system. The HUD is installed in a vehicle (*e.g.*, on the dashboard) and displays information windows. The driver can look at the information window displayed on the HUD as if it exists in front of the vehicle. The display area of the HUD covers the entire windshield. A color video camera is installed in the vehicle to capture the scene in front of the vehicle on video, and the captured images are utilized to estimate the appropriate display position for the information window. However, there are geometrical differences between the driver's view and the captured image. Thus, when displaying the window, it is necessary to adjust for these differences. In our system, it is possible to ignore the differences as the camera is set quite close to the driver's viewpoint.

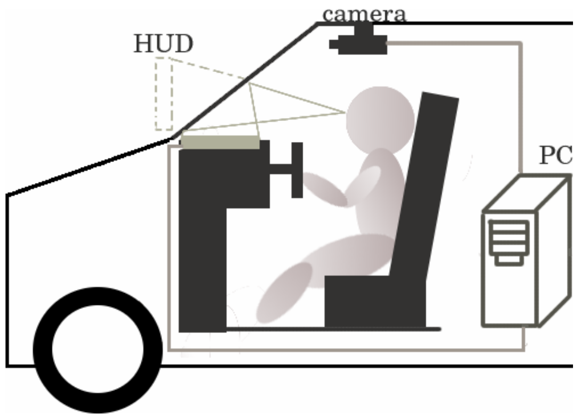

Figure 1 - System overview: The driver can look at both the information window and the road ahead simultaneously via the HUD.

Information provided to drivers can be classified into two categories:

> **Position-dependent information**: The position to display this information has meaning—*e.g.*, information pertaining to a certain object in a scene. In such cases, the information should be displayed on or close to the target object.
>
> **Position-independent information**: The effectiveness of this information does not vary depending of position of display. Examples of such information are maps, vehicle speed, or distance to the destination. We can place this type of information at any position on the windshield.

In this paper, we focus on position-independent information as the position of the former information should not be changed. The shape of the information window is set as a square, because information of any shape can be contained in a square window.

3. APPROPRIATE ESTIMATION OF DISPLAY POSITION

In this section, we describe the method to define and control the position of the information window.

3.1 Criteria to estimate the appropriate position of the information window

An information window should be displayed without interfering with the safety of driving. Thus, the window should be placed at a position where it does not interfere with important information from the road and is easy for the driver to observe. We set three criteria for estimating the appropriate position of information window display: legal restrictions, road conditions, and user factors.

> **Legal Restrictions**: Objects that drivers are required by traffic regulations to observe carefully (*e.g.*, traffic lights and traffic signs). Such objects present essential information for driving, such as prohibition or restriction of certain maneuvers. For safe driving, the information window should not overlap with such information.
>
> **Road Conditions**: Objects necessary for drivers to see to allow driving maneuvers (*e.g.*, vehicles, people, obstacles on/off the road). Displaying the information window over such objects may adversely affect safe driving.
>
> **User Factors**: Physiological characteristics of drivers, derived by eye movement and feelings of discomfort. Increases in eye movements will result in an increase in time taken to understand information. This will increase danger by looking at the displayed information. However, placing the information window immediately in front of the driver where it is not necessary to move the eyes at all may be uncomfortable.

When there are no important objects in the driving scene, the position is estimated only from user factors. If there are some objects in the scene, the position is estimated considering legal restrictions and road conditions in addition to user factors.

3.2 Display position control method

The best display position varies between different driving situations. If the information window is always displayed on the windshield, it is difficult to maintain the same position. Thus, it is necessary to consider how to change the position while best adapting to the driving situation. We propose some methods to handle this problem.

> **(A) Always relocating**: This method always relocates the information window to the best position at a certain interval. This method has the problem that the estimated position can be affected easily by sensing errors, and so it is difficult to stably display the information window.
>
> **(B) Relocating with a stabilization filter**: This method relocates the information window to the best position when the current position is unsuitable for display. The process of determination works as a stabilization filter.
>
> **(C) Setting a priority position**
>
> Sometimes, changing the position of the displayed information window may be uncomfortable for drivers. To solve this problem, we propose a method to set a priority position on the windshield, and fix the information window in this position for as long as possible. The priority position is defined by referring only to user factors. In cases

where the priority position becomes unsuitable for displaying the information window, we provide three types of controlling method:

(C-1) Always display at the priority position: This method always displays the information window at the priority position. Even if the position is not suitable for display, there are no changes to the position with this method.

