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Road Surface Development and Sight Distance Calculation with New Visualization Methods

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Abstract: - The recent advances in computer visualization methods have made it possible to exploit the possibility of applying scientific visualization methods in critical research areas in the field of transportation engineering. In this paper we develop new visualization methods for road design and safety. Typically, roads are designed by combining horizontal and vertical roadway alignments, to allow for adequate sight distance for driver comfort and safety. The traditional process of checking for adequate sight distance ahead of a driver is manual as it is performed by a manual check along the horizontal and vertical roadway alignments. Further, recent visualization applications in horizontal and vertical alignment design is a sequential process (i.e., visualization of horizontal and vertical alignments is carried out in separate stages; typically horizontal alignment is obtained first and a vertical alignment is subsequently fitted, which may lead to inaccurate sight distances along the roadway. For example, a section of a road with a vertical hog curve and a sharp horizontal curve together will lead to an illusion of the availability of a larger sight distance when driving. In this paper, a new visualization-based method for calculating the sight distance is proposed in which the sight distance is measured using a 3-dimensional (3D) road surface, solid cone, rectangular plane. The 3D cone with its vertex at a height 'h' from the road surface and line of height parallel to the tangent of the road centreline is moved along the roadway at regular intervals. The intersection of the road surface with the cone is used to obtain the intersected surface. The variation of the tangents along the intersected surface is used to obtain the profile of the intersected road surface centreline. Variable rectangular plane is used over the intersected road surface to get the sight distance. Given the 3D road centreline, a method is described to establish the road surface. Mathematical formulations to calculate the 3D surface and sight distance are presented. The paper concludes with the discussion of the application of the proposed methods for full-scale efficient roadway sight distance measurement as well as directions for future research.

Key-Words: - Visualization in Physical Sciences, Life Sciences and Engineering; Virtual Environments, Virtual Reality, Highway Design, Sight Distance

1 Introduction

The advancement in hardware and visualization software technology is making it possible to apply them in complex transportation engineering problems [2][6]. For example in the field of highway design, traditional sight distance measurement is based on 2-dimensional (2D) planar view of horizontal and vertical alignment separately. These methods were developed based on 2D view of the highway alignments separately because of the complexity involved in the measurement. Therefore, these methods may not give accurate results as they do not consider horizontal and vertical alignment simultaneously. Using the existing visualization techniques, new methods can now be developed that

reduce time and errors in sight distance measurement.

One of the complex tasks in highway geometric design from safety point of view is sight distance measurement. It is very important in highway geometric design that sight distance, stopping sight distance, passing sight distance be calculated at regular intervals along the highway and checked to ensure that it is sufficiently available in order to avoid any possible accident. Sight distance is the maximum length of the road that a driver can see an object of height 'h' ahead. Stopping sight distance is the distance available for a driver when he sees a hazard on the road ahead and applies his brakes to come to a complete stop to avoid accident [1].

Passing distance is the distance available for a driver to overtake a vehicle [1].

From safety point of view, the sight distance, stopping sight distance, and passing sight distance need to be calculated at regular intervals and checked against sight distance for sufficiency. The sight distance is always greater than the stopping and passing sight distances. This ensures that the driver has enough distance for reacting and applying brakes to avoid head on collision. More details on stopping and passing sight distances can be found in any of the standard transportation engineering text books.

Sight distance greatly depends on the characteristics of the alignment. The longer the straight portion of the road, higher the sight distance available. The sight distance reduces at curved portions of the road. It becomes more critical at portions where horizontal curve appears simultaneously with the vertical curve. It is practically not possible to manually check the sight distance at regular intervals and hence the above mentioned process is very tedious. The paper deals with calculation of sight distance using some of the visualization techniques.

