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16. Abstract

This report examined whether and how vehicle headlamp vertical aim affects a camera-based lane departure warning system (LDWS). It was observed during a field operational test involving 16 passenger cars that different vehicle headlamps had different vertical aim, and that the aim values were related to differences among the vehicles in lane tracking accuracy by the LDWS. As might be expected, the relationship existed for night driving but not for daytime driving. A follow-up test was conducted in which headlamp aim was systematically varied on one vehicle and lane tracking accuracy was examined. Lane tracking accuracy was affected by headlamp aim on surface streets, but was uniformly high on freeways. As in the field operational test data, the lane tracking system had higher accuracy when headlamps were aimed lower, which provided more illumination in the near foreground (the part of the roadway within the field of view of the camera), and may thereby have improved images of the lane lines. The fact that headlamp aim affected accuracy on surface streets but not on freeways may be due to differences in the quality of lane lines, which may be more marginal on surface streets. The effects reported here suggest that, as the use of automotive camera systems grows, it may become increasingly important to consider how the design of vehicle lighting systems might be used to optimize the performance of camera systems.

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Introduction

In-vehicle lane departure warning systems (LDWS) are intended to warn drivers of potential traffic hazards and to help drivers maintain safe performance, such as driving within the traffic lanes. The operation of an LDWS involves detecting lane markings ahead of the vehicle, monitoring the vehicle's position in the lane, and warning the driver when the vehicle is departing from the current lane without turn signal activation.

A current LDWS is typically camera-based, with a small video camera mounted on the vehicle's windshield. The camera produces video images of the upcoming roadway up to a certain distance. Algorithms within the LDWS interpret the video images of the lane lines to estimate the vehicle state (e.g., lateral position and speed) and roadway characteristics (e.g., lane width and road curvature). The systems issue warnings to drivers when they begin to depart a lane while travelling above a certain speed threshold and without activating a turn signal.

The lane tracking accuracy of a camera-based LDWS is subject to many vision-related factors, such as quality of lane markings and road surface conditions. At night, headlamp intensity may be another factor influencing LDWS performance. Vehicle headlamp beam patterns are composed of areas with different intensity levels. Figure 1 is an isocandela diagram depicting the beam pattern of a low-beam lamp on a 2006 Honda Accord (the type of vehicle discussed in this report). The blue dot marks the angular location of highest light intensity, which is about 1° below and 2° to the right of the optical axis of the lamp. That displacement is intended to protect the eyes of oncoming drivers from glare. In a typical meeting situation on a two-lane road, eyes of oncoming drivers would usually appear just above and to the left of the optical axis. The concentric curves show the progressive decrease in light intensity at angles outward from the point of maximum intensity.

Variations in the vertical aiming of headlamps may result in major changes in light intensity on road surfaces in front of the vehicle. Those differences can affect driver vision in important ways. This report is intended to evaluate whether LDWS performance can also be affected by headlamp aim. We first report on relationships between headlamp aim and LDWS accuracy of lane tracking that were noticed in data from a field operational test that had been conducted for independent reasons. We then report the results of a follow-up study in which headlamp aim was systematically varied on one test vehicle and the resulting effects on LDWS performance were measured. We hypothesize that LDWS lane tracking works better with more light (higher intensity) in the field of view of the camera. We also evaluate the effect of roadway type, which is likely related to quality of lane markings, and the interaction of roadway type with headlamp aim.