(C-2) Temporary display ON/OFF: This method displays the information window at the priority position, and does not change its position. When the priority position becomes unsuitable for display, it stops displaying the information window until the position again becomes suitable.

(C-3) Temporary relocation: This method basically displays the information window at the priority position. However, when the priority position becomes unsuitable for display, it temporarily relocates the information window to the best position until the priority position again becomes suitable. It then displays the information window at the priority position. When both the current position and the priority position are unsuitable, it re-locates the information window to the best position.

4. EVALUATION FOR ADAPTIVE POSITIONING

We evaluated our proposed adaptive positioning method using a driving simulator as shown in Figure 2. This simulator consists of a windshield where an information window is displayed and a screen where a driving scene is projected. The size of the projected driving scene is adjusted to be the same size as the real driving scene observed from a vehicle. Thus, the subjects' eye movement in the real driving situation can be reproduced accurately. It is possible to display the information window at any position on the windshield. All experiments were conducted with ten subjects, all of whom had driver license and drive cars in their daily lives.

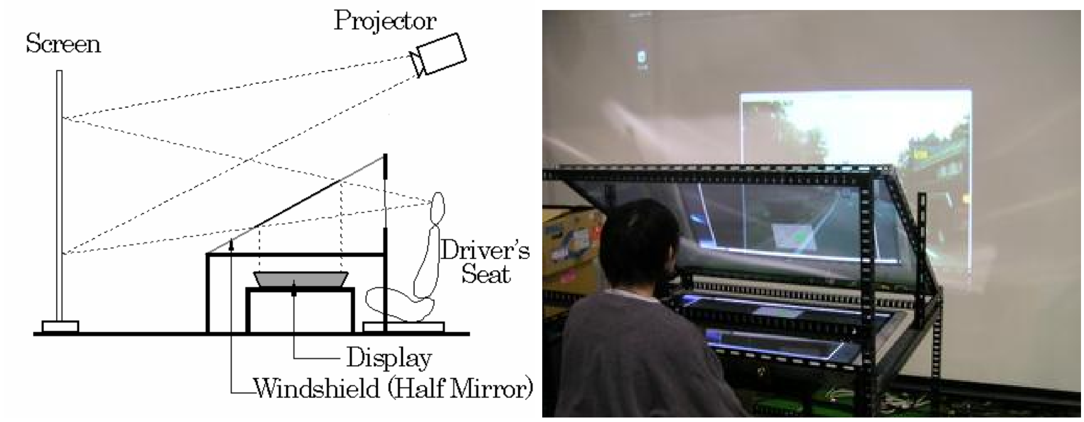

Figure 2 - Driving simulator: This simulator consists of a windshield where an information window is displayed and a screen where a driving scene is projected. It is possible to display the information window at any position on the windshield.

4.1 User Factors

Among the three criteria, only user factors can be estimated in advance because they do not depend on the driving situation. Therefore, we conducted an experiment to examine user factors.

Subjects were shown a driving video on a screen in front of the driving simulator and an information window displayed on the windshield. The subjects evaluated the suitability of the position of the information window at each of 25 positions on the windshield. In Figure 3, the red points show the evaluated positions, and the yellow square shows the information window corresponding to one red point. As described in Table 1, the evaluation was performed with a five-degree evaluation with lower values indicating lower evaluation results. To evaluate only user factors, the video was simple with little change, and did not contain any objects corresponding to legal restrictions or road conditions.

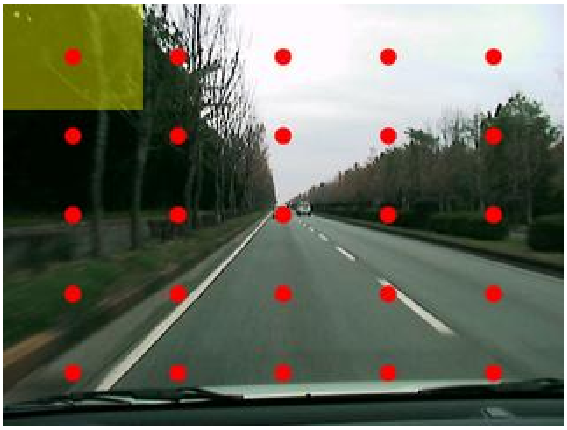

Figure 3 - Driving video: The red points show the evaluated positions, and the yellow square shows an information window corresponding to one red point.

