Automatic Traffic Signs and Panels Inspection System using Computer Vision

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Abstract

Computer vision techniques applied to systems used on road maintenance, either related to traffic signs or to the road itself, are playing a major role in many countries because of the higher investment on public works of this kind. These systems are able to collect a wide range of information automatically and quickly, with the aim of improving road safety. In this context, the correct visibility of traffic signs and panels is vital for safety of drivers. This paper describes an approach to "VISUALISE" (VISUAL Inspection of Signs and panEls), an automatic inspection system, mounted onboard a vehicle, which performs inspection tasks at conventional driving speeds. VISUALISE allows for an improvement in the awareness of roads signaling state, supporting planning and decision making on the administration and infrastructure operators' side. A description of the computer vision techniques is carried out as well as some experimental results obtained from thousands kilometers and the conclusions of the system are presented.

Key words:
Traffic signs, Inspection, Evaluation, Dynamic auscultation, Retroreflection

1. Introduction

Nowadays, increase of road safety is a key element of road network's management. Any company, organization or institution responsible for the management and operation of any road network should be able to diagnose the problems related to safety of drivers, to set up an integrated action plan, to coordinate efforts among all the involved organizations, to assign funds and resources, to supervise the implementation of the action plan and to evaluate the effectiveness of the measures taken. In this regard, there is a trend toward maintenance instead of construction, because supervising the damage of the existing roads is more worthwhile than building new roads.

The most difficult decision that an engineer has to take is how and when a road can be restored efficiently. Such an important decision cannot be taken without accurate information about the road's state. Among all the possible actions that can be taken, the evaluation and analysis of the vertical signaling state is vital because of its interrelation with road users.

The European objectives for improving road safety [1] highlight the importance of having a good visibility of traffic signs and panels in order to avoid accidents. In this regard, the European Commission states that making use of technical progress and collecting data of the roads' state is really important in order to detect potentially dangerous situations.

Since it is vital that traffic signs are visible at daytime and nighttime from a suitable distance, the supervision of the quality of vertical signaling is extremely important. Because of the fact that traffic signs are made of retroreflective materials that diminish as time goes by, it is necessary to make a periodic test of vertical signaling.

To date, the inspection and measure of the vertical signaling retroreflection has been made by using static pieces of equipment (retroreflectometers) that need to be in contact with the sign to be measured, thus leading to a clear danger, as operators need to put themselves next to the road, risking their own and other driver's lifes. In addition, it is necessary to close the road when a panel above the road is going to be measured. Therefore, manual devices are not useful to measure all the traffic signs present on the roads.

Typically, a few number of signs and panels are measured in a certain stretch of road, in order to extrapolate the results to the whole road, but this can lead to wrong decisions and it is not efficient at all.

Most of these problems could be solved if the inspection process were automated. However, there are only a few systems that can develop inspection and inventory tasks, and they have some limitations that make them less effective (see Section 2). Among the possible reasons why there is such a small state of the art, one of the most important is related to object detection in images, which is a difficult problem itself, but it is much more difficult when there is a non-controlled environment. In addition, traffic signs and panels have different colours and shapes. On top of that, the necessity of using a mobile platform, typically a vehicle, adds complexity to the problem, especially in a scenario where there is an uncertain number of mobile objects.

VISUALISE system has been developed as a solution to the vertical signaling inspection process. It has to be seen as a tool that allows us to know the traffic signs' state, according to the corresponding road signaling regulation.

This system is the result of the collaboration between the Department of Electronics at the University of Alcalá and a series of recognized and prestiged companies in the road safety and inspection industries, such as Euroconsult, 3M-Spain and Safecontrol. VISUALISE is a patented dynamic inspection system for traffic signs (including those panels above the road), mounted onboard a vehicle, which can perform inspection tasks at conventional driving speed by using computer vision techniques. This leads to a series of advantages versus the traditional means based on static measurements:

- The presence of people and vehicles parked on the side of the roads, close to where the measurements are taken, are not necessary at all.
- The use of auxiliary bulky pieces of equipment in order to take measurements (especially on those panels above the road) are not necessary at all.
- The efficiency of the inspection process is increased. Therefore, it is possible to analyse a major number of signs in a shorter period of time.

All these pros lead to a most important one: the better awareness of the road network signaling state, supporting planning and decision making on the administration and infrastructure operators' side, based on a set of high-quality data, and contributing to the increase of road safety.

A review of the state of the art on traffic signs inspection is going to be held on section 2, while a description of the VISUALISE system is going to be made on sections 3 and 4. Finally, the experimental results obtained as well as the conclusions drawn are shown in sections 5 and 6, respectively.

