ESTIMATION OF SIGHT DISTANCE ON HIGHWAYS WITH OVERHANGING ELEMENTS

Iglesias Martínez Luis1, Castro María2, Pascual Gallego Valero3, De Santos-Berbel César4
1 Depto. de Ingeniería Geológica y Minera, E.T.S.I. de Minas y Energía, Universidad Politécnica de Madrid, Madrid, Spain
2 Dept. de Ingeniería Civil: Transporte y Territorio, E.T.S.I. de Caminos, Canales y Puertos, Universidad Politécnica de Madrid, Madrid, Spain
3 Dept. de Estructuras y Física de la Edificación, E.T.S. de Arquitectura. Universidad Politécnica de Madrid, Madrid, Spain

Abstract: Sight distance is a key factor in road safety. Sight distance estimation is usually performed on a digital terrain model (DTM). A DTM is a 3D representation of the terrain surface which depicts exclusively the elevation of the bare ground. However, the reality contains many more elements influencing sight distance than the bare ground. Features such as vegetation, traffic signs, buildings and many other elements are not included in DTMs. The first approximation solution involves the use of digital surface models (DSM), which comprise these roadside features. The use of geographic information systems (GIS) in highway safety research is interesting due to the easy integration of different factors (accidents, traffic data, road features) on the same software platform. However, sight distance studies based on DSM may lead to biased results when there are elements (for example, overpasses, tree branches or cantilever signals) overhanging the roadway that cannot be interpreted by those models. This paper proposes a method to overcome such difficulties. The proposed solution is based on GIS tools (lines of sight) and multipatch datasets, which represent roadside features adequately, added on the DTM. It has been applied in a rural highway located in the Region of Madrid (Spain).

Keywords: road safety, sight distance, geographic information systems.

1. Introduction

Sight distance is a key factor in road safety. In response to this, guidelines for geometric design of roads in different countries set minimum sight distance threshold values (Ministerio de Fomento, 2000; AASHTO, 2011; FGSV, 2012). In order to facilitate the geometric design of roads, some guidelines for geometric design of roads proposes a two-dimensional analytical methodology to estimate available sight distance. Particularly, Easa (2009) devised a 2-D method to calculate sight distance on sag curves with overpasses. Nevertheless, these procedures may not be practical since they consider separately horizontal and vertical alignment, which may lead to overestimate or underestimate the actual available sight distance (Ismail and Sayed, 2007). It is more common instead, to develop an algorithm based on line-of-sight loops on digital terrain models (DTMs), using therefore a 3-D approach. Such procedures retrieve the cross-sectional profile of the terrain below the line of sight between the observer and the target location, identifying any possible obstruction. Ismail and Sayed (2007) devised a precise algorithm to compute the available sight distance. Besides algorithms based on line-of-sight loops, procedures based on viewsheds were developed to study available sight distance of roads (Castro et al., 2011; Jha et al., 2011).

Computer-aided applications for road design estimate and compare available sight distances to stopping sight distance and passing sight distance. They also include visualization tools that simulate the driver’s perspective while travelling (Kühn et al., 2011; Castro, 2012). Such visualization tools are utilized to supervise proper 3-D alignment coordination, yet it requires this checking procedure is performed by experienced engineers (Larocca et al., 2011). Methods based on line-of-sight loops enable the depiction of sight-distance graphs. These charts represent on the horizontal axis the stations where the driver is sequentially placed, and on the vertical axis the sight distance variables ahead each driver position (Kühn and Jha, 2011; Castro et al., 2014). Besides the comparison available and required sight distances, such charts are advantageous to evaluate the 3-D alignment coordination (Roos and Zimmermann, 2004; Jha et al., 2011; Castro et al., 2015). The German Road and Transportation Research Association provided a framework both for virtual perspective generation and sight-distance graphs on the design of rural highways (FGSV, 2008). Methods based on line-of-sight loops can be implemented on geographic information systems (GIS) (Castro et al., 2014). This approach is interesting because GIS enable that different factors and features may be treated and the data analyzed on a single software platform. For example, factors such as sight distance, geometric design consistency (Dell’Acqua, 2015), accidents, traffic data and road features can be studied together (Altamira et al., 2010; Castro and De Santos-Berbel, 2015).

