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A Method for Measuring the Field of View in Vehicle Mirrors

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ABSTRACT

A new method is presented for physically measuring drivers' field of view in rearview mirrors. A portable coordinate measurement apparatus (FARO Arm) is used to measure the mirror locations, contours, and curvature. Measurements of the driver's head and eye locations while looking into each mirror are also made. Raytracing is used to map the two- or three-dimensional field of view in each mirror. The method differentiates between monocular, binocular, and ambinocular fields of view, and can account for head movements. This method has been applied to passenger cars, light trucks, and heavy trucks to document how drivers aim their mirrors during normal use.

INTRODUCTION

Mirror field of view (FOV) is important in the consideration of improvements to current mirror systems. Smith et al. (1985) field-tested experimental mirror systems on commercial vans and concluded that the addition of the passenger side convex mirror aided in the reduction of crashes. Several studies conducted in the late 1970's and early 1980's relied on a range of FOV measurement techniques to map the FOV of mirror systems and found strong differences across designs in the fields of view.

Burger et al. (1974, 1980a, 1980, 1987) used photographic and object-sighting techniques to measure both direct and indirect (mirror) FOV. In the photographic approach, the reflection in each mirror of a target grid external to the vehicle was photographed by a camera positioned at a typical driver eye location. Object-sighting techniques were used in a study of blind zones around the right front of heavy trucks. A "standard observer" sat in the driver seat and viewed a grid placed on the ground to the right, rear, and forward of the vehicle (Burger et al. 1980a). The standard observer interacted with an experimenter outside the vehicle to map the direct and indirect FOV. Burger et al. (1980a) also used a simple analytical approach to define the closest viewable point to the right of the truck cab. A line constructed in rear view from the driver's eye through the top of the passenger door windowsill was used to determine vertical FOV in the adjacent lane.

Haslegrave (1993) described the "light bulb" technique for measuring FOV. The test vehicle is parked in an enclosed laboratory, and one or two light bulbs are placed inside the vehicle at typical driver eye locations. Obstructions in the driver's FOV cast shadows on the walls of the laboratory, defining the boundaries of the direct and indirect FOV. A calibrated grid on the walls of the laboratory is used to calculate the FOV. Although the analysis is simplified by using a single light bulb at a mid-eye (cyclopean) point, placing light bulbs at both the left and right eye locations allows computation of binocular and ambinocular fields of view.

Most studies of mirror FOV have examined the theoretical or maximum possible FOV provided by the mirrors, but few have examined the FOV that drivers actually obtain after adjusting the mirrors on their vehicle. Olson et al. (1985), as part of a larger study of vehicle characteristics relating to crash avoidance, used a pole-sighting method to measure the mirror FOV of drivers in their own vehicles. The horizontal FOV was measured from the first part of the vehicle visible to the driver in the mirror to the location of the pole at the outside edge of the mirror. The vertical FOV was measured from the ground plane nineteen feet aft of the mirror. No data are available from this study on eye locations or other vehicle geometry.

Reed et al. (2000, 2001) used pole-sighting techniques similar to those used by Olson et al. to measure mirror FOV for passenger car and light-truck drivers in their own vehicles. In addition, a portable coordinate measurement device was used to measure eye and mirror locations along with vehicle geometry. Raytracing procedures were used to calculate mirror FOV from eye locations and mirror geometry. The FOV calculated by this technique were validated by comparison to manually measured FOV.

This paper gives an overview of this new approach to measuring mirror FOV for vehicles in use. Details of the testing and analysis methods are presented along with an overview of the validation of the method for passenger cars and heavy trucks.

METHODS

Equipment and Facilities

Coordinate Measurement Machine – Coordinate data are recorded using a FARO Arm. Figure 1 shows the FARO Arm being used to record mirror geometry on a heavy truck. The FARO Arm is a multiple-axis articulated arm with a rotary transducer at each of its six joints. The location of the probe tip is recorded by a computer when the operator presses a button. Accuracy of the system is typically better than 1 mm throughout the working volume. Pre-test calibration checks are used to verify operation.

Figure 1. Digitizing a heavy truck mirror with the FARO Arm.

