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The development of an objective methodology for the evaluation of drivers' field of view

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Abstract

This paper presents research into driver vision and methods to quantify the field of view afforded a driver through a combination of direct vision (through windows) and indirect vision (through mirrors). Focusing primarily on Large Goods Vehicles (LGVs) a 3D projection technique has been developed to allow the field of view to be projected to form a visible volume of space representing what can be seen by the driver. This projection technique has previously been used in a qualitative manner to assess the presence of blind spots in proximity to LGVs and the degree to which other road users may be visible to the driver. To supplement this qualitative assessment a new quantitative, objective measure of field of view has been developed and implemented in the digital human modelling system SAMMIE. The objective measure involves the projection of the field of view afforded from a window aperture or via a mirror onto the surface of a sphere centered at the driver's eye point. The area of the resulting spherical polygon is calculated to provide an assessment of field of view that allows comparison between different vehicle configurations.

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Keywords: Vision; Digital human modelling; Field of view; Ergonomics; Cyclist safety; SAMMIE

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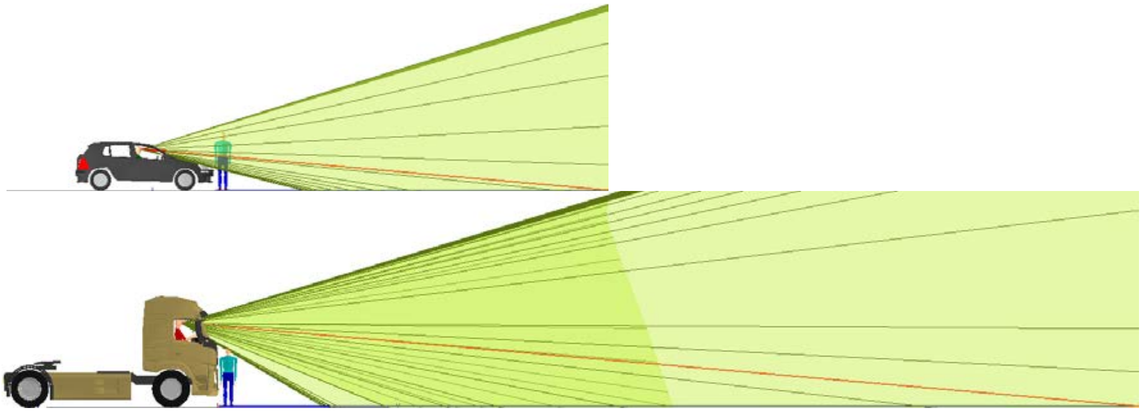

Fig. 1. Basic Illustration of the impact of driver eye height on FOV. Volkswagen Golf M1 Car (top), Volvo FM N3 LGV (bottom).

1. Introduction

This paper presents research into driver vision and methods to quantify the field of view (FOV) afforded a driver through a combination of direct vision (through windows) and indirect vision (through mirrors). Whilst vision is a primary safety issue for drivers of all vehicle types this research focuses on Large (or Heavy) Goods Vehicles (LGVs / HGVs) and in particular the largest category of these vehicles, designated as N3 in Europe and the UK. N3 vehicles are classified as good vehicles having four or more wheels and a maximum mass greater than 12 tonnes. Due to the weights and dimensions legislation that controls vehicle size in Europe most LGVs in Europe and the UK have the same basic configuration resulting in the distinctive flat fronted design, with the cab mounted directly above the engine. This configuration results in a relatively high cab and in particular a high driving position and eye point for the driver.

Issues with driver vision from LGVs have been a long standing area of concern and numerous research efforts have addressed elements of the problem. Of particular concern are accidents involving LGVs and so-called vulnerable road users (VRUs). The research presented here is part of a recent initiative by Transport for London (TfL) in the UK called Construction Logistics and Cyclist Safety (CLOCS). CLOCS is a multi-headed approach to the issue of LGV accidents with VRUs, particularly those in urban areas and is addressing all aspects of the issue including driver vision and blind spots in LGVs. One of the key elements of the research is understanding the FOV afforded to drivers of LGVs.