Table 1 - Five-degree evaluation: Lower values indicate lower evaluation results.

Score	
5	No Problem to display the information window
4	…
3	Slight Problem to display the information window
2	…
1	Should NOT display the information here

Table 2 shows the average score of each position corresponding to the red points. The positions with low scores were “just in front of the driver” and “at the corner of the windshield.” The former evaluation was because the window disturbed driving, and the latter was due to the large movement of the line of sight. The highest evaluated position was slightly below the center, which is used in position control method as the priority position.

Table 2 - Average score: The highest evaluated position was slightly below center.

2.1	2.7	3.0	3.0	2.5
2.9	3.8	2.9	3.6	3.3
2.9	3.7	1.9	2.9	3.2
2.6	3.6	3.9	3.8	2.6
2.2	2.8	3.7	3.0	2.2

We calculated the scores of all positions on the windshield by bilinear interpolation. Figure 4 shows a score map whose pixels correspond to those of the driving video. A score of 5 is plotted as the brightest color (white) and a score of 1 is plotted as the darkest (black). The brighter areas indicate more suitable positions for displaying the information window. The yellow rectangle indicates the priority position.

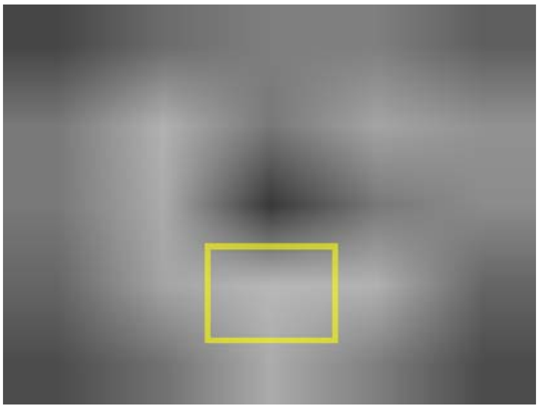

Figure 4 - Score map of user factors: A score of 5 is plotted as brightest color (white) and a score of 1 is plotted as darkest (black). The brighter areas indicate more suitable positions for displaying the information window. The yellow rectangle indicates the priority position.

4.2 Legal restrictions and road conditions

Subjects were shown various kinds of driving video on the screen. An example of the driving video is shown in Figure 5. These driving videos contained objects corresponding to legal restrictions and road conditions. Similar to the experiment concerning user factors, the subjects evaluated the suitability of the position of the information window at each of the same 25 positions on the windshield. They repeated the process with four kinds of driving video.

As the positions of traffic lights or other vehicles vary over time, the driving video was segmented into length of several seconds and each segmented video was repeated multiple times. The evaluation was given at the time of the worst situation. Different from the experiment on user factors, subjects were instructed to evaluate “how bad is it to hide the area” without considering the position or their eye movement.

Figure 5 - An example of driving video with legal restrictions and road conditions

We checked the results in each frame to examine the evaluation value and the objects occluded by displaying the information window. The scores when traffic lights, traffic signs, and other vehicles were occluded by the window are shown in Figure 6. The judgment of overlap was performed manually. Cases with partial overlap were eliminated because they may be unreliable. Overlap on traffic lights had an especially poor score. The average scores obtained in this experiment were used as weighting factors for the criterion when combining the three criteria. V_{light}, V_{sign}, and $V_{vehicle}$ denote the average scores of traffic lights, traffic signs, and other vehicles, respectively.