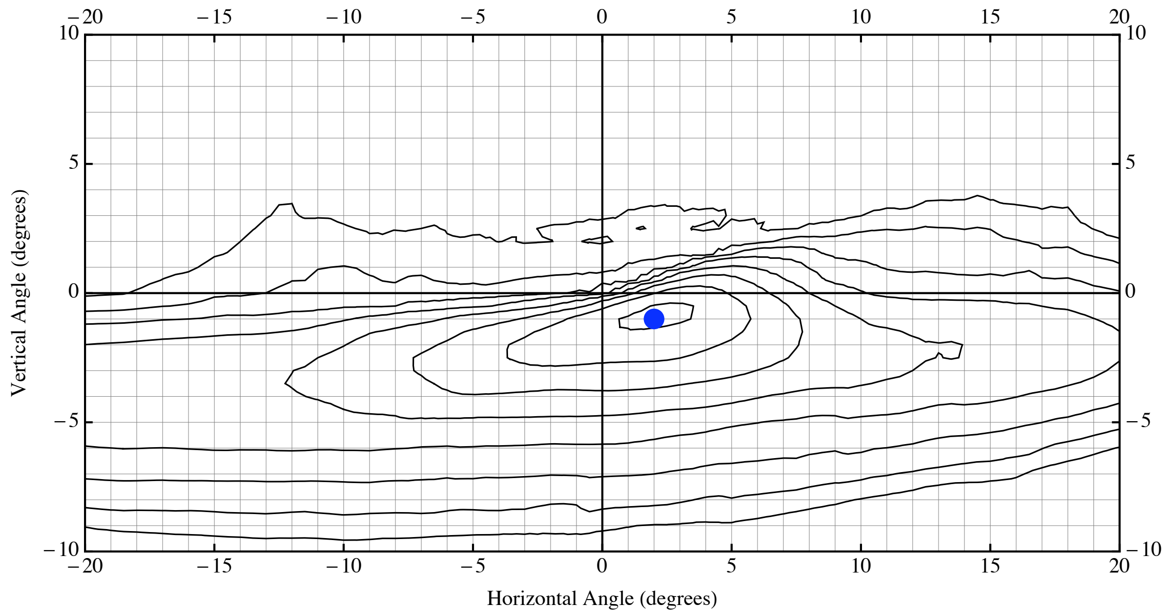

Figure 1. Isocandela diagram for the low-beam headlamp on a 2006 Honda Accord. The blue dot marks maximum beam intensity. Intensity values for contours are (from center): 20,000, 10,000, 5,000, 2,500, 1,200, 600, 300, and 150 cd).

Data From a Field Operational Test

In a recently completed field operation test of safety systems (Integrated Vehicle-Based Safety Systems, IVBSS) by Sayer and colleagues (Sayer et al., 2010), 16 instrumented test vehicles were driven a total of approximately 342,000 km (213,000 miles) by 108 randomly selected drivers. All 16 test vehicles were 2006 Honda Accords and were equipped with an integrated warning system that included four functions: lane departure warning, lane-change and merge warning, forward crash warning, and curve-speed warning. Over the course of about one year of data collection, each vehicle was assigned to about 7 drivers, to be used freely as a personal vehicle for a 40-day period for each driver. The drivers were balanced among three age groups (20 to 30, 40 to 50, and 60 to 70 years old); each age group had equal numbers of men and women.

The LDWS in the IVBSS project used a video camera mounted on the vehicle's windshield; the tracking area extended from approximately 8 to 15 meters ahead of the vehicle. The boundaries of that range correspond approximately to downward angles of 5.7° and 2.8° from the positions of the headlamps, which were mounted approximately 1.5 m forward of the camera and 0.65 m above the ground. The relationship of those angles to the light output of the lamps can be determined from Figure 1. The area of pavement that was in the field of view of the video camera was close enough to the front of the vehicle to be below the most intense parts of the headlamp beam pattern. One consequence of this is that downward aim of the lamps would tend to increase illumination of that area.

The headlamp vertical aim on both the left and right sides for each vehicle was measured multiple times during the test period, and those measurements were reasonably stable. The aims for the right and left lamps of each vehicle are shown in Figure 2. The lamps tended to be aimed high (positive values), and there was a moderate correlation between the aims of the left and right lamps on the same vehicles. Because the two lamps on individual vehicles were often at different aims, and because we expected that lower aim would result in greater illumination of the area of the pavement corresponding to the field of view of the camera, we expected that the lower of the two headlamp aims on each vehicle might be most closely related to lane tracking performance.