Not many sight distance measurement methods using visualization techniques could be found in literature. The methods that were developed for sight distance measurement were for either horizontal alignment or for vertical alignment. Girish et al. [4] described a methodology to find the available sight distance using Global Positioning System (GPS) data by examining the intersection of line of sight with the elements representing the road surface. But the sight distance was based on the vertical alignment only and did not consider the effects of horizontal curvature. David et al. [3] determined the sight distance based on horizontal geometry. However, they did not consider the vertical geometry for sight distance measurement.

Here a general purpose methodology is developed to calculate the sight distance irrespective of the nature of the road, i.e., horizontal or vertical. It takes the 3D centreline of the road for measuring the sight distance. The methodology is described in the subsequent sections.

2 Methodology

Before the methodology is explained, some terminology is used and described below for a better understanding of the methodology.

Centreline/Alignment: The centreline of a road is that line which is equidistant from the edges of the road. The centreline is made up of a number of lines. Each small line is called centreline element. Each centreline element has a start and end point which defines the direction of the centreline. The end of an element is always connected with the start of the next element. In that way every element of the centreline has two connected elements, one ahead and one behind, except for the first and last element. The centreline and its elements are shown in Figure 1

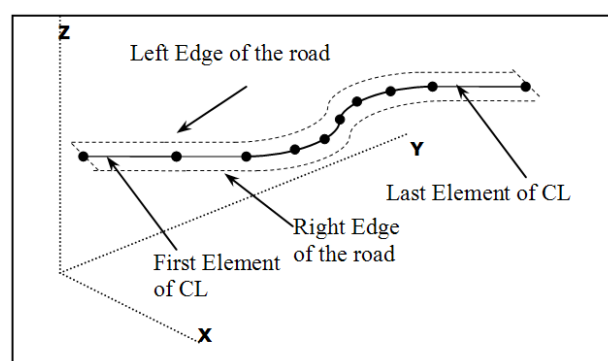


Figure 1 Centreline (CL) of road and centreline elements

Horizontal Alignment (2D): The horizontal alignment is the view of the centreline of the highway when seen from top of the road surface (See Figure 2 (a)). The horizontal alignment has two curves namely left and right curves with tangents connecting them. In Figure 2 (a), the curve in the region 1-2 is a right curve where as in the region 3-4 it is a left curve. Regions S-1, 2-3 and 4-E are called tangent regions. LE and RE indicate left and right edges of the road respectively. CL indicates the centreline of the road.

Vertical Alignment (2D): Vertical alignment is the view of the centreline of the highway when seen along the longitudinal cross-section of the road (See Figure 2 (b)). Generally the vertical alignment is composed of two types of curves namely crest/hog and valley/sag curve with tangents connecting these curves. In Figure 2 (b), curve in the region 1-2 is crest curve whereas in the region 3-4 is valley curve. Regions S-1, 2-3 and 4-E are called tangent regions.

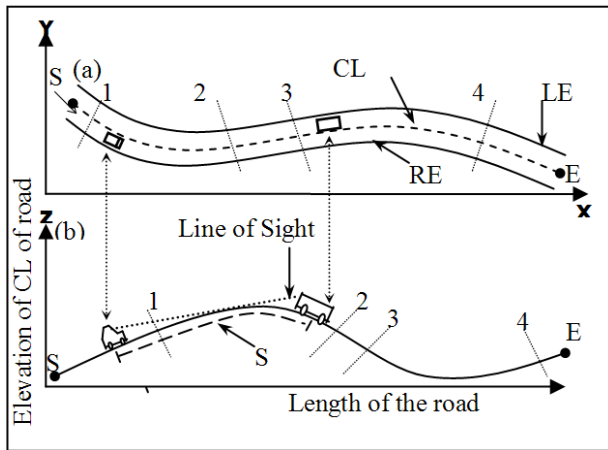


Figure 2: (a) Horizontal alignment (b) Vertical alignment: Cross section profile when seen along the centreline of the road