The locations to be measured on the vehicle and driver usually span a volume larger than the working range of the FARO Arm, necessitating movement of the FARO Arm during measurements. Two methods are used to merge the data from multiple measurement positions into a single coordinate system.

The FARO Arm software has a feature for repositioning the arm while maintaining the initial coordinate system called the “leap-frog” procedure. This procedure involves digitizing three datum points with the digitizer in two different locations. The software performs a transformation based on the displacement of the arm and updates the data so that all of the successive points will be recorded in the originally defined coordinate system. This measurement procedure allows the user to make measurements on both sides of the vehicle while maintaining one coordinate system.

One disadvantage to the leap-frog procedure is that the digitizer must be repositioned several times to move from one side of the vehicle to the other. An alternative is to use fixtures that provide reference points accessible on both sides of the vehicle. In laboratory studies of passenger vehicles (Reed et al. 2000, Reed et al. 2001) reference points in known positions with respect to the laboratory coordinate system were located on either side of the vehicle. Digitizing these points after moving the FARO Arm allowed all data to be merged into a common coordinate system for analysis. In a field study of heavy truck mirror FOV, a fixture spanning the width of the cab was placed on the ground beneath the vehicle.

Reference Points – If data are collected with the driver both in and out of the vehicle, reference points on the vehicle may be necessary to allow data from the two conditions to be merged. In the passenger car study, data collected with the driver out of the vehicle were aligned to the driver-in-vehicle condition via reference to a set of three points on the vehicle body structure digitized in each condition.

Measurement Procedures

Body, Head, and Eye Locations – Body landmark locations are digitized as the participant sits in a normal driving posture and looks into each mirror. Landmarks on the head define the eye locations and head position and orientation. For each mirror, the investigator digitizes the participant’s glabella, left infraorbitale, left corner of eye, and left tragion landmarks, as shown in Figure 2. In addition, the right tragion, right infraorbitale, and corner of the right eye are measured in one condition to determine the location of both eyes with respect to the landmarks on the left side of the head. Additional body landmarks are usually recorded to characterize the driver’s posture more fully, including points on the sternum and shoulder. Because drivers often move their heads to expand their mirror FOV, additional measurements can be made while the drivers are asked to simulate particular maneuvers, such as backing or making lane changes.

Figure 2. Locations digitized on the participant’s head: (1) glabella, (2) left infraorbitale, (3) left corner of eye, and (4) left tragion landmarks.

Mirror Geometry – The FARO Arm is used to digitize the perimeter of each mirror, characterizing both the shape and the location of the mirror. For convex mirrors, the radius is measured using a spherometer and the methods described in Federal Motor Vehicle Safety Standard 111. Horizontal and vertical profiles are also digitized to verify the spherometer readings. More detailed measurements would be needed for aspheric mirrors.

Other Vehicle Geometry – In some vehicles, the driver's view of the mirrors is limited by vehicle structure. Digitizing the window openings, mirror housing, and other components that may affect mirror FOV quantifies this obstruction and provides the opportunity to calculate the associated limitations on both indirect and direct FOV.

Calculation Procedures

Eye Locations – Driver's eye locations are calculated in each position using the head landmark data. A head origin is established at the midpoint between the right and left tragion landmarks. The intertragion vector defines the Y axis, the Z axis is defined perpendicular to the plane containing the left and right tragion and left infraorbitale, and the X axis is mutually perpendicular to the Y and Z axes. The eye points are then calculated using the X (fore-aft) and Y (lateral) coordinate of the infraorbitale landmark and the Z (vertical) coordinate of the corner-eye landmark. These eye points lie approximately at the center of the orbit, i.e., the approximate pivot center for the eyeball. The relationship between the two eye points and the glabella, left infraorbitale, and the left tragion landmarks is stored so that the eye locations can be calculated from the latter three points. The midpoint between the two eye points, known as the cyclopean eye, is also calculated.

Ray Tracing and FOV – Using a least-squares approach, planes are fit to the coordinate data from the perimeter of each mirror. Projected (effective) eye points for planar mirrors are calculated by reflecting the measured eye locations behind the plane of the mirror as shown in Figure 3. The effective eye point can be viewed as the perceived location of the eye relative to the indirect visual field. For planar mirrors, rays from the effective eye points through the perimeter of the mirror define the FOV in the mirror. Separate calculations of the FOV are made for the left eye, right eye, and cyclopean eye.