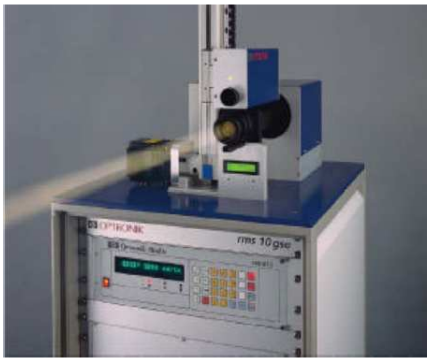
2. State of the art

Despite many works have been developed in the field of traffic sign detection and recognition [2], [3], [4], [5], [6], [7], automatic traffic signs inspection using computer vision techniques have not been thoroughly studied yet. The main reason of the absence of works of this kind is that there is not a global standardization on vertical signaling. Each country has its own traffic signaling regulation. Besides that, detection by using computer vision techniques in non-controlled environments is an extremely complicated problem that has not been entirely solved. Some typical problems of using computer vision algorithms to traffic sign detection are due to changing lighting conditions, presence of objects that cause obstructions and shadows and a wide range of variation in the appearance of the traffic signs and panels in the image.

Traffic sign detection can be taken out by analysing color or grey-scale images. Inside the first group, different color spaces, such as RGB [2], [8], HSI [9], [10] and LUV [11], have been used. Other works have focused on the use of data bases [12], textures [8] and fuzzy classifiers [13]. On the other hand, works that use grey-scale images usually take out edge detection and shape recognition, as it is done in [6], which applies Hough transform over a series of contours obtained from an edge image.

The existing systems for vertical signaling inspection can be divided into two groups: manual and automatic inspection devices. Inside the first group, there are portable pieces of equipment, used for measuring the retroreflection coefficient of a traffic sign or panel manually, and laboratory devices, which are employed for taking out several experiments by modifying different parameters that affect to the retroreflection measure, such as the distance to the sign and the observation angle. Figure 1(a) shows an example of a portable system. They usually consist of a reflectometer, a light source, a light detector, an amplifier, a display to read the measure and rechargeable batteries. The geometry is typically fixed to an input angle of -4º and an observation angle of 0.2º. On the other hand, figure 1(b) shows a laboratory piece of equipment, the reflectometer RMS 10 GSE by Optronik. It consists of a illuminator and a reflected light receiver. The observation angle can be fixed from 0.2º to 20º [14].

(a) Example of a manual inspection device



(b) Example of a laboratory inspection device

Figure 1: Manual inspection devices

The main drawback of manual devices is that they need to come into contact with the element to be measured (or at a maximum distance of a few meters), which means having a huge number of disadvantages, which were described on section 1. Automatic inspection devices solve these problems. However, it has not been developed any automatic piece of equipment capable of taking retroreflection measures. While the systems developed by AEPO [15] and GEOCISA [16] merely do inventory tasks, the system SASV, which was developed by INTEVIA (Instituto Técnico de la Vialidad y el Transporte) [17], is able to make an inspection of the quality of the signs, but only in terms of luminance, but not in terms of retroreflection, which is actually used to decide if a sign fulfills the minimum values required by the regulation in force, as manual devices give their measures in terms of retroreflection. The system described on this article is able to give not only retroreflection values at a certain distance, but also retroreflection measures at different distances, generating a curve that helps to take more reliable decissions instead of using just one measure.

3. System description

The VISUALISE system has been developed as a solution to the vertical signaling inspection problem. It inspects traffic signs' state, according to the corresponding road signaling regulation. This automatic inspection system for traffic signs and panels uses both measures of retroreflection and contrast of every sign and panel. These measures are obtained by using active infrared illumination and high resolution cameras. Therefore, the inspection process is done at nighttime in order to guarantee that the main source of light is that one corresponding to the infrared illuminator, since the light provided by this element is the one used to calculate the retroreflection value. The aim is to achieve as much light homogeneity as possible on the vast majority of different scenarios where the inspection is going to be held.

The developed system is based on the light retroreflection principle. This is the reason why an active infrared illuminator, whose features are perfectly defined and known, is used as a pattern light source. Part of the infrared light that comes into contact with the signs and panels is reflected. Then, the reflected light is captured by an stereoscopic system made up of two high-resolution cameras. As a consequence, the luminance level of the traffic signs, which is given in grey-level units by the two cameras, is directly proportional to the grade of luminance measured in candels per square meter units (cd/m^2). The relation between the luminance measure and the retroreflection measure is defined by considering the distance and angular orientation between the light source, the retroreflective material and the measurement system (observation and input angles). This relation (luminance-retroreflection) is set through a prior calibration process.

