Interurban visibility diagnosis from point clouds

Óscar Iglesias¹, Lucía Díaz-Vilariño²*, Higinio González-Jorge¹ and Henrique Lorenzo¹

¹Department of Natural Resources and Environmental Engineering, Campus Lagoas-Marcosende, 36310, Vigo, Spain
²Department of Cartographic and Land Engineering, Calle de los Hornos Caleros, 50, 05003, Ávila, Spain
*Corresponding author, e-mail address: lucia@usal.es

Abstract
We present an approach for automatic visibility analysis in interurban roads from point clouds. The methodology is based on a ray-tracing algorithm followed by an occlusion detection to identify potential obstacles between the driver and the theoretical position of pedestrians and cyclists. As a result, the area of visibility from each driver position is obtained. The method compares the performance and suitability of point clouds acquired from both Airborne and Mobile Laser Scanning. The methodology is tested in six real case studies. In most cases, results obtained from MLS are more accurate since the point clouds are acquired from a perspective similar to driver and they have higher resolution.

Keywords: Visibility, point clouds, Mobile Laser Scanning, Airborne Laser Scanning, road safety.

Introduction
Enhancing traffic safety is an on-going request. Despite of the reduction of accident rates during the last decade, traffic accidents still cause large number of human injuries and huge economic losses. Pedestrians and cyclists are the most vulnerable group of road users and efforts are needed towards a zero accident concept [Shinar, 2012; COST, 2014]. According to the European Transport Safety Council (ETSC), 31% of pedestrian deaths occurs on interurban roads (including rural roads and motorways). In addition, collisions with cars make up slightly more than a half of the total number of cyclist deaths in the EU (52%) [Adminaite et al., 2015].

Road safety problem for pedestrians and cyclists is being quite documented [World Health Organization, 2004], and high efforts are made to analyse the causes of crash incidences for road users according to the characteristics of the built environment. Poor visibility is highlighted as one of the most important causes of road accidents [Hills, 1980]. One of the corrective actions aimed at solving the lack of visibility in roads has been adding reflectance elements to the pedestrians and cyclists, such as reflective vests to get better visibility when illumination in roads is low [Kwan et al., 2002]. However, low levels of illumination are not
the only cause. The design of roads, both their geometry and their traffic speeds, is a critical aspect for visibility because roads are often designed as desirable for motorist safety while not for pedestrians and cyclists [Dumbaugh and Li, 2010]. Therefore, analysing the design of roads in terms of visibility is fundamental for detecting and quantifying dangerous road areas such as curves or hills.

Visibility analysis demands realistic 3D models of roads and their environment [Biljecki et al., 2015]. The as-built conditions of a road often differ from the as-designed ones because roads can be subjected to changes in the layout when they are being constructed. New constructions and the growth of vegetation can modify their environment [Ural et al., 2015]. Mobile Laser Scanning has been well-established for infrastructure inventory analysis and routine inspection [Varela-González et al., 2014]. Intense efforts have been focused in recent years to facilitate the automatic process of mobile scanning data, with special emphasis on object modelling and recognition. There is a wide range of literature on the segmentation of road, elements, and their related environment from MLS point clouds. Yang et al., [2013] provide a detailed review about this topic. Riveiro et al. [2015] approach the automatic detection of zebra crosses in urban environments, while Iván Puente et al. [2014] focus on the task of detection of luminaries in road tunnels. Even more, Serna and Marcotegui [2013] review several approaches for tackling the detection, segmentation, and classification of urban objects in order to assure freedom for vulnerable people. The focus of this work is the visibility analysis in interurban areas from point clouds. The method establishes a comparison between Mobile Laser Scanning (MLS) and Airborne Laser Scanning (ALS) to determine limits and suitability of both data sources for visibility analysis. This work is part of the project: “Reduction of run over cases through analysis of driver - pedestrian visibility using MLS data”, aiming to determine road safety in as-built conditions for a vulnerable group (pedestrians and cyclist) with the final objective of reducing the probability of accidents in interurban areas.