A DTM is a 3-D representation of the terrain surface which depicts exclusively the elevation of the bare ground. However, the reality contains many more elements influencing sight distance than the bare ground. Features such as vegetation, traffic signs, buildings and many other elements are not included in DTMs. The first approximation solution involves the use of digital surface models (DSM), which comprise these additional roadside features (Khattak and Shamayleh, 2005). DSMs provide, in fact, further information about elements by the roadsides which could not be depicted in the available sight distance. However, the intrinsic features of DSMs make difficult such sight distance analysis when using these entities that do not enable two points on its surface to have the same plan projection while their heights are different. This fact hinders a reliable representation of overhanging features, which is particularly awkward when they

1 Corresponding author: luis.iglesias@upm.es
are partially located above the road, as occurs for tree crowns or cantilever signals. To overcome this issue, Castro et al. (2016) proposed to remove the overhanging part of these elements from DSMs. Campoy-Ungría (2015) proposed a procedure to estimate available sight distance on highways based on prismatic line-of-sight buffers launched directly on a high-density LiDAR cloud of points, not requiring any terrain surface.

This paper proposes an alternative method to address the problem of overhanging features on the roadway. The proposed solution is based on GIS tools (lines of sight) and multipatch datasets, which represent roadside features adequately, added on the DTM. It has been applied in a rural highway located in the Region of Madrid (Spain).

2. Materials and methods

The first part of this section describes the developed procedure for estimation of sight distance based on GIS tools and multipatch datasets. This procedure was applied to a road with a cantilever traffic signal. The case study is presented in the second part of this section.

2.1. Procedure

The developed procedure for sight distance calculations is performed using a geoprocessing model. This model is based on the use of Construct Sight Lines (ESRI, 2016a) and Line Of Sight (ESRI, 2016b) tools from the 3D Analyst extension of ArcMap. Line Of Sight tool may not only use a DTM and a file containing the points that define vehicle track, but obstructions consisting of a surface (multipatch).

The data required to launch this geoprocessing model comprises the theoretical path followed by a vehicle, a DTM recreating the highway and its roadsides and a multipatch model that includes the possible roadside obstructions to vision. Three stages have been followed so as to enable the study of sight distance:

1) Terrain model processing

The DTM used with this procedure can be obtained from different sources. In this case, a high resolution scanning LiDAR was used to obtain the cloud of points. To create such model, the cloud of points needs first to be processed and classified. Whereas the points within the ground class will define the DTM, the points captured on the cantilever signal define another interesting point class in this case study. The scheme in Fig. 1 shows the procedure for processing those data. The point processing includes change of coordinate system as well as automated and manual classification. These operations were carried out using highly efficient, batch-scriptable, multicore command line LiDAR tools. These tools can be run via toolboxes for ArcGIS and are included in the LAS tools software suite (Rapidlasso, 2016). The change of coordinate system was performed using las2las (transform), ground classification was performed using lasground, and manual classification was performed using LAS datasets tools of ArcGIS.

2) Construction of multipatch model

A multipatch is a 3-D geometry used to represent the outer surface, or shell, of features that occupy a discrete area or volume in 3-D space (ESRI, 2016). This type of geometry can be constructed with other non-GIS 3D software packages such as Collaborative Design Activity (COLLADA) and SketchUp.

In order to build the multipatch model, the points identified as a cantilever traffic signal during the processing stage were used to set the dimensions of signal. These dimensions were used to define the multipatch model and build the model using 3-D design tools (3D Builder [Microsoft, 2016], and Google SketchUp [Trimble, 2015]). Once the model was built up, an interchange file format COLLADA was used to import the feature into ArcGIS. The exact positioning of model was performed in ArcScene, creating a new multipatch shapefile and using 3-D editor tools,

3) Geoprocessing model launch

Geoprocessing model was built into ArcGIS ModelBuilder. The procedure proposed was based on Construct Sight Line and Line Of Sight tools of ArcGIS (Fig. 2). Prior to launch Construct Sight Lines, it is necessary to convert the 2-D point feature class into a 3-D feature class as well as to input the observer and target point heights. This was made using Interpolate Shape and Calculate Field of ArcGIS tools. In order to apply the Line Of Sight tool, the computation model only considers lines matching the observer and stations ahead, up to a maximum given distance. After launching the Line Of Sight tool, a Feature Layer was created and added to a Geodatabase. Finally, detailed sight-distance graphs can be drawn if data are exported to a spreadsheet.

2.2. Case study

The procedure developed was applied on a two-lane rural highway (M-601) located in the Region of Madrid (Spain). A section including a cantilever traffic signal was selected as test site. Fig. 3 shows the actual appearance of the roadway and the roadsides in the section at the cantilever signal position. Fig. 4a shows the vertical alignment of the highway around the cantilever signal, located at station 950, on a grade between a crest vertical curve and a sag vertical curve. Fig. 4b shows the plan view, where the cantilever signal is on a tangent located after a horizontal left curve and before a roundabout followed by a horizontal right curve. The crest vertical curve overlaps, approximately, the horizontal left curve and the sag vertical curve matches, approximately, the horizontal right curve.
Fig. 1.
Terrain model processing schema

Fig. 2.
Flowchart of the geoprocessing model
First, in order to validate the new geoprocessing model, its performance is to be compared with the previous Add-in, developed by the authors (Castro et al., 2014), through the calculation of sight distance in four scenarios:

- Scenario 1: Using the previous Add-in and DTM (without cantilever signal),
- Scenario 2: Using the previous Add-in and DSM (including intrinsically cantilever signal),
- Scenario 3: Using the new geoprocessing model and DTM (without cantilever signal),
- Scenario 4: Using the new geoprocessing model and DSM (including intrinsically cantilever signal).