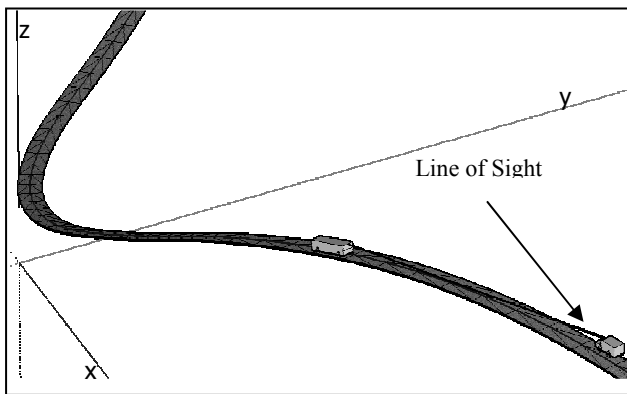


Figure 3: 3D alignment from the superimposition of horizontal and vertical alignments.

3D Alignment: The 3D highway alignment is the superimposition of 2D horizontal and vertical alignment (See Figure 3). It is assumed that change in tangents over the 3D alignment is smooth, i.e., the alignment does not change its path abruptly.

Sight Distance: Sight distance is the maximum length of highway that a driver with his eyelevel at a height ' h_d ' from the road surface can see a vehicle ahead of height ' h_v '. For example in Figure 2 (b), SD indicates the sight distance for a typical case when the car is at the shown location.

There are many roadside features like buildings, trees etc. that reduce the sight distance. These features are not considered in the proposed methodology. Even the terrain is not considered. To reduce the complexity of the problem, only the road is considered for sight distance measurement.

The proposed methodology has three stages. Road surface development, virtual field of view surface

development and virtual line of sight plane development. Once the three surfaces are developed in the said successive three stages, a procedure is used to measure sight which is described in the subsequent sections.

2.1 Road surface model

This stage involves the development of the surface of the road from the three dimensional centreline of the road. It is assumed that any line on the surface of the road drawn perpendicular to the centreline of the road is parallel to the horizontal plane xy . This assumption is made on the basis that the front or rear edge of a vehicle is perpendicular to the centreline of the road and parallel to the ground (See

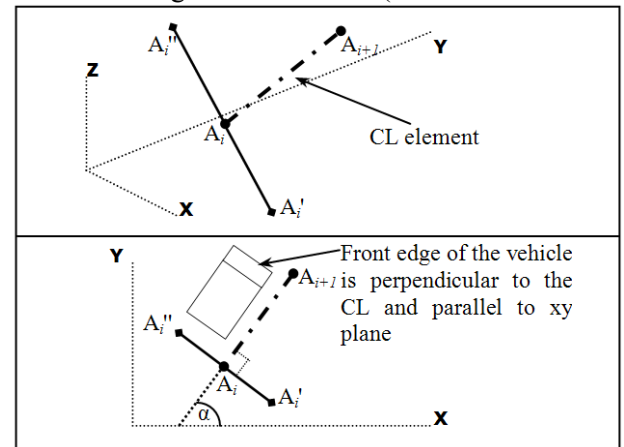


Figure 4) except at horizontal curved portions of the road.

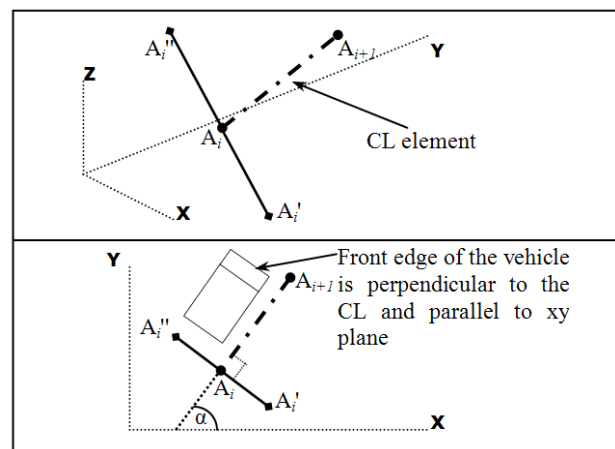


Figure 4: The top figure illustrates the 3D view and the bottom figure illustrates the 2D view of a centreline element

