A Quantitative Comparison of Operator Field of View for Vehicle Design

M.D. King, Jeffrey Jinkerson, Teena Garrison, Derek Irby and Daniel W. Carruth

Abstract This paper outlines the preliminary application of a quantitative method for assessing field of view using spherical projections of categorical visual information overlaid by occlusion maps based on vehicle geometry. The project goal was to quantitatively assess not only *where* a vehicle operator can see but *what* visual information is available in the operator's field of view. By creating a driving environment dataset coded for visual information, we can indicate the probability of a type of visual information appearing in the operator's field of view in a given vehicle. Next, we overlay probability maps with vehicle and operator eye height-specific occlusion maps, giving us a quantitative representation of visible information. This method was applied to three vehicles: a midsized sedan, a light-duty pickup truck, and a full-sized pickup truck using eye heights corresponding to those of 5th percentile females, 50th percentile females, 50th percentile males, and 95th percentile males.

Keywords Field of view · Driving · Vehicle design

1 Introduction

A key aspect of task performance when operating a vehicle is the ability of the occupant to sense task-relevant visual information in the driving environment. Current methods for quantitatively evaluating field of view in manned ground vehicles allow researchers to assess where operators are likely to look and where

M.D. King (✉) · J. Jinkerson · T. Garrison · D. Irby · D.W. Carruth
Center for Advanced Vehicular Systems, Mississippi State University, Starkville, MS, USA
e-mail: mdk106@msstate.edu

T. Garrison
e-mail: teenag@cavs.msstate.edu

D.W. Carruth
e-mail: dwc2@cavs.msstate.edu

V.G. Duffy (ed.), *Advances in Applied Digital Human Modeling and Simulation*, Advances in Intelligent Systems and Computing 481,
DOI 10.1007/978-3-319-41627-4_2

they are able to see [1, 2]. Recent techniques for evaluation of field of view for manned ground vehicles include the spherical projection of Ray and Teizer [3] and the masking technique of Bostelman et al. [4]. Ray and Teizer's technique presented an automated method for calculating blind spots in construction vehicles. To do this, the cabin or the exterior of the construction equipment was scanned. From these scans, they created a point cloud representation of the equipment, resulting in a map for measuring blind spots. Bostleman et al. developed a masking technique in which they manually masked digital panoramas in a photo editor, giving a representation of what can be seen from the given eye height position. In addition to using scans of vehicles, CAD models can be used for evaluation of field of view [1, 2].

It is intuitive to assume that the less visual information occluded by vehicle geometry, the better able to safely and effectively operate a vehicle one will be. However, this does not account for where in the field of view task-relevant visual information will appear. Using their volumetric technique, Cook et al. demonstrated that a line of cyclists could easily be obscured in a certain location near a commercial vehicle [5]. This type of additional test of whether critical visual information is occluded by vehicle geometry is necessary as a vehicle design with quantitatively greater field of view as determined by analysis of a spherical or cylindrical projection may not be safer or more effective if what is visible is irrelevant to the operator's task.

In this paper, we present an initial application of a proposed method for evaluating the occlusion of task-relevant visual information. The authors are unaware of other methods for quantitatively determining the likelihood that general task-relevant visual information will be visible or occluded by vehicle geometry. We have addressed this by creating probability maps of specific categories of visual information for comparison with maps of the occlusion of the visual field by vehicle geometry.

2 Methods

2.1 *Task-Specific Visual Information*

As previously mentioned, one of the primary goals of this project was the development of a quantitative method for assessing the probability that certain task-specific visual information would appear in the driving environment and where in the operator's field of view that information would likely be present. To address this need, we created a driving environment database using 360°, panoramic, static images. Locations were sampled using GIS software that randomly selected latitude and longitude points within the boundaries of the top 25 most populous cities in the continental United States as defined by US census shapefiles [6]. Images for selected locations were acquired from an online mapping service.