The methodology starts with the segmentation of the point cloud. Segmentation is the process of dividing a point cloud into a number of disjointed subsets which are spatially connected [Rabbani, 2006]. In this work, road pavement is removed automatically and separated from roadside elements, vegetation, and other elements. This distinction is made by various factors. First of all, point clouds of roads are typically massive and calculations with them are computationally expensive. Thus, a strategy to simplify the dataset is welcomed. It is assumed that road extraction does not influence in the visibility area as the objective of the work is trying to identify objects or roadside elements that interrupts vision. In addition, extract the road from the point cloud will help the workflow by defining afterwards the trajectory of the vehicle with this road section.

After that, a ray-tracing algorithm is implemented to calculate visibility in the Line Of Sight (hereinafter referred as LOS) [Alsadik et al., 2014; Previtali et al., 2014] between car and pedestrian/cyclists, taking the theoretical position of driver eyes as the starting point of the LOS. The LOS is rotated on the vertical axis, taking into account the trajectory of the vehicle and the field of view of the driver. For each position of the LOS, a buffer is created to detect potential visibility occlusions. If the buffer intersects with point cloud an occlusion may occur and this can be classified as a non-visibility area, dangerous for both the pedestrian and the vehicle driver.

The proposed methodology is evaluated through different real case studies acquired from
interurban roads in Galicia (Spain). These cases have been selected in areas surrounded by different environments and roadsides elements with the aim of validating algorithms and techniques developed in this work regardless the properties of the area of analysis. This paper is organized as follows. Section “Related work” reviews the related work in the state of the art of visibility analysis from point clouds in road environments and establishes the main differences with regard to this work. Section “Methodology” explains the visibility analysis methodology, while Section “Results and discussion” introduces the data acquisition devices and presents the comparative results for the MLS and ALS from applying the methodology to several case studies. Finally, Section “Conclusions” deals with the main conclusions extracted from this work.

Related work
Visibility problem is a major computer graphics topic and several approaches have been treated already. For instance, Alsadik et al. [2014] study different techniques for visibility analysis with point clouds obtained from photogrammetry [Rothermel, et al., 2012], showing the differences between the techniques and their pros and cons. They summarize techniques for visibility analysis in three groups. The first group corresponds to the triangulation approaches, wherein the normal direction of the triangles or the intersection of the parts of the triangulated models with the LOS are studied. The second group refers to voxel approaches: methods with models expressed as voxels where it is verified if the voxels intersect LOS from different points of view. Hidden Point Removal (HPR) approach is the last technique which consists in the projection of the convex hull of the object that can be seen from one point.

Yin et al. [2012] review some visibility techniques based on sight calculations and projection methods. They create models to calculate visibility in urban areas for urban planning purposes. With the same aim, they introduce visual field analysis. In this approach, one point is took as point of view and, for all the possible LOSs around all the directions from this point, the immediate obstacle is calculated. This approach is taken into account for the method proposed in this article.

In terms of road visibility, there is a need to know which are the roads and areas where an accident is more probably to happen and to guarantee vision between drivers and pedestrians. This can be done by the analysis of Available Sight Distance (ASD) and some more related variables in roads such as Stopping Sight Distance (SSD), Decision Sight Distance (DSD), etc. The ASD [Campbell, 2012] indicates the distance free of obstacles from a point of the vehicle trajectory to another point further ahead on the route. This value can give an idea of “how much safe a road is” and so, it can be useful to identify potential danger zones and possible crashing or outrage areas where pedestrians may be in danger. In this work, an adaptation of ASD is proposed and it is shown as a projected area on the 3D models that define the roads and their surroundings.

Different approaches to calculate ASD from point clouds and stereovision are addressed by Tarel et al. [2012]. They implement a ray-tracing algorithm, but they run it in a triangulation instead directly in the point cloud as this work approaches. Another example using the ASD technique for visibility analysis in roads is the one proposed by Hassan, Easa, and El Halim [1996]. They use parametric finite elements, resulting in a quite expensive computational technique. Mertzanis et al. [2015] modify the technique of ASD to calculate SSD (the
distance a vehicle driver needs to be able to see in order have room to stop before colliding with something in the road). However, they build their own 3D models and do not test the algorithm in real examples.

Most part of visibility analysis research, including pedestrian considerations, is focused on urban environments, where improving the safety of pedestrians is of great importance. Several articles propose the integration of LiDAR sensors inside cars to detect pedestrians with risk of suffer an accident. For example, Ogawa et al. [2011] present an approach for the detection of pedestrians based on a LiDAR system integrated inside the cabin of vehicles that implements a method for tracking pedestrians and a pattern recognition to define road lanes in order to estimate a risk for the pedestrian. Even more, Broggi et al. [2009] have built an automatic mechanism that while detecting pedestrians, it proceeds with an automatic breaking system in danger situations but it is limited to a few danger cases.