Let $i = 1, 2, 3, \dots, n$ indicate 3D CL elements where n is the number of elements. $i = 1$ indicates the first element and $i = n$ indicates the last element. Let $A_i A_{i+1}$ be a 3D centreline element of the road. Let A_i' and A_i'' be the right and left edge points of the road respectively at A_i . According to the assumption $A_i' A_i''$ will be perpendicular to the centreline element and parallel to the ground/plane xy . Let w_r be the width of the right edge of the road. Let w_l be the width of the left edge of the road. Let line $A_i A_{i+1}$, projected on plane xy , make an angle α radians with the horizontal in the anticlockwise direction. Based on the above assumption the following equations are developed.

Let coordinates of A_i be (x_i, y_i, z_i) and A_{i+1} be $(x_{i+1}, y_{i+1}, z_{i+1})$. then

$$\alpha = \tan^{-1} \left(\frac{y_{i+1} - y_i}{x_{i+1} - x_i} \right) \dots \dots \dots$$

For the 3D element $A_i A_{i+1}$, the coordinates of A_i are considered to get the coordinates of A_i' and A_i'' using Eq. (1).

Coordinates of A_i' (x_i', y_i', z_i') are calculated as

$$x_i' = x_i + w_r * \sin(\alpha)$$

$$y_i' = y_i - w_r * \cos(\alpha)$$

$$z_i' = z_i$$

Coordinates of A_i'' (x_i'', y_i'', z_i'') are calculated as

$$x_i'' = x_i - w_l * \sin(\alpha)$$

$$y_i'' = y_i + w_l * \cos(\alpha)$$

$$z_i'' = z_i$$

Similarly the coordinates of A_i' and A_i'' of all the 3D elements can be calculated. Once the coordinates of A_i' and A_i'' of all 3D CL elements are known, then the surface of the road can be developed using a triangulated network [5]. The developed road surface using the described method is shown in Figure 5

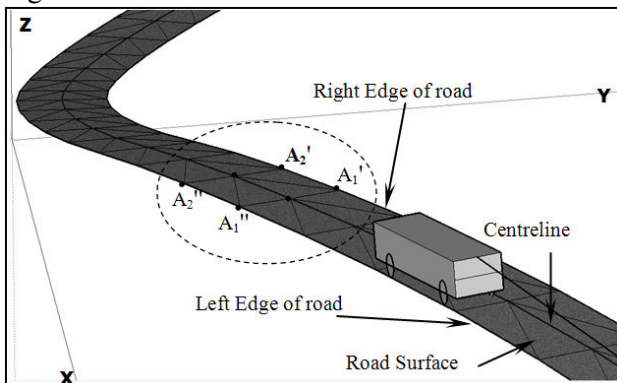


Figure 5 : 3D road surface made of triangles. Typical CL elements A' and A'' and its surrounded triangles can be seen within dotted ellipse

2.2 Field of view surface model

Field of view is the maximum angle of vision of an eye. It can be assumed to be a virtual cone of infinite height with its vertex located at the eye. Based on this concept, a 3D cone of angle α_c is considered which behaves like a human's field of view. Most visualization software can generate 3D cone surfaces. Humans cannot differentiate objects beyond a certain range of visibility. For practical purposes, this range is taken as the height of the cone. This height is measured from the base of the cone. This 3D cone is a solid cone. 3D cone which is a virtual field of view is shown in Figure 6