This work follows on from previous research in which a volumetric projection technique was developed to aid in the visualization of FOV. This volumetric FOV was implemented in the digital human modelling system SAMMIE. The volumetric approach has been used to identify blind spots in LGVs however it is predominantly a qualitative technique providing a visualization of the view afforded the driver. In order to support the aims of the CLOCS project an objective technique was required to provide metrics that could be used for comparative evaluations between different vehicle designs and vehicle configurations. This approach would then be instrumental in supporting arguments to improve driver vision by highlighting the efficacy of particular design solutions and identifying best-in-class vehicles for the benefit of vehicle operators and ultimately other road users.

2. Vision issues in large goods vehicles

Due to the height of LGVs the driving position is also relatively high compared to the general driving environment and that of many other road users. This height leads specifically to a high driver's eye point. Figure 1 shows a simplified interpretation of the impact of driver eye height on FOV. UNECE Regulation 125 [1] that concerns the approval of motor vehicles with regard to the forward FOV in Europe specifies a lower vertical datum point of the eye point of 5 degrees below the horizontal. In the Figure, the red lines show this 5 degree requirement applied to a Volkswagen Golf category M1 car with 50th %ile UK Male driver (top), and a Volvo FM category N3

LGV with 50^{th} %ile UK Male driver (bottom). For the car the intersection of this lower datum with the ground plane occurs 11.7m in front of the vehicle. For the LGV the intersection occurs 27.9m in front of the vehicle. Thus, for a window aperture of equivalent size and location with respect to the driver's eye point, the FOV of the space adjacent to the vehicle is decreased as the eye height increases. Alternatively any blind spots around the vehicle are increased as driver eye height increases.

As already described, the regulation of vehicle length in Europe and the UK has resulted in a degree of standardization in LGV design. In the case of forward vision this exacerbates the limitations on FOV as other road users are able to get closer to the driver whilst still being below the lower limit of driver's vision. The FOV projections (yellow cones) in Figure 1 clearly show the size of the resulting blind spot to the front of the vehicle and the visibility of a pedestrian (50^{th} %ile UK male positioned directly to the front).

3. The CLOCS project

In 2012 Transport for London (TfL) initiated the beginnings of a project entitled Construction Logistics and Cyclist Safety. The project acknowledged the large number of cyclist fatalities occurring in London that involved a large goods vehicle and the disproportionate number of those that involved a construction vehicle. One of the tenets of the CLOCS project was that the causal factors influencing the occurrence of accidents involving LGVs was not solely down to vehicle design and ultimately vehicle manufacturers. Whilst blind spots around LGVs and in particular construction vehicles were a significant issue, there are other compounding factors that also need to be addressed in a holistic approach to road safety. In particular these included the fundamentally different approach in the industry to road safety in comparison to on-site safety.

3.1. The modelling of driver vision

TfL commissioned The Design Ergonomics Group at Loughborough Design School, Loughborough University to perform an analysis of vehicle FOV through the modelling of LGV blind spots. The basic aim of the research was to perform 360 degree, 3D FOV analyses of a range of vehicles. With the support of the Society of Motor Manufacturers and Traders (SMMT) the data for the registrations of new category N3/N3G vehicles were obtained and examined to determine which makes and models of vehicles were to be tested in the project. Analysis of the data identified a total of 11 vehicles from across six manufacturers including: DAF, Dennis Scania, MAN, Mercedes and Volvo.

With the vehicle makes and models established discussions were held with representatives from each manufacturer to explore the variability of the available options for each model. This highlighted that there are a significant number of available vehicle configurations through the specification of different suspension type, cab type, axle configuration, and engine size. These variables result in a wide range of cab mounting heights within a vehicle model. Initially it was proposed that the highest and lowest cab height configurations should be selected for the analysis, however a review of sales data with two key manufacturers highlighted that the highest and lowest vehicle cab heights were sold in low volumes as they had specific, and limited application.

This resulted in a strategy where the most sold configuration for each vehicle was selected for analysis. Each manufacturer was asked to provide the height of the cab for the most sold configurations of the identified vehicles. This method had the advantage of representing the largest number of vehicles that are in operation, in a fair and equitable manner, but has the limitation that the more extreme vehicle heights are excluded from the analysis.