In these four previous scenarios, sight distance parameters took values according to the Spanish highway design standard (Ministerio de Fomento, 2016):

- Vehicle path: 1.5 m from the centerline,
- Driver’s eye height: 1.1 m,
- Target object height: 0.5 m/

The vehicle path was extracted from the cartographic data of the highway. The two procedures for calculating sight distance use an algorithm based on line-of-sight loops, hence the vehicle path has to be defined as a discrete set of stations. They are spaced 5 meters apart along such path, where driver and target are successively placed while performing the loop. From each of those stations where the driver’s eye is located, the application checks whether a target located in the stations ahead is actually seen or, on the contrary, the line of sight is intercepted by the DTM surface.

In all cases, roadway and roadside were modelled from a high-resolution set of 3-D points. These points were obtained through three LiDAR devices mounted on a car travelling along the road (Mobile Mapping System IPS2-Compact of Topcon). There were two sideward-oriented laser devices and a third one downward oriented, all of them installed at vehicle rear. Other components of the equipment are used for locating and orientating the survey. The GNSS device provides geospatial position, IMU device provides orientation and odometer the distance travelled, speed and angle of rotation of the vehicle wheels (Topcon, 2010). Vehicle speed during data collection was circa 50 km/h; consequently, the set of points is arranged in 12-centimetre spaced cross sections. As mentioned in previous section, the LiDAR devices saved the points in LAS format. Then, the LAS file was processed through the software LASTools so as to be usable on ArcGIS.

Additionally, four scenarios were studied using the new geoprocessing model, the DTM and the cantilever signal (modelled as a multipatch). As mentioned in the previous section, two pieces of software were used in order to build up the cantilever signal multipatch: 3D Builder (Blender) and SketchUp. The first one was used to build the model and the second one to export it as COLLADA format file. Finally, the COLLADA file was imported in ArcGIS. The characteristics of these four scenarios, including cantilever signal multipatch to validate the new procedure, were:

- Scenario 5: Using the new geoprocessing model, DTM (without cantilever signal) and cantilever signal modelled by multipatch. Vehicle path: 1.5 m from the centerline; driver’s eye height: 1.1 m; target object height: 0.5 m,
- Scenario 6: Using the new geoprocessing model, DTM (without cantilever signal) and cantilever signal modelled by multipatch. Vehicle path: 1.5 m from the centerline; driver’s eye height: 2.5 m; target object height: 0.5 m,
- Scenario 7: Using the new geoprocessing model, DTM (without cantilever signal) and cantilever signal modelled by multipatch. Vehicle path: 1.5 m from the centerline; driver’s eye height: 6 m; target object height: 0.5 m,
- Scenario 8: Using the new geoprocessing model, DTM (without cantilever signal) and cantilever signal modelled by multipatch. Multipatch was displaced to station 900 m. Vehicle path: 1.5 m from the centerline; driver’s eye height: 6 m; target object height: 0.5 m.
Fig. 4.  
a) Road vertical alignment (profile view);  
b) plan view showing stations and the cantilever signal location (scenarios 1 to 7)

3. Results and discussion

Sight distance was studied for the validation of the new procedure on the eight scenarios set out and analyzed through the corresponding sight-distance graph. It is a chart in which stations are on the horizontal axis and sight distance, measured along the vehicle track, is on the vertical axis. Each green cell represents stations ahead the driver that are seen while the red ones depict non-seen stations, at the distance given by the vertical axis. Finally, the chart is characterized by a blue line which quantifies the available sight distance at each station.

Fig. 5 shows the different sight distance outcomes of the scenarios 1 to 4. Fig. 5a shows the sight-distance graph corresponding to scenario 1 (i.e. using the previous add-in and DTM). In this graph, the available sight distance decreases between stations 480 and 650 due to the horizontal left curve and the vertical crest. In contrast, it increases again as the driver leaves these alignments behind. Fig. 5b shows the sight distance results corresponding to scenario 2.
(i.e. using the previous add-in and DSM, including cantilever traffic signal). Although the results of scenario indicate that there is a strong reduction of the available sight distance down to zero as the driver approaches the cantilever traffic signal (station 950), the actual visibility conditions greatly differ from that as it can be noticed in Fig. 3. This bias in the results flags the issue when using DSM since cantilever features cannot be shaped. Fig. 5c shows the sight distance results corresponding to scenario 3 (i.e. using the new geoprocessing model and DSM). Results from scenario 1 and 3 match at 99%. Similarly, Fig. 5d shows the sight distance outcome corresponding to scenario 4 (i.e. using the using the new geoprocessing model and DSM, including cantilever traffic signal). As occurred in scenario 3, there is a biased result in scenario 4 on the section prior to the cantilever signal. Likewise, results from scenario 2 and 4 match at 99%. Both scenarios 2 and 4 highlight the problems of sight distance studies based on DSM when there are elements such as the cantilever signal overhanging the roadway that cannot be correctly interpreted by those models.