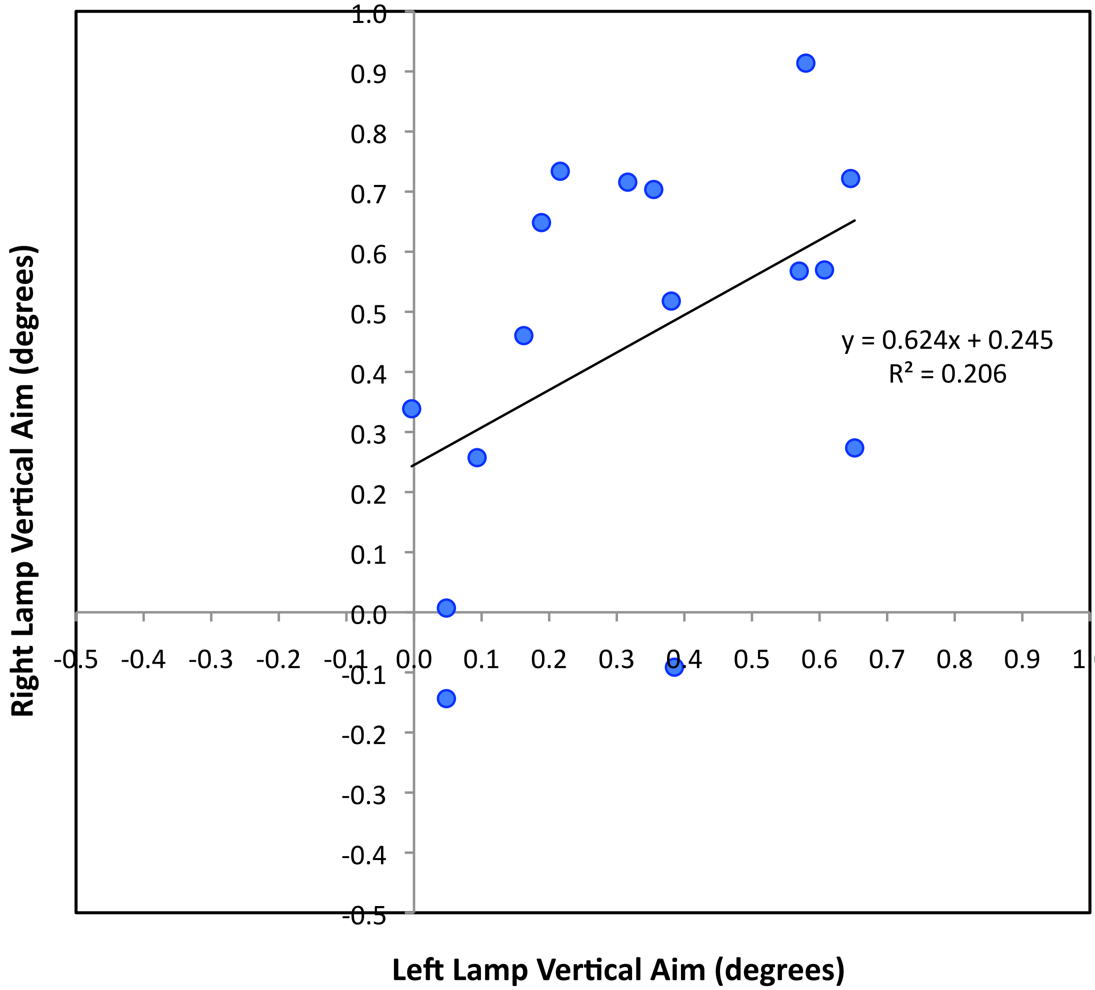

Figure 2. Vertical aim (positive values are upward aim) for the left and right headlamps of the 16 test vehicles. Each vehicle corresponds to one point.