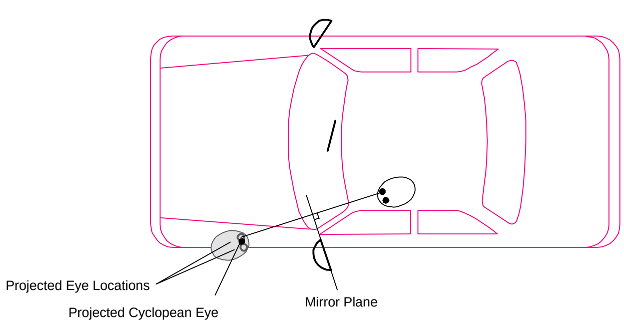

Figure 3. An example of projected eye points.

For spherical mirrors, the radial center of the mirror is calculated by fitting the equation of a sphere to the perimeter points using the measured radius. The FOV is obtained by reflecting rays from the driver's eye point through the perimeter points on the surface of the mirror sphere.

Many software tools provide mirror simulations or other raytracing capability. Digital human modeling tools, such as Jack™ (EDS, Inc.) and RAMSIS™ (Human Solutions, Inc.), include mirror view simulations. In studies at UMTRI, custom software has been written to perform the ray tracing and to calculate fields of view from the measured data.

Validation

These methods have been used in three studies examining in-use mirror FOV for passenger cars, light trucks, mini-vans, sport utility vehicles, and heavy trucks (Reed et al. 2000, Reed et al. 2001). In each of these studies, comparisons were made between the manually measured FOV and the FOV calculated from mirror geometry and eye locations.

In the first study, mirror fields of view for 43 men and women were measured in their own passenger cars. A manual pole-sighting method similar to that used by Olson and Winkler (1985) was used to find the left, right, top, and bottom of the FOV in the left-outside, right-outside, and center-inside mirrors. The methods described in this paper were also applied. A second study using identical methods was conducted with 48 men and women who were tested in their own pickup trucks, minivans, and sport-utility vehicles.

In a third study, the FARO-Arm methods were applied to the measurement of FOV in heavy truck mirrors. As part of the methods development, the manually measured mirror FOV for a heavy truck was compared to FOV obtained with the FARO-Arm technique. Sample results from the validation phases of all three studies are presented below. Additional details are in Reed et al. (2000) and Reed et al. (2001).

RESULTS

Passenger Cars

The validity of the method for calculating FOV by projecting rays from the measured eye locations through the mirror perimeter can be evaluated by comparing the resulting FOV angles with those obtained by the pole-sighting method. The comparison is best made for the outside edges of the horizontal FOV in the side mirrors, since these angles are not delimited by the vehicle. Figure 4 compares the outside edge angles for the left and right mirrors obtained by the two methods. In general, there is strong correlation between the two values (0.86 for the outside edge of the left mirror, 0.90 for the outside edge of the right mirror). The plots in

Figure 4 show that there is some bias in the calculated FOV for each mirror. The outside edge of the left-mirror FOV obtained by the pole-sighting method is an average of 1.5 degrees more outboard than the edge obtained by projecting rays from the driver's right eye location (the right eye has the most outboard FOV in the left mirror). This difference probably results from small driver head movements during the pole-sighting measurement.

The difference in the angular FOV edges in the driver-side mirror for the left and right eye of a driver is typically about 5 degrees. Since the driver's eyes are usually about 65 mm apart, a lateral head movement of only about 20 mm would be needed to produce a change in outboard FOV angle of 1.5 degrees. A bias similar in magnitude but opposite in effect is observed for the right mirror. The calculated outboard edge of the FOV in the right mirror is an average of 2.8 degrees further outboard than the angle measured by the pole-sighting method. Since head movements have smaller effects on FOV in the right mirror than in the left mirror, this difference may be due to image quality degradation at the edge of the FOV in the convex right mirrors.