On the other hand, Fig. 6 (scenarios 5 to 8) shows the outcome of the new procedure based on the new geoprocessing model, the DTM and the multipatch (the cantilever signal is modelled as a multipatch). Note that the new procedure, based on the geoprocessing model, uses the ArcGIS function Line Of Sight whilst the previous procedure (Add-in) use the ArcGIS function Get Line of Sight. Line of Sight function considers multipatches as possible hindrances to vision while the Get Line of Sight function does not. In the case of a car driver (driver’s eye height = 1.1 m), the cantilever signal does not reduce visibility (Fig. 6a). This occurs because the height of top and bottom parts of the cantilever signal above the terrain are, respectively, 7.5 and 4.5 m. It would be more likely that the cantilever signal reduces the visibility in the case of a truck driver (driver’s eye height = 2.5 m), but as this cantilever signal is on a grade, this does not happen either (Fig. 6b). From the comparison of Fig. 6a and 6b, it can be deduced that visibility conditions are more favorable for the truck driver than for the car driver as the red area in the chart is more reduced. These scenarios (5 and 6) show that the new procedure provides unbiased results (in agreement with the fact that the line of sight goes under the cantilever signal). However, in order to validate the new procedure, it is necessary to simulate a case where lines of sight intersect the traffic signal. Thus a driver’s eye height of 6 m was considered in scenario 7. Fig. 6c (scenario 7) shows indeed a sharp decrease of the available sight distance due to the traffic signal around station 950. Furthermore, multipatch objects could be placed easily at any location. In this way, object (multipatch) location effect on visibility could be easily simulated. Fig. 6d (scenario 8) shows sight distance diagram corresponding to traffic signal location at station 900, displacing the multipatch backwards. In this case, the available sight distance is reduced due to cantilever signal at around station 900.

Fig. 5.
Sight distance results: a) Scenario 1 (using the previous Add-in and DTM, without cantilever signal); b) Scenario 2 (using the previous Add-in and DSM, including cantilever signal); c) Scenario 3 (using the new geoprocessing model and DTM, without cantilever signal); d) Scenario 4 (using the new geoprocessing model and DSM, including cantilever signal)
Fig. 6.
Sight distance results using the new geoprocessing model, DTM and cantilever signal modelled by a multipatch: a) Scenario 5 (driver’s eye height: 1.1 m); b) Scenario 6 (driver’s eye height: 2.5 m); c) Scenario 7 (driver’s eye height: 6 m); d) Scenario 8: cantilever signal were moved to station 900 m; driver’s eye height: 6 m

In this case study, the multipatch was built from a real element of the highway whose dimensions were determined by LiDAR surveying. However, due to the availability of multipatch datasets libraries, these studies could also be directly inserted. In this way, several objects could be simulated with less effort.

4. Conclusions

A new 3-D procedure for sight distance estimation was developed that overcomes the difficulties inherent to the presence of overhanging elements. This procedure was checked and validated by means of a comparison with a previously developed procedure. The new procedure is able to yield an unbiased sight distance outcome since, unlike procedures based exclusively on DTMs or DSMs, it builds up a real 3-D depiction of the highway and its roadside features. It may be useful, for example, to model either brand new or already-built highways where overhanging elements influencing sight distance such as trees or gantries could be present. This fact was shown by means of the cantilever traffic signal case study.

The easiness to place multipatch objects is an additional advantage provided by this procedure. This simplifies the simulation of object location to evaluate its possible effects on sight distance. Also, due to the availability of multipatch datasets libraries, modelling effort is reduced. Therefore, several objects on diverse locations could be easily simulated. Moreover, the use of GIS offers further advantages owing to its capabilities, the data integration, information management and analysis tools. Therefore different factors such as sight distance, accidents, operating speed, traffic volume and geometric features can be treated and analyzed on a single software platform.

As future lines of research, authors plan to apply this procedure to analyze the effect of overhanging elements on sight distance at or near sag vertical curves, overlapped with different alignments on the horizontal plan. Elements such as cantilever traffic signals could reduce drivers’ available sight distance. Factors such as traffic signal location (station along the road), signal dimensions, clearance height and highway geometric design features will be taken into account.

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