Linear regression was used to examine how the LDWS tracking accuracy from the IVBSS project varied with headlamp vertical aim (Proc Mixed procedure in SAS 9.2). The dependent variable was lane tracking accuracy defined as the proportion of time the LDWS indicated 100% confidence of accurate tracking. Independent variables included time of day (daytime or nighttime) and road type (freeways or main surface streets; minor surface streets were not included). Nighttime was defined as the period from the end of evening civil twilight through the beginning of morning civil twilight, i.e., the period when the sun is 6 or more degrees below the horizon. The lower of the two vertical aims for each vehicle was included in the regression model as a continuous independent variable.

Tracking accuracy varied by roadway type. The average of tracking accuracy on freeways was significantly higher than on surface roads, $F(1, 15.7) = 1114.5$, $p < 0.0001$, with an average accuracy of 0.93 observed on freeways and 0.59 on surface roads. There was a significant interaction between headlamp aim and time of day, $F(1, 17.1) = 4.60$, $p < 0.05$. Figure 3 shows the nature of that interaction. During the day, lane tracking accuracy was not related to headlamp aim, whereas at night it was lower for vehicles with higher headlamp aim. The lack of an effect of headlamps during the day is as expected, because the headlamps, even if they were on, would have little effect on the overall illumination of the roadway. Furthermore, because the camera field of view was below the most intense portions of the headlamps, it may be that downward lamp aim increased the light available to the camera, which may have improved images of the lane lines.