Once the vehicles were identified, data for each vehicle was obtained through a process of digital scanning. Due to the lack of consistent availability of manufacturer CAD data, the approach was taken to capture the data from the vehicles using a 3D laser scanning system. Using a FARO Photon 120 scanner, each vehicle was captured using a total of six scans. Four scans were used to capture the exterior of the cab and two were used to capture the interior. The scans were then post-processed to align the scans and remove noise prior to importing into the SAMMIE digital human modelling (DHM) system.

Whilst the scanning process captured the whole vehicle there were a number of critical elements that required special consideration to ensure accuracy of any subsequent analyses. Firstly the clear portions of the window apertures were carefully identified and extracted from the 3D scans. Secondly each mirror and mirror housing were scanned using a ZCorp hand held laser scanner in each of the four extremes of their adjustability ranges. This allowed the mirror surfaces to be recreated, for the radius of curvature to be accurately modelled and for the limits of adjustability to be determined. In addition, care was taken to capture the driving package. Using an SAE H-point manikin the seat position and adjustability was recorded. Pedal locations and steering wheel adjustability were also captured.

The data were then combined into the SAMMIE DHM system. The 3D scan data were imported and manipulated to provide a recognizable vehicle. Each vehicle was mounted at the height provided by the manufacturers. The window apertures and mirror surfaces were imported and adjustability ranges set. Three human models were created representative of 5^{th} %ile UK female, 50^{th} %ile UK male and 95^{th} %ile UK Male. The three human models were postured in representative driving postures based on data captured from real drivers.

In posturing the human models of particular importance was the resulting eye point. The analyses that would be subsequently be performed all stemmed from the driver’s eye point as the origin of the visual projection techniques. Thus variability in eye point would lead to variability in results. In order to standardize the posturing of the human models and provide a consistent methodology for eye point location the process defined by Reed [3] that builds upon SAE J941 [4] on the definition of motor vehicle drivers’ eye locations was used.

With the eye points established the final setup included adjusting the mirrors including the two Class II, two Class IV, the Class V and the Class VI mirrors in accordance with the requirements of 2003/97/EC [5] and UNECE Regulation 46 [6]. Figure 3 shows the regulated areas and the subsequent projection of the mirror fields of view corresponding to each area.

Fig. 2. Example exterior scans for the Scania P cab vehicle. The reference spheres used to aid alignment of the scans are visible in the images.

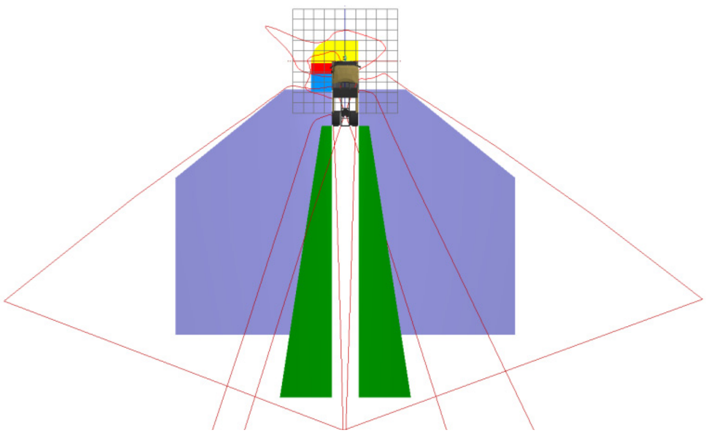

Fig. 3. Plan view of the mandated visual areas as defined in 2003/97/EC and the projection of the six mirrors on the ground plane.

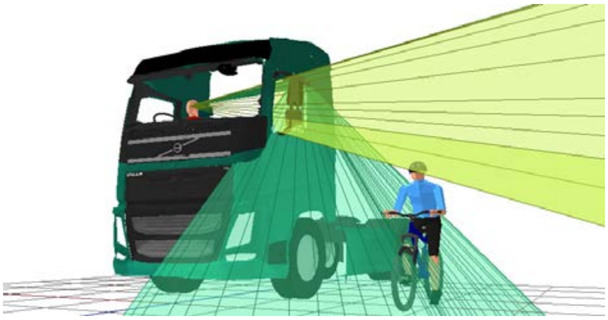

Fig. 4. 3D volumetric aperture projection shown through the passenger window and mirror projection shown for the Class V look-down mirror.