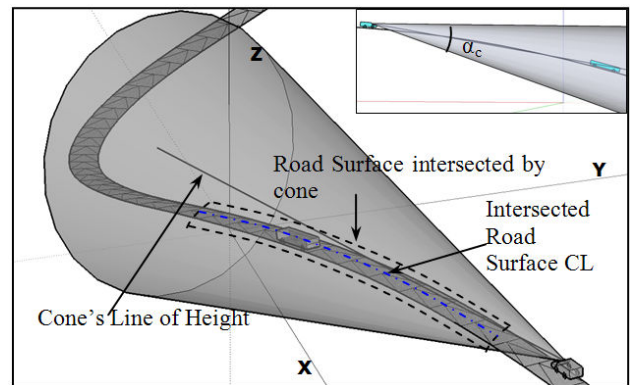


Figure 6: Virtual field of view cone

2.3 Line of sight plane

A line of sight plane (rectangular in shape) is modelled in such a way that the two edges PQ and P'Q' of the rectangle have very large lengths and are always parallel to the xy plane. PQ edge is at a height ' h_d ' and the other edge P'Q' is at a height ' h_v ' from the road surface. The very large lengths of PQ and P'Q' will accommodate any horizontal curvature. The other two edges PP' and QQ' are variable in length. The virtual line of sight of the rectangular plane can be seen in Figure 7

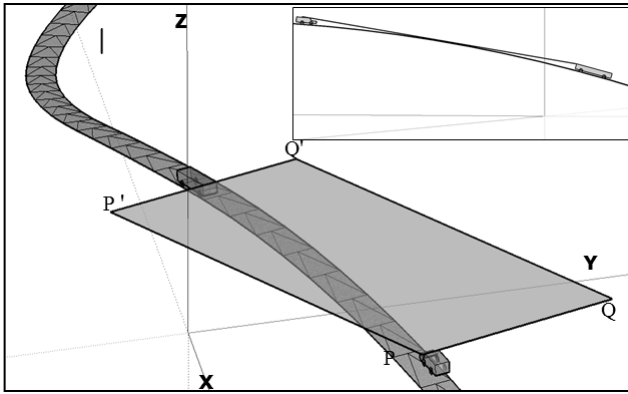


Figure 7: Virtual line of sight of the rectangular plane

2.4 Sight distance measurement

2.4.1 Obtaining Intersected road surface

Given a point on the centreline line of the road, the solid cone's vertex is placed at a height ' h_d ' (driver's eyelevel) from road surface with the cone's line of height parallel to the tangent at the given point (virtual line of sight of human eye). The intersection of the solid cone with the road surface is used to calculate the sight distance. On the intersected surface, the tangents are taken at regular intervals on the centreline of the road. The variation of tangent over the Intersected Road Surface Centreline (IRSC) is examined. Four possible variations of tangent are possible as shown in Figure 2 (b)

Region S-1: In this region the tangent is positive. The tangent is constant or decreasing gradually.

Region 1-2: In this region the tangent varies from positive to negative. The tangent is decreasing gradually. This region indicates a hog curve. The tangent will be zero at the peak point.

Region 2-3: In this region the tangent is negative. The tangent is constant or increasing gradually.

Region 3-4: In this region the tangent varies from negative to positive. The tangent is constant or increasing gradually. This region indicates a sag curve.

The above said regions give us the nature of the profile of the intersected road surface centreline.

2.4.2 Variable virtual line of sight plane

PQ edge of the rectangle is placed at the start of the intersected road surface and the edge P'Q' is moved at regular intervals along the road surface at a height ' h_v '. At any stage if the rectangular plane touches the intersected road surface, then the distance between the two edges PQ and P'Q' measured along the intersected road surface CL gives the sight distance. If the rectangular plane does not touch the intersected road surface throughout, then the entire intersected road surface centreline length is reported as the sight distance. The above procedure is illustrated in Figure 8