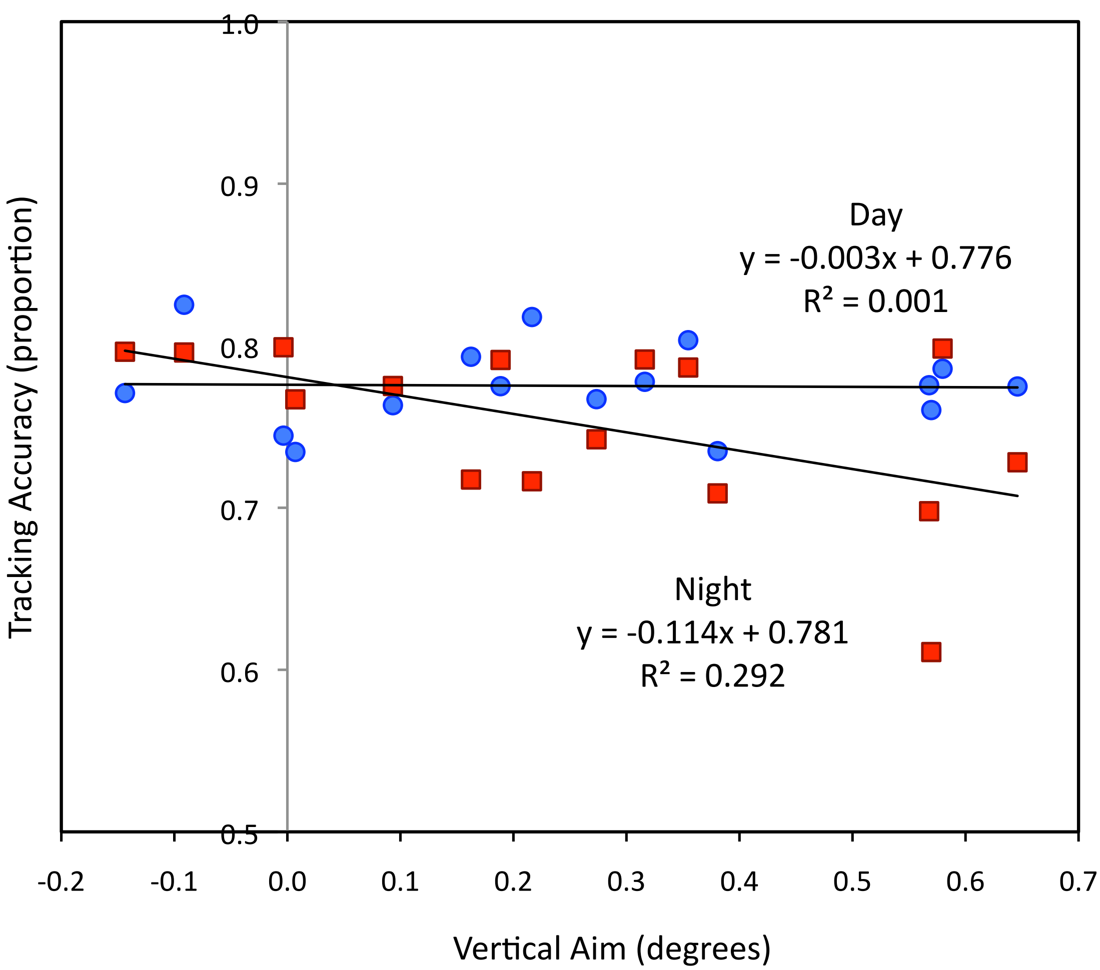

Figure 3. Headlamp vertical aim (positive values are upward aim) and lane tracking accuracy during day (blue circles) and night (red squares) for each of the 16 vehicles.

Follow-Up Test With Systematic Headlamp Aiming

In the field operational test data, LDWS tracking accuracy varied with vehicle headlamp vertical aim, being less accurate at night with higher lamp aim. The fact that headlamp aim and time of day interacted in the way one would expect—the relationship with aim was seen at night but not during the day—supports the conclusion that headlamp illumination was responsible for the differences in LDWS tracking. However, because headlamp aim was not experimentally controlled, there were potentially many confounding variables that might have led to the observed relationship as well. To provide an experimental test of the effects of headlamp aim, we conducted a follow-up test with one of the vehicles from the field operational test.

Methods

In this test, an UMTRI researcher drove one IVBSS test vehicle multiple times along a predefined route in the Ann Arbor area. As shown in Figure 4, the total driving route was about 32 km (20 miles) with about on third being a freeway segment (shown in green) and about two thirds being surface streets (shown in red). The driver drove the vehicle over the route five times, once with each of five headlamp vertical aiming conditions: +0.5º, 0º, -0.5º, -1º, and -1.5º (with positive values corresponding to upward aim). All the drives were conducted late at night with limited traffic on the roads. The dependent variable was lane tracking accuracy defined as in the field operational test data, as the proportion of time that the LDWS indicated 100% confidence of accurate tracking. Independent variables included road type (freeway or surface streets) and the five levels of headlamp vertical aim.