3.2. Previous work

Earlier research performed by the Loughborough team led to the development of a 3D volumetric projection technique for the evaluation of driver's FOV. This was subsequently validated and implemented within the SAMMIE DHM system [7, 8]. The implementation involved projecting a ray from the driver's eye point through each vertex of a polygonal window or mirror object and then tracing that ray to a user definable cutoff. The result is a polygonal volume that allows an assessment to be made in which anything within the volume should be visible to the driver directly, or via a mirror. Figure 4 shows an example volumetric projection.

This projection technique has been employed in the evaluation of driver FOV for a range of vehicle types including category M1 (cars), M2 (minibuses), N2 and N3 (medium and large goods vehicles) vehicles as part of research performed for the UK Department for Transport [9]. The evaluations performed using the technique were predominantly qualitative, involving a heuristic assessment of the degree to which a visual target would likely be visible through the intersection of the projected volume and the target model. In addition to 3D evaluations 2D ground plane plots were also generated to allow blind spots to be identified alongside the mandated areas of visibility defined by the regulations. Later research performed for TfL and Transport and Environment focused on the design of new, high visibility truck cab designs and employed a modified methodology where visual targets were positioned at the limits of visibility, such that they were in a position just *not* visible to the driver [10]. Linear measures were then provided to allow comparison between different design concepts. The premise was that the larger the distance to the visual target the larger the blind spot. However, in order to provide a more objective and comparative technique for vehicle evaluation a further development of the volumetric projection technique was investigated.

3.3. An objective measure of field of view

To provide an objective measure of FOV a common methodology is to measure the limits of the FOV projected onto a surface. The projection is typically performed onto a 2D plane, such as the ground. These planes can be subdivided to allow measures to be taken of the extents of the projection. These measures then provide metrics that can be compared between vehicles. However, because the projections result in complex 2D projections, linear measurements are rarely a satisfactory description of the form. Furthermore each mapped intersection between the projection and the plane will be at a different distance from the eye and thus the 2D areas produced are distorted.

Based on earlier research performed by the Loughborough team into the investigation of vision assessments as a potential extension to the European new car assessment programme (Euro NCAP) the use of a sphere was explored as the projection surface. The premise was that a sphere provides a surface with a consistent distance from its center, if the center was located at the driver's eye point any resulting distortion from an intersecting projection would be minimized. Furthermore the area of the resulting spherical polygon could then be calculated and used as an objective means of comparison between window or mirror designs. Finally, as the projections are formed on a surface originating at the eye point, the issue of the vehicle height and thus variations in driver eye height are removed and calculated areas are directly comparable between vehicles.

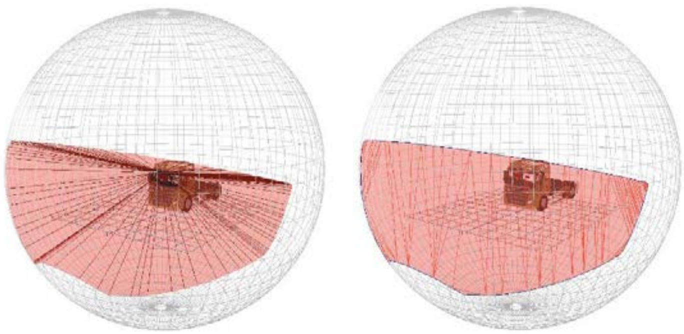

Fig. 5. Field of view projection of a windscreen. The left image shows the rays extending form the eye point to the sphere. The right image shows the resulting polygon projection on the surface of the sphere and its tessellation.

3.3.1. Spherical projection

The basic projection technique relies on a simple ray extension originating at the driver's eye point, extending through each vertex of an aperture definition until its length equals the radius of the projection sphere, typically 10m though the value is arbitrary. The end point of the ray forms a new vertex, the combination of the new projected vertices define the projected boundary of the FOV afforded by the aperture mapped onto the spherical surface (see Figure 5). The resultant projection is a spherical polygon, whereby each edge between adjacent vertices is in fact a curve on the surface of a sphere.