Several studies have proposed the creation of Digital Elevation Models (DEM) from MLS and ALS data in order to compare their performance in sight distance analysis [de Santos-Berbel et al., 2014]. Castro et al. [2015] go in deep with the effect of model resolution by doing a statistical analysis. They conclude that model resolution has influence on the visibility results, but they find problems when some elements overlap roadway areas and they need to pre-process their models to get a good result. Liu et al. [2007] and Tomljenovic and Rousell [2014] have analysed the relation between accuracy of DEMs and density of point clouds. The results show the point cloud characteristics or requirements that should be selected for certain tasks or studies. For being able to detect occlusions in ASD, the proposed algorithm needs more resolution than the one studied in [Tomljenovic and Rousell, 2014; Liu et al., 2007], so the models used in this article have a higher resolution covering a wider range of point cloud density.

With respect to other works in the state of the art, we aim at obtaining visibility areas at interurban roads from the point of view of driver and compare the results given by different data sources (ALS and MLS) to analyse the limitations of both data sources.

The final objective is to develop a complete methodology to diagnosis of road visibility from the point of view of the driver. At the same time, the parameters of the algorithm must be optimized to obtain the most accurate results of the actual available visibility depending on the point cloud density in each case study. The visibility algorithm proposed in this work is automatic. The only process that needs to be done manually is the selection of the vehicle direction once that the trajectory gets defined with the road extraction.

Methodology

The methodology presented in this paper is summarized in Figure 1. The methodology starts with acquisition and pre-processing of data (section “Data preprocessing”) in order to build a 3D model. After that, a visibility analysis is performed on the model (section “Visibility analysis design and parameter determination”) taking into account the occlusion condition (section “Occlusion detection”). As result, a 2D area is obtained as an estimation of the visibility in each section of the road.
Data preprocessing

First step of the methodology consists on segmenting point cloud to determine which part of the 3D model belong to road and which correspond to non-road elements or roadsides. As long as two different data sources are compared in this study, ALS and MLS, the segmentation process is different because it depends on the quality of data source. In case of MLS datasets, segmentation is based on the calculation of curvature, roughness features, and subsequent comparison of normal directions. These features have been calculated with Cloud Compare Software (http://www.danielgm.net/cc/). The road is defined as a smooth (it is required that roughness has a value of less than 1 mm), plane (from curvature analysis, the road is defined as a section with zero curvature), and one-directional (from normal analysis, an average normal direction is obtained and the points with similar normal are considered).

With regard to ALS datasets, the methodology is modified in order to obtain an accurate road segmentation. The criterion described above does not work with low density datasets and minor changes in curvature or roughness would not be detected resulting in a wrong road segmentation. In this case, segmentation proposed for the airborne datasets consists in analysing the differences on the elevation of neighbouring points. The gradient of the height scalar field in road areas is close to zero.

One of the purposes of this paper is to compare data sources for visibility analysis in interurban environments. If ALS point cloud is not denser enough to compare it with

![Workflow of the proposed methodology.](image-url)

Figure 1 - Workflow of the proposed methodology.
correspondent MLS point cloud, it is submitted to a Delaunay Triangulation in order to reconstruct a surface model and, after that, resample the point cloud with the desired density. Finally, segmented road is used to define the position of the drivers’ point of view along the road. According to regulation [Ministerio de Fomento, 1999], the point of view of the driver is fixed in a distance of 1.5 m from the external border of the lane to the car. Therefore, driver position, to which the ray-tracing algorithm is applied, is estimated from the segmented road.

**Visibility analysis design and parameter determination**

The visibility analysis conducted in this study is based on a ray-tracing algorithm, which consists on creating a LOS from one point to an objective point, and check that there are not obstacles causing occlusions between the beginning and the end of the LOS [Alsadik et al., 2014]. In this methodology, LOS starts in the position of driver eyes (1.1 m. above car trajectory on road surface [Ministerio de Fomento, 1999] and continuous in the direction of the car trajectory.