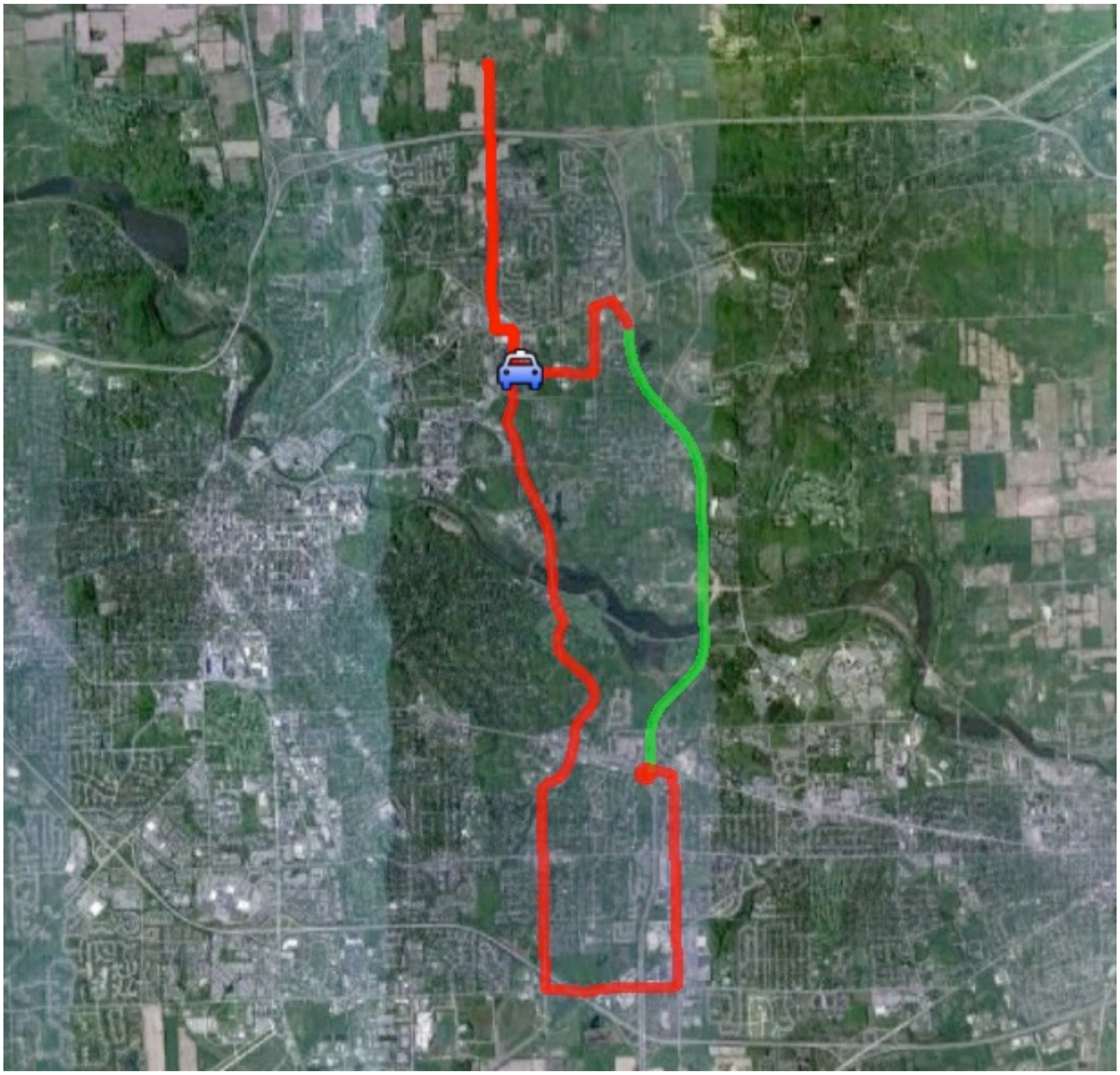

Figure 4. Map of the test route, showing sections of freeway (green) and surface streets (red).

Results

Table 1 summarizes the average lane tracking accuracy across the five vertical aim conditions and the two road types, and the same results are shown graphically in Figure 5. Overall, higher aim led to lower tracking accuracy. As in the field operational test data, tracking accuracy on freeways was substantially higher (0.985) than on surface streets (0.800). Tracking accuracy on freeways was uniformly high for the five aim levels (all within a range of 0.967 to 0.995), whereas a significant aim effect was observed on surface streets, $F(1,3) = 40.5$, $p < 0.01$, as shown in Figure 5. Lane tracking accuracy decreases with higher aim. When driving on surface streets, tracking accuracy was 0.844

with the lowest level of headlamp aim (-1.5º), whereas it was 0.749 with the highest level of headlamp aim (+0.5º). These results suggest that headlamp vertical aim does have an effect on LDWS system performance when driving on surface streets. The differences between freeway driving and surface-street driving may be caused by differences in lane line quality, with lane marks on freeways in a better condition than the ones on many surface streets. Perhaps lowering headlamp vertical aim, and the resulting increase in foreground illumination, can partially compensate for low-visibility lane lines.