To calculate the area (*A*) of a spherical polygon a generalized formula can be used, where Θ is the sum of the internal angles of the polygon, *n* is the number of sides and *r* is the radius of the sphere:

$$A = [\theta - (n-2)]\pi r^2 \quad (1)$$

However as the polygon cannot be guaranteed to be convex the polygon needs to be tessellated. Tessellation is performed using a Delaunay triangulation [11]. The formula for the area (Δ) of a spherical triangle can then be used and summed for all triangles in the tessellated polygon, where *A*, *B* and *C* are the internal angles of the triangle:

$$\Delta = \left[(A + B + C) - \pi\right] r^2 \quad (2)$$

The internal angles are calculated from spherical geometry where *A*, *B* and *C* are the internal angles and *a*, *b* and *c* the angular lengths of sides:

$$\cos A = -\cos B \cos C + \sin B \sin C \cos a \quad (3)$$

For indirect (mirror) projections, the projected ray must be reflected in the mirror. All vehicle mirrors are assumed to be spherical convex mirrors and as with window apertures their boundary is defined as a polygonal surface, in addition the center of curvature and radius of curvature are defined. The process is then equivalent to that defined above with the resulting projection being mapped onto the same sphere.

3.4. Refinements to the measurement of FoV

After a period of experimentation the basic spherical projection methodology was adapted to account for two observations from the evaluation of FOV when combining direct and indirect vision. Direct vision aperture projections always result in a series of discrete areas, as shown in Figure 6. However, indirect vision projections often result in overlapping areas (see Figure 7 left).

When evaluating both direct and indirect projections the potential for overlap is increased. The implications for overlapping areas is that for a total FOV calculation the overlapping areas are essentially double counted. Thus the methodology was extended to combine any overlapping projections to remove the overlap and only provide a single

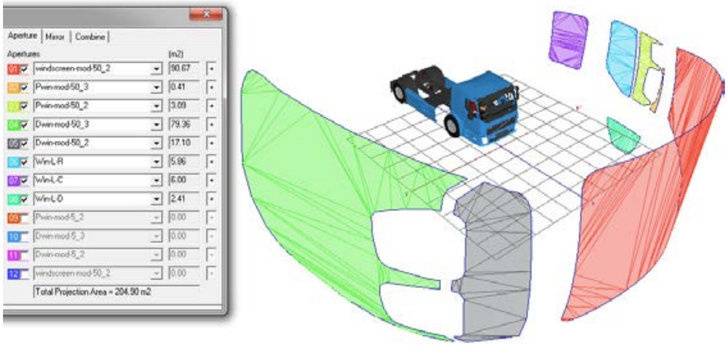

Fig. 6. Spherical aperture projection showing aperture area calculations and a total direct FOV of 204.90m^2.

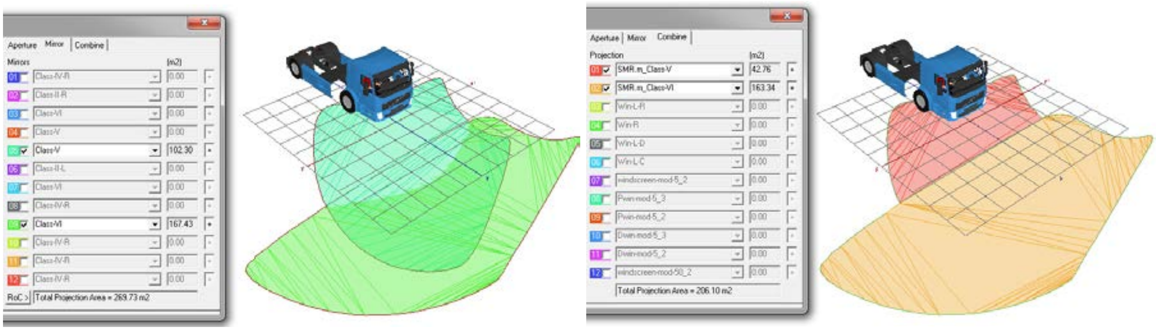

Fig. 7. Spherical projection of Class V and Class VI mirrors clearly showing the overlapping projections (left) and the combined, projection of Class V and Class VI mirrors with the overlap removed (right).