Light Trucks, Minivans, and Sport Utility Vehicles

The validity of the calculated FOV method using measured eye and mirror locations was similar to the previous study. FOV angles calculated by ray projection were compared with those obtained by the pole-sighting method. The correlation was 0.90 for the left mirror outside edge and 0.95 for the right mirror outside edge. These values compare favorably with the correlation coefficients of 0.86 and 0.90 obtained in the previous study. As in the passenger car study, the mean outside edge angle for the left mirror was slightly smaller than the value obtained by the pole-sighting technique (-10.6 vs. -12.1 degrees), a difference that is probably due to small head movements during the pole-sighting measurements.

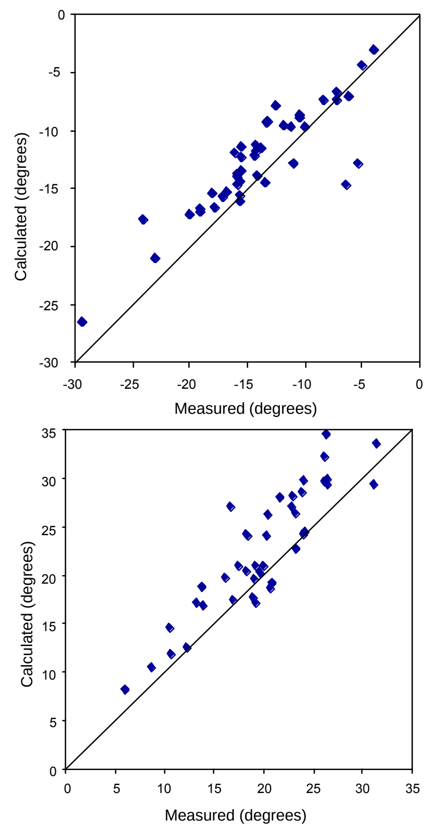

Figure 4. Comparison of FOV calculated using ray projection from measured eye locations and that measured using the pole-sighting technique for 43 passenger-car drivers. The plots show FOV angles measured from the projected right-eye point for the outer edge of the left-mirror FOV (top) and relative to the projected left-eye point for the outside edge of the right-mirror FOV (bottom). Angles are in degrees with respect to the longitudinal axis of the vehicle.

Heavy Trucks

An evaluation of the FARO-Arm method for heavy trucks was conducted using a single cab and driver with the mirrors adjusted to multiple positions. In passenger cars, the mirror FOV can be reasonably represented by the inside and outside edge angles. For heavy trucks, the entire plan-view contour of the FOV is important, particularly for the convex mirrors. For each mirror and mirror aim, the locations of a midsize-male driver's eyes were digitized as described above, along with the perimeters of the mirrors. For comparison, the FOV was also mapped by an investigator who placed cones on the pavement surrounding the truck at the edges of the FOV reported by the driver in each mirror. This process involved iterative communication between the driver and the investigator. The driver was instructed to report the FOV obtained while looking comfortably in the mirror without subsequent head or torso movement. Figure 5 shows the cones outlining the mirror FOV for one mirror aim.

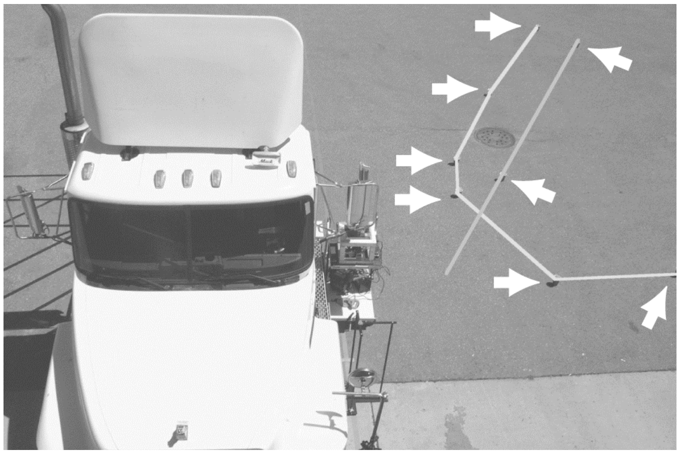

Figure 5. Manually measuring mirror FOV for a heavy truck. Arrows show the locations of cones positioned to mark the boundaries of the FOV in one planar and one convex mirror.