Table 1. Mean lane tracking accuracy (proportion) by headlamp aim and road type

Vertical aim	Road type		Overall
	Freeway	Surface	
0.5°	0.988	0.749	0.868
0.0°	0.967	0.784	0.876
-0.5°	0.995	0.786	0.890
-1.0°	0.986	0.835	0.911
-1.5°	0.990	0.844	0.917
Overall	0.985	0.800	0.892

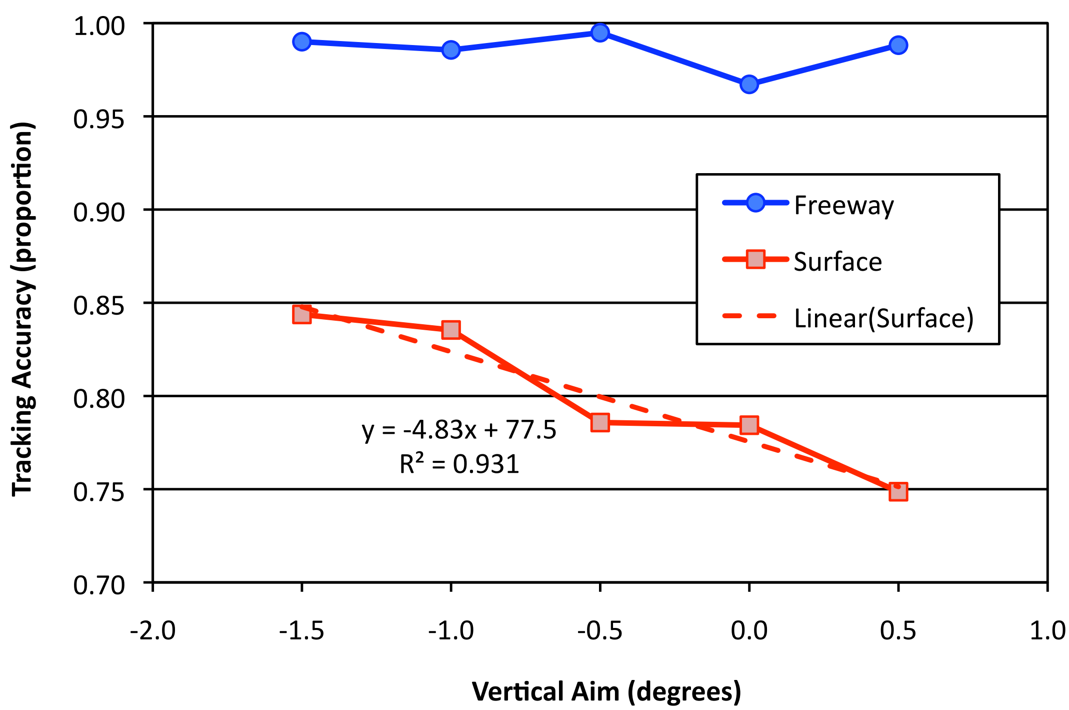

Figure 5. Mean tracking accuracy with varying vertical aim for the two roadway types.

Conclusions

Both the data from the field operational test and the follow-up test indicate that lower headlamp aim is associated with higher lane tracking performance with the LDWS used here. The hypothesis that the higher performance is attributable to increased foreground light resulting from lower headlamp aim could be further tested by more specific manipulation of the illumination of the field of view of the camera. However, any additional testing should probably include the real-world characteristics of the roadway and traffic environment that were used here (e.g., actual roads with a variety of lane markings, driving speeds typical of actual traffic).

In some applications, camera systems offer better performance than human vision, and it may often be possible to make camera systems perform at levels of sensitivity and image quality that make them virtually independent of variations in vehicle lighting. However, the effects reported here suggest that may not always be the case. As the use of automotive camera systems grows, it may become increasingly important to take into account camera performance, rather than just human vision, in the design of vehicle lighting systems. Backup cameras, for example, are designed to cover areas immediately behind a vehicle that are not directly visible to drivers, but the illumination from backup lamps has traditionally been intended to cover areas further from the vehicle, that a driver can see directly.

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