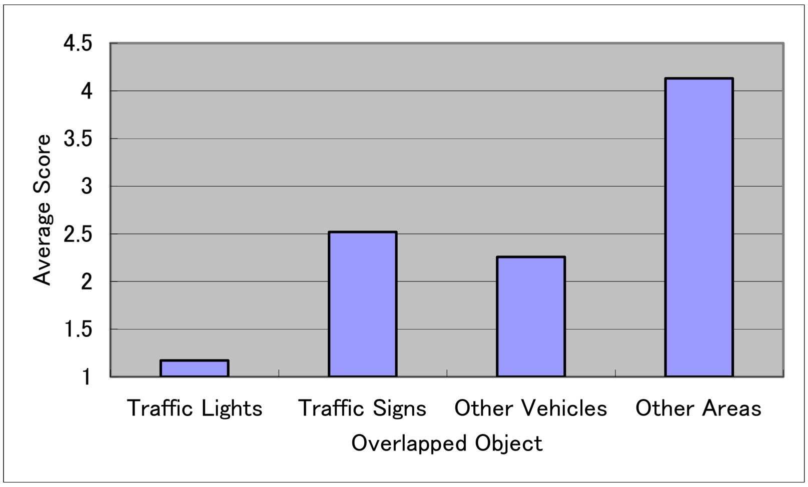

Figure 6 - Average scores of legal restrictions and road conditions

5. POSITION ESTIMATION PROCEDURE

In this section, we describe the method for estimating the position on the windshield taking the three criteria into account.

5.1 Obtain an image of the road scene

A camera captures an image of the scene in front of the vehicle. An example of the captured image is shown in Figure 7. The camera is fixed to capture images from straight ahead of the vehicle, and it is assumed that the driver sees almost the same scene as this image. With this assumption, we calculate the appropriate position for displaying the information window in this image. Pixels with the coordinates (x, y) in the image are denoted by $I(x, y)$. The origin of the image coordinate system is the bottom-left of the image.

Figure 7 - Example of an input image: A driver sees the external scene through the windshield.

5.2 Extracting legal restrictions

To extract regions of traffic lights and traffic signs from the image, we use the HSV color system. For each pixel $I(x, y)$, we check whether the pixel is included in the region of traffic lights or traffic signs, and calculate the score $V_{legal}(x, y)$. For this process, the color distribution data of traffic lights and signs should be collected in advance. The collected colors for traffic lights are green, yellow, and red (color set denoted as S_{light}). The colors for traffic signs are blue, red, yellow, and green (color set denoted as S_{sign}). When the color of a pixel in the captured image belongs to the color set, the score for the pixel is given the average score of traffic light, V_{light}, or traffic sign, V_{sign}, obtained by the experiment in the above section. Otherwise, the score for the pixel is set to 5.

The observed positions of traffic lights and traffic signs are also taken into account, because they are basically set at high positions in the real world. We search for regions of traffic lights and traffic signs at positions elevated above the horizontal line, H_0, in the image. Finally, as shown in Figure 8(a), a score map of legal restrictions, V_{legal}, is calculated. Pixels with a score of 5 are drawn in white, and those with a score of 1 are drawn in black. The black area indicates the presence of an object indicating legal restriction information, and the white area corresponds to positions suitable for displaying the information window.

$$V_{legal}(x, y) = \begin{cases} 5 & if & y \le H_0 \\ V_{light} & elseif & I(x, y) \in S_{light} \\ V_{sign} & elseif & I(x, y) \in S_{sign} \\ 5 & otherwise & \end{cases} \quad (1)$$

5.3 Extracting road conditions

As the road generally has a uniform appearance, few edges or differences between frames would be extracted in the road region. However, if there are any objects, such as vehicles, pedestrians, or signs on the road, their outlines are extracted. We focus on the differences, and extract the objects that express the road conditions using the edges, $E(x,y)$, and inter-frame subtraction information, $F(x,y)$. The Sobel operator is employed for edge detection. When the vehicle is not moving, the values of both $E(x,y)$ and $F(x,y)$ of moving objects become high. When the vehicle is moving, it is not possible to extract other vehicles running in front at the same speed by the inter-frame subtraction value. However, they can be extracted using the edge values. Then, the images of the edges, $E(x,y)$, and inter-frame subtraction information, $F(x,y)$, are added and binarized by the threshold, T. The value of the experimental results regarding road condition, $V_{vehicle}$, is given to the pixel as the representative object of road conditions.