With the objective of detecting all occlusions that might cause some visibility problem, scan is carried out all around the horizontal field of vision of the driver for each position of the trajectory. In order to achieve this task, the LOS is rotated counterclockwise around the vertical axis through the field of peripheral vision, forming an angle of ±60º with the centred LOS represented by adopted line on Figure 2. Left side directions are taken as negatives as it is shown in Figure 2 [Spector, 1990; Bhise, 2011].

![Figure 2 - The peripheral vision angle is considered of ±60º centred in the position of driver eyes.](image)
LOS rotation is carried out by varying a rotation angle (Δ) in the horizontal plane as the algorithm detects an occlusion (Fig. 3). The angle of rotation of the LOS through the X-Y plane (Δ) is determined in order to ensure that the whole field of view is scanned (Eq. [1]).

\[
\arctan(\Delta) = \frac{r}{d} \Rightarrow \arctan(\Delta) = \frac{0.25}{150} \Rightarrow \arctan(\Delta) = 0.0017 \text{ m} \Rightarrow \Delta = 0.1^\circ
\]

Figure 3 - Image with buffer and delta calculation representation. The yellow circle indicates the point of view of the driver.

In order to define a maximum distance to occlusion, in this approach we consider that a car driving at 100 km/h can stops in a distance (d) of 150 m [Dirección General de Tráfico, 2015]. Henceforth, considering a car driving at 100 km/h, the maximum distance to occlusion is fixed as 150 m. This parameter is taken into account for presenting the methodology but it should be corrected according to the car technical specifications and the environmental conditions (i.e. weather).

Occlusion detection is performed by looking for points of the 3D model in a cylinder around the LOS with a radius (r) of 0.25 m. Authors consider that a cylinder of 0.5 m diameter of vision should be enough to detect a person.

As a result, a polyline is formed with the occlusions detected by the algorithm. Projecting this area onto the X-Y plane, a surface is defined and it corresponds with the area of visibility available from one point of the driver trajectory (Fig. 4).
The projection takes in account only x and y components of the points detected as occlusions and the area of the polygon is calculated utilizing the Gauss formula in the 2D projected line (Eq. [2]).

\[
Area = \frac{1}{2} \left| \sum_{i=1}^{n} (u_i v_{i+1} - u_{i+1} v_i) \right|
\]

where, \( u \) and \( v \) are the vectors with the x and y components of the list of vertex of the polygon, respectively, and \( n \) is the number of vertexes of the polygon, taking the position of the vehicle as first and last vertex. The visibility analysis together with the occlusion detection explained in the next subchapter have been implemented in Matlab software.

**Occlusion detection**

In the proposed approach, occlusion is defined as the existence of a determined number of points of the 3D model that interrupt the LOS between the driver and the object that needs to be seen, being pedestrians the objective to detect. There could be some points in the model that are not defining a real element of the actual road or these points belong to an object that has not the volume enough to behave as an actual obstacle. Therefore, it is needed to define a condition to consider when the occlusion detected in the model can be considered as a real obstacle for occluding vision of a pedestrian.

For each LOS, a cylindrical volume is created around this LOS and the algorithm checks if there are points of the point cloud inside the cylinder. In the case of a point is detected inside of the cylinder, it is needed to know if it is an isolated point, which do not affects the visibility, or if it corresponds to a cluster of points that avoids visibility.

Occlusion condition depends on the local density of the 3D model. Therefore, the number of points in the surroundings is evaluated in the volume where the point detected is located.
This local density is calculated as the number of points of the model that are inside of a sphere with centre in the LOS and with the radius fixed in buffer radius. Figure 5 gives a representative example of the occlusion condition algorithm.

![Figure 5 - Representation showing how the algorithm apply the occlusion condition.](image)

To summarize, it can be said that the existence of an occlusion in the model is defined as the existence of n points of the point cloud inside a sphere of a 0.5 meter radius with the centre in any point along the LOS. As the purpose is to detect obstacles affecting to pedestrians or cyclists, authors consider that analysing the environment between 0.5 m below and 0.5 m above driver position is enough. The election of the number of points that should be inside the sphere to consider it occlusion determines the resulting visibility area, as it can be seen in the Figure 6.

![Figure 6 - Different conditions in the occlusion for the algorithm. Black arrow indicates the direction and position of the car.](image)

In order to establish the optimum number of points, point clouds with different density are generated to analyse the variation of the visibility area depending on the occlusion condition.
Through the process of the analysis of different case studies, 3D models of the same sections of roads with different point cloud density are created to compare the performance. Point cloud density is calculated with Cloud Compare v2.6.1 software taking as density value the number of points inside a sphere of one meter diameter. Note that density is a local value that varies along the point cloud. The mean value of density is used just as an approximated way to compare models.