Once acquired, these images were individually coded using digital editing software for the appearance of eight visual information categories relevant to various ground vehicle operator tasks. The current analysis addresses only three of the eight layers: roadway surfaces, navigation signs, and road side vehicles. The roadway surfaces layer includes drivable roadway surfaces (paved or otherwise). It does not include driveways, parking lots, or other drivable surfaces. The navigation sign layer include all indicators of appropriate traffic behavior visible to the driver. These include, but are not limited to speed limit signs, stop signs, traffic cones, and traffic lights. Road side vehicles include all vehicles stopped on or near roadways and certain areas that they may appear: parked cars, parking lots, driveways, and other vehicle entrances to non-roadway areas.

2.2 Occlusion Maps

As mentioned briefly in Sect. 1, Bostelman et al. developed a physical method for creating panoramic occlusion maps [4]. Using “a standard Red, Green, Blue (RGB) camera and a motorized camera mount,” they obtained images from the driver’s perspective in construction equipment, stitched the images into panoramas, and then manually masked the appropriate regions of the stitched panoramas. Our own researchers mounted a smartphone on a tripod situated at approximate eye points for various vehicles and collected panoramic images using a commercially available application. The portions of the vehicles obscuring the outside environment in the flattened versions of these panoramas were then manually masked. In this way, we were able to create occlusion maps of physical vehicles to compare to our digital models.

Möller and Trumbore [7] developed an algorithm for determining the intersection of rays and triangles. Lagae and Dutré [8] built upon this foundation to develop an efficient test for the intersection of rays and convex quadrilaterals which determines whether intersections exist at all before trying to determine their precise locations. In order to create digital occlusion maps, we employed a modified version of the raytracing method on vehicle models with triangular meshes and a modified version of the methods on vehicle models with quadrilateral meshes [7, 8]. By sending rays from approximate eye locations, we were thus able to render fields of view as spherical projections. When flattened, the images on these spheres became our digital occlusion maps. Figure 1 depicts a digitally rendered occlusion map for an artist’s recreation of a manned ground vehicle.

At this point, our analysis is roughly equivalent to [2]. We can calculate the percentage of the field of view that is visible or occluded by the vehicle geometry. However, as pointed out previously, this analysis treats the entire potential visual field equally and does not address where task-relevant visual information is more or less likely to appear.

Vehicles We selected three vehicles representative of commercially available vehicle classes: a full size pickup, a light-duty pickup, and a midsized sedan. We acquired 3D artist representations of vehicles with geometry based on scan data.

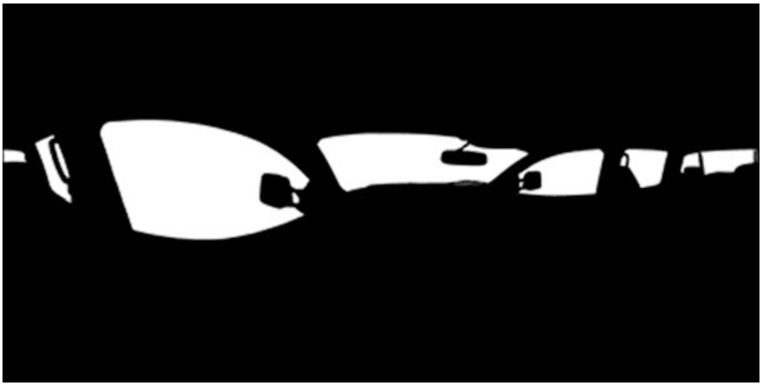

Fig. 1 Example of digitally rendered panoramic occlusion

Our primary calculations of field of view are based on the 3D digital models of these vehicles (see Fig. 2). As described previously, we assessed the validity of the selected digital models, by ensuring that the artistic renderings were accurate in scale and design by comparing them to published vehicle dimensions and comparing with physical vehicles using the masking technique of [4].

Occupants Using SAE anthropometric standards, we calculated approximate eye points for 5th percentile female, 50th percentile female, 50th percentile male and 95th percentile male. These eye heights were chosen to give a range of possible eye heights from small to large. Vehicle reference points (Ball of Foot Reference Point [BOFRP], Seating Reference Point [SgRP], Accelerator Heel Point [AHP], and derived variables [L1, L6, H8, H30, and W20]) were estimated using a simulated H-point device placed relative to the driver's seat of the 3D model. β was set to the default estimated value of 12.0.