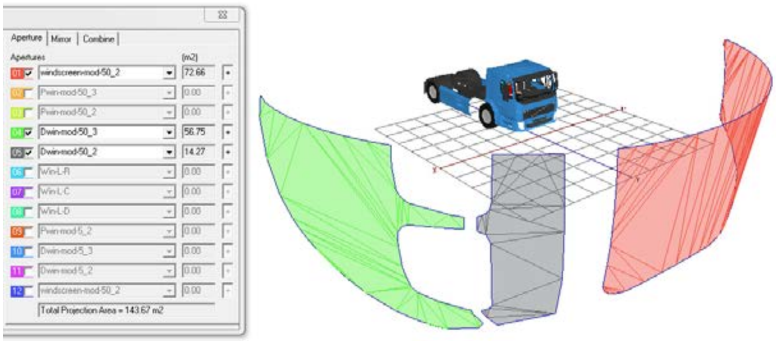

Fig. 8. Clipped spherical projection of a number of vehicle window apertures and their area calculations.

area calculation. The right image in Figure 7 shows the result of a combined spherical projection. The projected area is shown as 206.10m^2 in contrast to the uncombined, overlapping projections shown on the left in Figure 7 with an area of 269.73m^2.

The second observation concerns the potential for the objective FOV metrics to be artificially inflated through FOV provision in areas not relevant for this research. For example, a vehicle may offer a window aperture that affords the driver a view of high level elements in the driving environment e.g. traffic signals. This work is focused on the visibility of VRUs that are primarily at a relatively low level around the vehicle. Thus the methodology was adapted to allow clipping of the direct vision projections to an angle either side of the horizontal plane through the driver's eye point. Any angle can be specified within ±90 degrees, however an angle of +7 degrees was specified in line with UNECE Regulation 125. Whilst it is acknowledged that Regulation 125 does not apply to LGVs it is the only standard available in this regard and provides a consistent figure for analysis purposes.

Figure 8 shows the result of a clipped projection where the top of the windscreen and driver's side windows have been clipped to the +7 degree limit. The clipped areas of $72.66m^2$, $56.75m^2$ and $14.27m^2$ can be compared to the unclipped areas shown in Figure 6 for the same apertures of $90.67m^2$, $79.36m^2$ and $17.10m^2$.

4. Discussion and conclusion

The spherical projection tools have subsequently been used on the CLOCS project to evaluate the FOV for 11 vehicles from the six manufacturers identified earlier. Whilst the results of these analyses have yet to be published the objective spherical projection technique has addressed the need to supplement the qualitative evaluations using the 3D volumetric projections with a quantitative evaluation. The metrics produced allow direct comparison between vehicle manufacturers and between vehicles for a single manufacturer.

There are complications in the process that do result in some difficulties with the projection. Because the Delaunay triangulation has to happen in 2D, the 3D spherical polygon has to be flattened onto a 2D plane. For window and mirror apertures this is not a problem, however when larger projections are combined they may form a projection that when flattened can lead to self-intersecting polygons or results in the projection never intersecting with the 2D plane. In such instances work-arounds have to be implemented, such as manually splitting a projection into more manageable areas. In the work performed thus far these instances have been rare but it is a known limitation with the current implementation of the technique. Further work is also required to improve capability to handle complex intersections of highly concave polygons that when combined result in multiple smaller areas. These typically do not occur in standard window apertures but if obscuration elements are to be considered, e.g. mirror bodies and their obscuration of the side windows, the resulting apertures and projections can be problematic for the method to manage in an automated manner.

Overall the spherical projection research has resulted in the desired objective method for the evaluation of field of view. The refinements to allow combined projections to be produced and projections to be clipped to remove the influence of less relevant portions of the 360 degree FOV have allowed qualitative assessments to be performed on a range of current UK LGVs. These findings will be published as part of the ongoing CLOCS project in the UK and used to inform operators on the difference between vehicles and to aid manufacturers in improving visibility from their vehicles.

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