Results and discussion

Data sources
The methodology has been tested through two different data sources (ALS and MLS) to determine the usability of open access ALS data from Spanish geography provided by the Centro Nacional de Información Geográfica (CNIG) [2015]. The ALS point clouds have a density of 0.5 points/m², including colour, and are obtained with the LMQ-Q680i LiDAR [RIEGL, 2015]. With regard to MLS, data is acquired with a LYNX MOBILE MAPPER [OPTECH, 2015] installed in a van. Both systems are based on the technique of Time of Flight (TOF) as measurement principle and their characteristics according to the manufacturer datasheet are summarized in the Table 1 [Puente et al., 2013; RIEGL, 2015].

| Specifications                  | Mobile LiDAR          | Airborne LiDAR         |
|---------------------------------|-----------------------|------------------------|
| Maximum range                   | 200 m (@20%)          | 2000 m (@20%)          |
| Range precision                 | 8 mm (1)              | 20 mm (1 m)            |
| Range accuracy                  | ±10 mm (1)            | 20 mm (1 m)            |
| Laser measurement rate          | 75-500 kHz            | Up to 266 kHz @ 60° scan angle |
| Scan frequency                  | 80-200 Hz             | 10-200 Hz              |
| Laser wavelength                | near infrared         | near infrared          |
| Scanner field of view           | 360°                  | ±30° = 60° total       |
| Operating temperature           | 10°-40° C             | 0°-40° C               |
| Angular resolution              | 0.001°                | 0.001°                 |

Visibility analysis design
The algorithm proposed for visibility analysis is sensitive to some parameters. In order to check the sensibility of the Δ value, the algorithm has been run with different values for rotation angle. Results show that an angle of 0.1° (selected for being able to detect an occlusion at 150 m) does not show important differences with the minimum angle studied (0.01°). Variations of the angle under 0.01° do not affect the result of the algorithm, so they are not studied (Fig. 7). Methodology has been tested in six real case studies. All of them are collected in Galicia, a region in the Norwest of Spain, and they have been selected according to the elements of their roadside in order to ensure representativeness and consistency. For each case study, visibility area has been compared for both data sources and elements in the point cloud that do not reproduce accurate results have been analysed in order to determine their limits for visibility analysis.
Figure 7 - Different curves representing the area of visibility in function of the occlusion condition.

Figures 8-13 show the results obtained from each case study. On the left, the plan view of the road is represented, showing the position of the vehicle in the road and two areas of visibility: the red one, calculated from ALS, and the blue one, calculated from MLS. On the right, figures represent the specifications of the area of study, the legend, and a photography of the road from a driver point of view in the direction of the vehicle.

**Case Study 1**
The Case Study 1 is represented in Figure 8. On the right side of the road, there is a continuous guardrail and several trees and brushes behind it, meanwhile on the left side of the road there is a continuous slope with brushes in the upper part.

Figure 8 - Case Study 1.
The results for visibility analysis show a similar limit for both data sources with regard to the left side. The slope behaves as a clear occlusion for both data sources because it can be correctly surveyed by MLS and ALS. On the right side, it is appreciated that the algorithm finds more occlusions while using MLS than using ALS. This difference can be explained by the detection of the guardrail when using MLS data while not with ALS. This behaviour is caused because the guardrail is a thin and vertical element and it is not well depicted by airborne point clouds due to their low density and the point of view of ALS during acquisition.

Case Study 2
The Case Study 2 (Fig. 9) corresponds to another section of the same road as in the previous Case Study 1. In this case, there is a continuous rock slope at both sides of the pavement with vegetation on the upper part. Because both slopes are correctly surveyed by MLS and ALS, results show the identification of slopes as visibility occluders, obtaining a similar result in terms of visibility area for both data sources.

Figure 9 - Case Study 2.