As road conditions are defined as objects on the ground, we consider them at a given height on the image. As tall vehicles can be located at a high position on the image, we do not neglect the upper area completely and give the area a higher score, $V'_{vehicle}$. Then, we obtain a score map of road conditions, V_{scene}. As the image of the edges and inter-frame subtraction is comprised solely of the outlines of objects, we paint out the inner areas, which yields a new score map, V'_{scene}, as shown in Figure 8(b). The score 5 is white and score 1 is black.

$$V_{scene}(x,y) = \begin{cases} V'_{vehicle} & if \quad E(x,y)+F(x,y) > T, y > H_1 \\ V'_{vehicle} & elseif \quad E(x,y)+F(x,y) > T, y \le H_1 \\ 5 & otherwise \end{cases} \tag{2}$$

5.4 Comprehensive evaluation

In addition to the score map obtained by extracting legal restrictions and road conditions, the score map of user factors, as shown in Figure 4, is also used. $V_{user}(x,y)$ denotes the value of the coordinates (x,y) of user factors on the score map. The three score maps are integrated by weighting the sum into one total score map that is used to estimate the position of the information window. As legal restrictions and road conditions are more important than user factors with regard to the safety, the value of user factors is reduced by the weight, W.

$$V(x,y) = V_{legal}(x,y) + V'_{scene}(x,y) + WV_{user}(x,y) \tag{3}$$

The value shows the appropriateness of placement of the information window at each pixel. The total score map, V, is shown in Figure 8(c). The brighter areas are those suitable for displaying the information window.

5.5 Search for the best position

The suitability of display of a square information window on a certain area on the total score map is defined as the sum of each pixel of the area on the map overlapped by the information window.

$$S(xc, yc) = \sum_{j=yc-\frac{h}{2}}^{yc+\frac{h}{2}} \sum_{i=xc-\frac{w}{2}}^{xc+\frac{w}{2}} V(i, j) \tag{4}$$

where (xc, yc) are the coordinates of the center of the information window, and w and h are the width and height of the information window, respectively. Higher scores indicate greater suitability. When the size of the information window is given, the system searches for the best position for display, *i.e.*, the highest suitability score, in the total score map. An example of the best position for an image of 640×480 pixels with an information window of 160×120 pixels is shown in Figure 8(d).

5.6 Display of the information window

When the current position has a lower suitability score than a certain number of other positions, the current position is defined as unsuitable for display. We consider suitability to be a relative relationship with the other evaluation values. If there are many other areas with higher scores, the subject evaluates the position as unsuitable, regardless of the absolute suitability score. On the other hand, if the position has the highest score, the position is always evaluated as suitable regardless of the absolute score. Therefore, we used a relative score in the present study.