Fig. 2 Rendering of the three 3D models selected for the current study

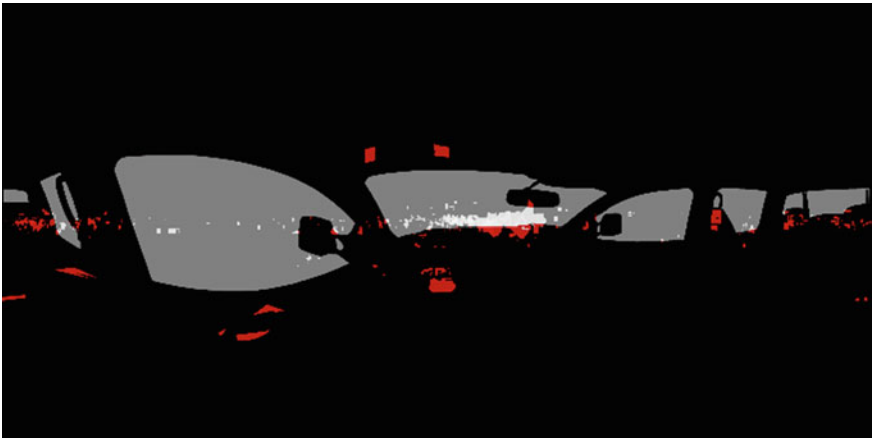

Fig. 3 Visualization of an overlay of occlusion map for the full sized pickup truck on the navigation sign. *Red* indicates occluded information. *White* indicates visible information

2.3 Figures

In the next step of our analysis, we overlay the coded visual information maps from our driving environment dataset with the generated vehicle occlusion maps. Figure 3 provides a visual representation of this overlay. Visual inspection of the overlay provides an impression of the quantity of visual information occluded and by what vehicle geometry.

A quantitative assessment of the quality of the field of view for specific task-relevant information can be calculated by determining the percentage of available visual information that is not occluded by the vehicle geometry. We calculated the percentage of visual information available for the three vehicles (full-size pickup, light-duty pick-up, and four-door sedan) at each eye point (5 % female, 50 % female, 50 % male, 95 % male) for each map of task-relevant visual information (roadway surfaces, navigation signs, and roadside vehicles).

3 Results

The analysis of visibility of roadway surfaces reveals that a very small percentage (0.5–4.5 %) of the total potentially visible roadway surface is not occluded by the vehicle geometry (see Fig. 4). This is not surprising considering that our current analysis evaluates the field of view as a sphere surrounding the operator. While the total potential visible information may be larger than necessary for the current case, the analysis reveals relative differences in visibility not related to the fact that most of the roadway surface is beneath the vehicle. The visibility of roadway surface to

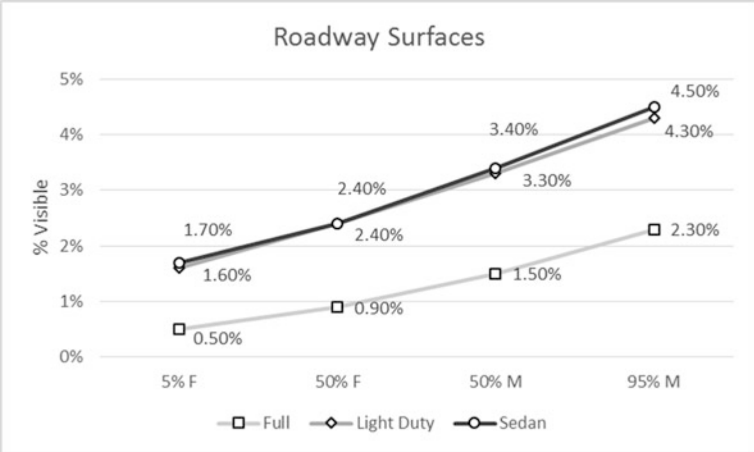

Fig. 4 Comparison of visibility of roadway surfaces by vehicle and eye height

operators of the full size pickup truck (0.5–2.3 %) is approximately 1/3 to 1/2 of the visibility for the pickup truck (1.6–4.3 %) and the sedan (1.7–4.5 %) depending on the height of the operator. Roadway surface visibility increases almost linearly with height. There appears to be no difference in visibility between the light-duty pickup and the sedan.