Case Study 3
The Case Study 3 corresponds to a road section with a small slope on the left side with large amount of vegetation and on the right side sparse vegetation including isolated trees, etc (Fig. 10). The results show that both techniques identify the occlusion produced by the mountain terrain on the left side of the road. However, there are some differences on the right side (Fig. 10). Triangulation method applied to ALS data to improve point cloud density increases the size of small objects and magnifies an occlusion and causing a restriction of visibility area with regard to MLS data.
Case Study 4
In the Case Study 4, road is placed in a village where there are several isolate buildings, roadside elements such as traffic signals and vegetation making both sides of the road very different. Figure 11 shows the results of visibility analysis and it is noticed a high disparity in resulting areas from MLS and ALS. The reason corresponds to the existence of some elements such as refuse containers and notice boards, that are described in a very good manner from MLS point clouds but not from ALS point clouds due to their low resolution. When ALS point clouds are resampled through a Delaunay triangulation (Section “Data preprocessing”), the resulting point cloud does not allow to clearly identify some elements with little spaces between elements such as buildings, close bushes or refuse containers. Therefore, in this case, small spaces between elements are treated as real obstacles while they do not occlude the actual visibility of drivers.
Case Study 5
Case Study 5 is shown in Figure 12. Both methods show differences in the areas obtained by the algorithm. This road is another section of the road of Case Study 4 and it can be seen that in the presence of several buildings and roadside elements the area of visibility calculated by the algorithm considerably varies depending on the data used as case study. In road surface both systems agree in the fact that the road is visible for the driver. In the situation of buildings and roadside elements, the methodology used with ALS shows a shorter visibility in almost all directions, because of the non-accurate volume of objects implemented by the triangulation used to resample the point cloud.

Case Study 6
In Case Study 6, both methods claim that all the road in front of the car is visible (Fig. 13). The differences come up when looking at the result of the area of visibility outside the road, where ALS and MLS are not congruent. The triangulation done in the preprocessing increases artificially the real volume of trees and vegetation (as happens in Case Study 4 and Case Study 5) and this fact produces occlusions that are not detected when the algorithm uses MLS data.
Conclusions

In this work we propose an automatic and robust approach to analyse visibility in roads by detecting the occlusions that can interrupt the Line Of Sight between the point of view of the vehicle driver and the theoretical place where the pedestrian could be. At the same time, this work compares both Mobile Laser Scanning and Airborne Laser Scanning data sources aiming to establish their limits for road visibility analysis purpose.

From the results, the following main conclusions can be drawn:

- The representation of the proposed visibility area increases the quality of the Available Sight Distance based methods giving 2D information, while related works approach the visibility problem in one-dimensional variable;
- The visibility area gives visual information about which areas may became a problem when safety of pedestrians in roads is needed to be ensured;
- The area of visibility is highly dependent of the value of the number of points for the occlusion condition and it is related with the density of the point cloud of the 3D model;
- For most part of the case studies, the results show that the area of visibility is an accurate representation of the actual field of view of the driver from its point of view, for both Mobile Laser Scanning and Airborne Laser Scanning datasets. Furthermore, visibility areas from different data sources are very similar, except for the Case Study 4 and Case Study 5. The addition of buildings, lamp posts, and refuse containers in the model made differences between the results with both data sources and difficult the process to define an accurate area of visibility for the driver;
- The methodology proposed with Airborne Laser Scanning has its limitation in order to get an accurate 3D model of some roadside elements that can interrupt the vision of the drivers when they are too small. In addition, triangulation method applied to improve the density of the point cloud can increase the size of objects generating an under-vision effect (considering some elements obstacles when they are not big enough to occlude a pedestrian in the reality);
- Airborne Laser Scanning data works accurately for the visibility analysis in conditions with a high quantity of vegetation, high walls, and large items, when there are no any roadside elements that data acquisition method could miss. Examples of these good results with the algorithm and Airborne Laser Scanning data are Case Study 2, Case Study 3 and Case Study 6, where the region of the road that is visible from driver’s point of view is obtained accurately.

As future work some improvements in the algorithm technique could be done. Authors would like to research about the application of the visibility analysis to formulate an index of visibility to identify “black points” on roads, determine the optimal maximum speed for some roads attending to the visibility, and check if the horizontal and vertical road signs are adequate to the road characteristics. Another improvement in the algorithm could come from the inclusion of the road slope in the occlusion detection in order to detect in which places the infrastructure can perform as an obstacle for the visibility. Furthermore, adverse weather conditions for driver visibility such as rain and fog are going to be considered for future research as an improvement of the presented methodology.
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