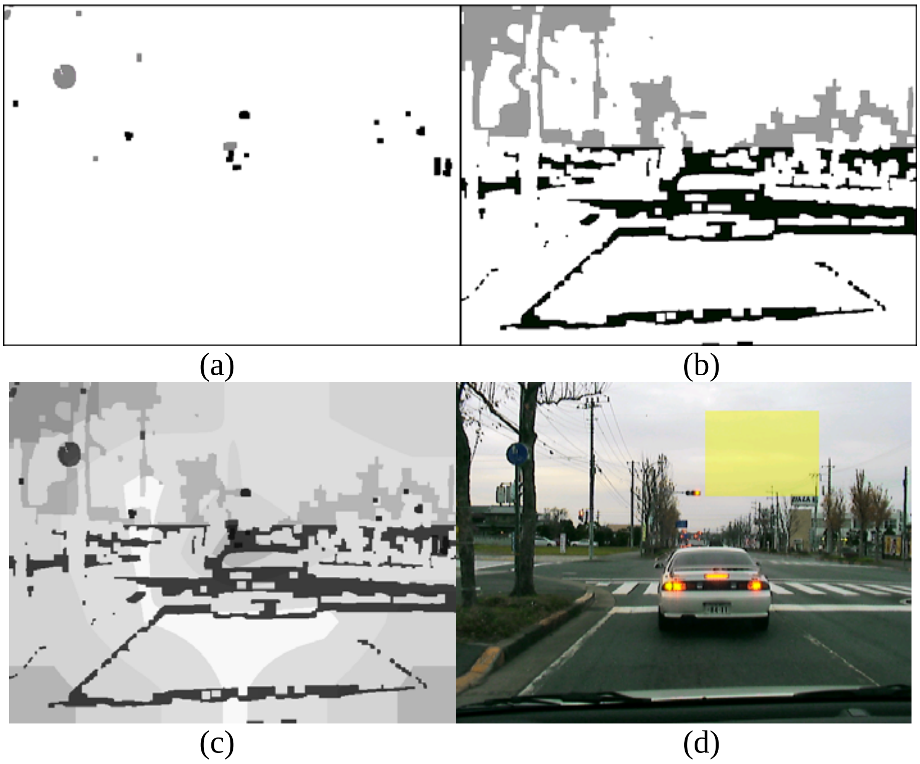

Figure 8 - Position estimation process: (a) score map of legal restrictions, (b) score map of road conditions, (c) total score map integrating (a), (b) and the score map in Figure 4, (d) an example of the best position.

6. EXPERIMENTS ON POSITION CONTROL METHOD

We performed an experiment to examine the position control method of the information window. Subjects were shown a driving video with an information window whose position changed based on each position control method. The subjects were asked to answer the questionnaire shown in Table 3. The evaluation was made using the criteria described in Table 4.

The results are shown in Figure 9. "Always relocating (A)" did not have a high score because the position of the information window changed frequently on the windshield and the movement disturbed the driver's concentration. These results indicated that unnecessary changes in position should be avoided. "Relocating with a stabilization filter (B)" had a higher score because of the low frequency of position change. However, this method sometimes keeps the current position when a more suitable position is available. Thus, appropriate adjustment of the threshold is necessary. "Always display at the priority position (C-1)" had a higher score than the first two methods even though it sometimes overlapped with the vehicle in front. As this method does not change the display position, there was no evaluation for Q2. "Temporary Display ON/OFF (C-2)" and "Temporary relocation (C-3)" had higher scores. These methods solved the disadvantage of "Always displaying at the priority position" by not displaying at unsuitable positions. These results indicated that the position of the information window did not disturb driving, but the evaluation changed significantly depending on the position control method used.

The frame rate of all processes, from capturing the image to displaying the information window, was 3 [fps] using a notebook PC with a 2.8 GHz Pentium-4 processor. When the system changes the display position at short intervals, the evaluation value is low. Thus, we consider that the processing frame rate does not affect the evaluation results.

Table 3 - Average score

Question 1	Suitability of the position
Question 2	Appropriateness of moving the information window
Question 3	Comprehensive evaluation

Table 4 - Criteria

5	Good
4	Acceptable
3	Fair
2	Poor
1	Bad

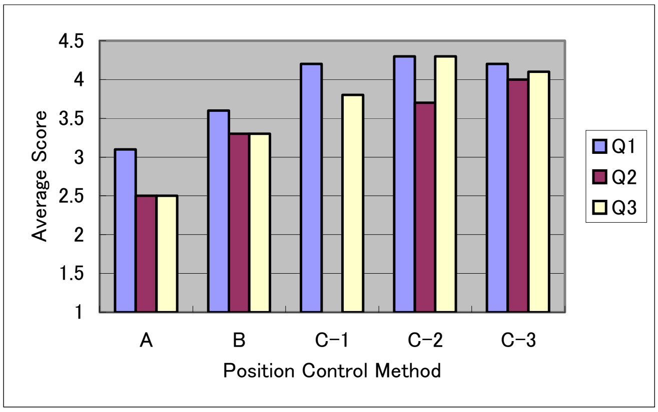

Figure 9 - Average score of position control method

7. CONCLUSIONS

We proposed a method for adaptive positioning of an information window on a windshield. Our method estimates the most appropriate position for window display based on three factors: legal restrictions, road conditions, and user factors. In addition, the window position is changed based on the position control method. With regard to extraction of legal restrictions or road conditions, better extraction results can be obtained by using other research targeting traffic signs or vehicles [4][5]. The experiments reported in this paper differed from real driving conditions in several respects. First, the experiments were performed in a simulation environment, and the subjects did not have to operate the vehicle. It is possible that the results would be different under real driving conditions. In addition, it is possible that the results would be different under different traffic conditions, *e.g.*, when the priority position is frequently unsuitable, such as in traffic jams or in urban area. Therefore, further experiments are required using a real vehicle with varied driving scenes.

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