The visibility of navigation signs for an operator of the full size pickup truck ranges from 23 to 32 % (see Fig. 5). Navigation sign visibility increases almost linearly with height for the full size pickup truck operator. However, while visibility of navigation signs for an operator of both the light-duty pickup truck and sedan are

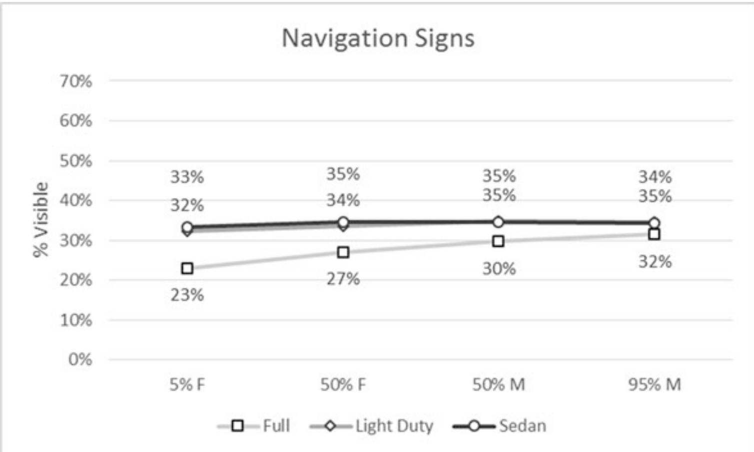

Fig. 5 Comparison of visibility of roadside vehicles by vehicle and eye height

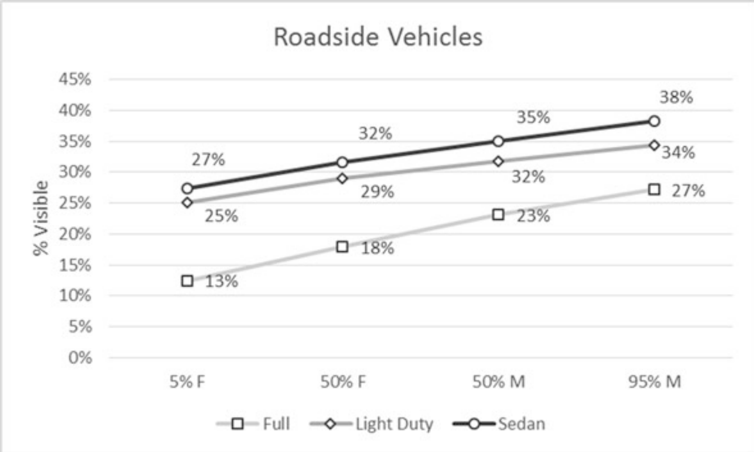

Fig. 6 Comparison of visibility of roadside vehicles by vehicle and eye height

higher than visibility from the full size pickup, visibility does not increase with height.

The visibility of roadside vehicles has a similar profile to the visibility of roadway surfaces (see Fig. 6). Visibility increases linearly with occupant height for all three vehicles. The full-size pickup truck again has the lowest visibility (13–27 %) of the vehicles. However, unlike the visibility of navigation signs and roadway surfaces, the light-duty pickup truck demonstrates consistently lower visibility of roadside vehicles compared to the sedan.

4 Conclusions

This initial analysis indicates relatively poorer performance of a full size pickup truck than a light-duty pickup truck and a sedan. Visibility from the full size pickup truck consistently increases as the height of the operator increases. Flat, superior visibility, as seen for the light-duty pickup truck and sedan for navigation signs, may indicate superior vehicle design to accommodate occupants of varying heights.

The current analysis assessed visibility for three types of visual information. The value of multiple visual information maps is dependent on differences existing in the distribution of task-relevant visual information across the field of view. As demonstrated here, while the relative visibility from the three vehicles was similar across all three maps, there are sufficient differences between the three selected information maps to reveal potentially meaningful differences in the vehicle designs.