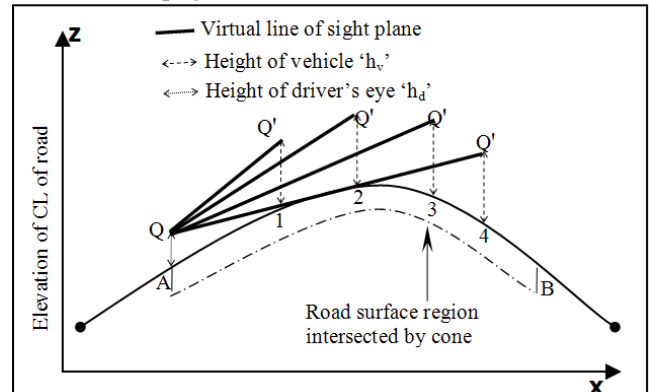


Figure 8: Sight distance measurement procedure

Figure 8 shows the road surface region (AB) intersected by the cone when the vertex is placed at Q. The virtual line of sight rectangular plane PQQ'P' is perpendicular to the paper and hence it is seen as a line. The edge PQ (is perpendicular to paper) is fixed at location A at a height ' h_d '. The movement of P'Q' at a height ' h_v ' from position 1 to position 4 increases the length of the rectangular plane PQQ'P' along PP' or QQ'. Therefore, as described in section 2.3, the two edges PP' and QQ' are variable in length. The movement of P'Q' is not required beyond the position 4 because the rectangular plane PQQ'P' touches the road surface. This gives the indication for sight distance measurement. The sight distance is measured along the centreline of intersected road surface from position A to position 4.

3 Discussion

For a given centreline of a road, a stepwise procedure for sight distance measurement is given below:

3.1 Stepwise procedure

1. Divide the given centreline into n equal parts. n depends on length of the road. The larger the n value the better the sight distance.

2. Develop a road surface for the given centreline as explained in the methodology.
3. Develop a 3D cone (Virtual field of view) making an angle α_c at its vertex.
4. Select an element of the centreline.
5. Place the vertex of the cone at the start point of the element at a height ' h_d ' from the road surface with its line of height parallel to the tangent at the start point.
6. Obtain the surface that is formed by the intersection of the solid cone with the road surface.
7. Select the first CL element of the intersected surface formed in step 6. Develop the rectangular plane PQQ'P'. Place PQ on the midpoint of the element at a height ' h_d ' from the road surface.
8. Place P'Q' on the midpoint of the next CL element at a height ' h_v ' from the road surface and check whether the rectangular plane is touching the intersected road surface.
9. If the rectangular plane touches the intersected road surface or if the intersected surface CL element is the last element in the intersected road surface then report the sight distance measured along the centreline and go to step 11.
10. If the rectangular plane does not touch the intersected road surface then go to step 8.
11. If the element selected in step 4 is the n^{th} element stop else select the next CL element of the previously selected element in step 4 and go to step 5.

Given the centreline of a road, the proposed method can measure sight distance irrespective of the profile of the centreline. An analysis of the proposed methodology shows that the method is computational inefficient if the road length is large or if the number of divided centreline elements is high. On the other hand if the CL is divided into smaller number of parts then the sight distance measured would be inaccurate.

4 Conclusion

This paper describes a methodology to measure sight distance of a road using visualization techniques. The proposed method has three stages namely road surface development, virtual field of view surface development, virtual line of sight plane development. A procedure to measure the sight distance is described from the three developed surfaces.

5 Future research

The proposed methodology is in nascent stage and needs to be developed and tested on real world highways to measure sight distance. In this paper only the surface of the road is considered to measure the sight distance. In fact, there are a number of features like buildings, trees, etc. that are alongside the road and terrain that affect the sight distance. These features obstruct the line of sight and hence the sight distance reduces. These factors need to be considered to get the actual sight distance.

6 Acknowledgments

The authors would like to thank Centre for Advanced Transportation and Infrastructure Engineering Research laboratory at the Morgan State University for providing necessary software and instruments for developing the model.

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