Figure 6 shows the results of calculations for one aiming condition of each of four convex mirrors located on the truck. In the figure, the thick lines show the manually measured FOV on the ground plane and the thin lines show the calculated FOV. As with the passenger-car and light-truck studies, the correspondence between the manually measured and calculated FOV is strong. The largest differences between manually measured and calculated FOV are found in the mirrors closest to the driver, presumably because the effects of head movements in increasing the FOV are greatest in mirrors that are closest to the driver. Figure 6 shows that the method accurately captures the FOV for all four convex mirrors, particularly in the lanes adjacent to the truck.

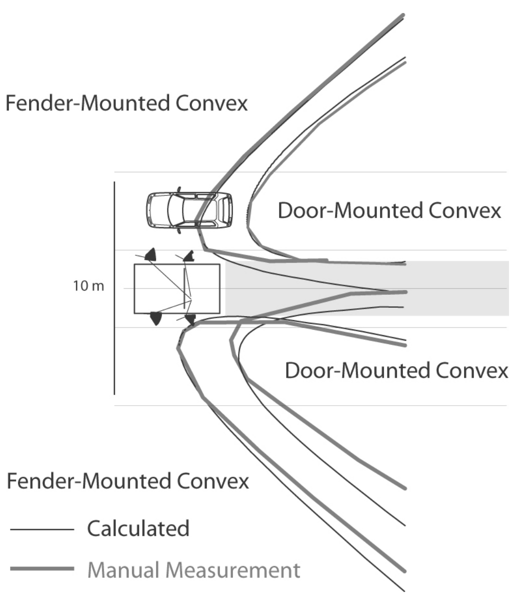

Figure 6. Comparison of manually measured (thick lines) FOV and FOV calculated from digitized mirror and eye locations (thin lines) for four convex mirrors on a heavy truck cab. Three standard lane widths and a midsize passenger car are shown for scale.

DISCUSSION

Since the late 1960s, computerized ray-tracing techniques have been used for estimating the fields of view provided by mirrors (Devlin and Pajas 1968, Haselgrave 1993). Using eye locations calculated from the design eyellipse, the mirror FOV are calculated by tracing rays through the perimeters of the mirrors using specified orientations for the mirrors. However, the FOV that drivers experience in their own vehicles, with their particular eye locations and mirror adjustments, has previously been measured using interactive sighting of targets in the indirect visual field. The methods presented in this paper combine the computerized analysis methods with measurement of actual driver eye and mirror location to obtain accurate measurements of mirror FOV.

The new methods have substantial advantages over traditional manual measurement techniques. The time requirement is slightly greater than that associated with manual measurement of the inboard and outboard edges of the FOV for a passenger car, but the new method provides a true three-dimensional representation of FOV. The advantages of the method are particularly apparent for heavy trucks. The manual recording of the FOV for multiple truck mirrors requires a large open area around the vehicle and several hours of work. In contrast, digitizing the necessary points on the driver and four to seven mirrors can be accomplished in less than 30 minutes with the vehicle parked adjacent to other vehicles. The data can also be used much more flexibly. For example, calculating the plan-view FOV on a plane a certain distance above the ground is trivial.

The primary limitation of the new method is that the digitizing equipment is considerably more expensive than that required for manual measurements. Olson and Winkler (1985), for example, collected their data with little more than a tape measure and a pole. On the other hand, the equipment cost is likely to be a small fraction of the total cost of a large-scale study of mirror FOV.

Another limitation of the new method is that it is not well suited to quantifying the head movements that may be made during driving. Eye locations are recorded separately for viewing each mirror, but the normal, static viewing position is only one of many that are possible. The analysis of differences between the manually measured FOV and that calculated from the digitized data shows largest differences for the mirrors closest to the driver, probably because of head movements during manual measurement. Fairly small changes in head position (~100 mm) can change the driver-side mirror FOV nearly 100% for some passenger cars. Dynamic recording of head movements could be combined with data on mirror aim to calculate how drivers use head movements to expand their effective mirror FOV.

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