The results of the application of this preliminary method demonstrated an extended quantitative analysis of what task-relevant visual information is occluded by vehicle geometry. The analysis demonstrates differences in field of view across three vehicle models representative of commercially available equipment. The quantitative and task-specific nature of the analysis will allow the analysis tool, following additional development, to provide insights into the impact of vehicle design decisions on the vehicle operator's ability to perceive critical visual information.

4.1 Limitations

Because this is a preliminary application of a new method, there are several limitations worth noting and addressing in future research. One significant issue in our analysis is the need to determine an appropriate field of view for analysis. While the analysis of visibility of roadway surfaces allows a comparison of relative performance across the three vehicles, it is difficult to interpret actual visibility of visual information due to the inclusion of visual information that can reasonably be expected to be occluded in all vehicles (i.e., the road beneath the vehicle). This also applies to the inclusion of portions of the sky above the vehicle that, while potentially visible through a sunroof, are unlikely to be the source of visual information critical to the operator's task. However, there are potentially cases where these areas of the field of view are critically relevant. For example, forklift or crane operation may benefit from visibility of overhead portions of the field of view. Similarly, the current analysis does not account for the normal, forward-facing orientation of the human head and weighs visual information available from the side and rear windows as having the same relevance as information available from the front. We expect our next steps in developing this tool will include determining appropriate areas of analysis and providing a method for defining those areas.

An additional concern is the impact of the source of our driving environment database. The cameras used to capture the panoramic source images are not located at eye height and we do not have 3D data associated with the images. In practice, the result is that the visual information maps do not perfectly reflect the location of visual information for a vehicle operator. Future work will be necessary to determine the impact of the difference in camera height and operator height and to determine potential methods for adjusting the results.

Also related to the driving environment database is the time investment necessary to construct the data sets. Many hours were spent manually coding panoramic images of randomly selected locations for the categories of visual information of interest. Generating databases of additional locations or different categories of visual information will require significant investments of time. We are currently undertaking generation of an extended number of datasets and assessing potential for generating representative datasets through simulation.

Acknowledgments Effort sponsored by the Engineering Research and Development Center under Cooperative Agreement number W912HZ-15-2-0004. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the Engineering Research and Development Center or the U.S. Government. The authors would also like to acknowledge the invaluable efforts of Patience Judy and Maverick Smith for their many hours of assistance manually coding the images in the driving environment database.

References

1. RAMSIS Cognitive, http://www.human-solutions.com/mobility/front_content.php?idcat=325
2. Marshall, R., Summerskill, S., Cook, S.: Development of a volumetric projection technique for the digital evaluation of field of view. Ergonomics **56**(9), 1437–1450 (2013)
3. Ray, S., Teizer, J.: Computing 3D blind spots of construction equipment: implementation and evaluation of an automated measurement and visualization method utilizing range point cloud data. Autom. Constr. **36**, 95–107 (2013)
4. Bostelman, R., Teizer, J., Ray, S., Agronin, M., Albanese, D.: Methods for improving visibility measurement standards of powered industrial vehicles. Saf. Sci. **62**, 257–270 (2014)
5. Cook, S., Summerskill, S., Marshall, R., Richardson, J., Lawton, C., Grant, R., …, Clemo, K.: The development of improvements to drivers' direct and indirect vision from vehicles—Phase 2. Technical Report, Loughborough University (2011)
6. TIGER/Line Shapefile, 2013, 2010 nation, U.S., 2010 Census Urban Area National, http://www2.census.gov/geo/tiger/TIGER2013/UAC10/tl_2013_us_uac10.zip
7. Moller, R., Trumbore, B.: Fast, minimum storage ray-triangle intersection. J. Graphics Tools **2**(1), 21–28 (1997)
8. Lagae, A., Dutre, P.: An efficient ray-quadrilateral intersection test. J. Graph. GPU Game Tools **10**(4), 23–32 (2005)

http://www.springer.com/978-3-319-41626-7

Advances in Applied Digital Human Modeling and Simulation
Proceedings of the AHFE 2016 International Conference on Digital Human Modeling and Simulation, July 27-31, 2016, Walt Disney World®, Florida, USA
Duffy, V.G. (Ed.)
2017, XI, 327 p. 129 illus., 98 illus. in color., Softcover
ISBN: 978-3-319-41626-7