Several measures of distance, luminance and retroreflection are taken for every sign and panel detected on the image sequence. Therefore, both luminance and retroreflection curves as a function of the distance are obtained for every element inspected. These curves refer to the brightest parts of the sign, which are those that are white. Therefore, it is crutial that the system is able to locate the white elements on every sign and panel by using image processing algorithms. So, the different parts of the signs and panels (border, text-pictogram, background) are automatically separated by means of image segmentation techniques.

By doing this, it is possible to take independent luminance measures for each part of the sign (border, text-pictogram, background). From the luminance and retroreflection measures of each part of the sign, the system is able to calculate the contrast value, just in case it is absolutely necessary or it is required by the corresponding road regulation. The contrast is defined as the relation between the retroreflection value of the background and the one of the border, or between the one of the text-pictogram and the corresponding retroreflection value of the background, depending on which are the key elements to estimate the traffic signs' legibility. Actually, these key elements must be specified by the road regulation in force.

The VISUALISE system is made up of different hardware components, as shown in figure 2.

4. Inspection process

The inspection process can be divided into two phases, among which there are different tasks, as it is shown in figure 3:

- On-line process. A vehicle worked by two people (a driver and a supervisor) is used at this first stage of the process. The vehicle is equiped with all the necessary devices and software applications in order to carry out the acquisition and recording of the input stereoscopic image sequences corresponding to actively illuminated roads by the onboard infrared illumination system. These image sequences are stored on hard disks, so as to being processed later.

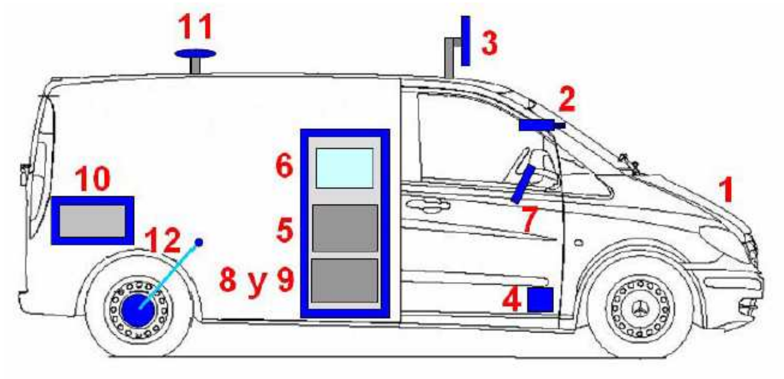
- Off-line process. At this second stage, the previously recorded sequences are processed by using an image processing device based on a personal computer. As a result, a report, which contains the retroreflection and the contrast values of every sign and panel in the analysed road stretch, is generated.

4.1. On-line process

The goal at this stage is to carry out the acquisition of the stereoscopic image sequences and the recording on a hard disk. Each one of these sequences consists of images of different road stretchs illuminated by the onboard infrared illumination system. The cameras are inside the vehicle beside the windshield and looking at the road, with a base line of 35 centimeters, in order to guarantee the maximum precision when it comes to take distance measures, especially at long distances.

Both the position of the cameras and their angular aperture allow to cover a minimum area of 10 meters on each side of the vehicle for distances up to 20 meters. Therefore, the system is able to take measures of every sign and panel located on the road, even those placed on both sides of the road. In addition, the cameras are calibrated with fixed values of gain and shutter. As well as this, the stereo system is also previously calibrated.

The illumination system emits infrared light with a maximum power of 60 watts. Such a low power guarantees that the infrared light does not affect the rest of cars driving on the same road. Furthermore, the illumination system has an angular aperture of 30^o, so it reaches a maximum illumination range of 160 meters. The infrared illuminator is placed over the roof of the vehicle and equidistant from each camera, so as to guarantee that the light is captured homogeneously by each one.



1. Sketch of the vehicle used to do the automatic auscultation of signals and panels.
2. High resolution digital cameras (two per each vehicle), which are installed inside the vehicle and, together with their associated optics, make up an stereoscopic vision system capable of providing 18 frames per second.
3. Infrared illuminator, synchronized with the cameras.
4. Hardware control, which guarantees the synchronism between the image acquisition by the cameras and the infrared illuminator.
5. Data processor, based on a personal computer installed over a shock-absorbered industrial rack.
6. TFT monitor to visualize the results of the image acquisition.
7. Touchscreen that allows to log incidences that take part during the acquisition process.
8. Rack, which allows to store sequences on a maximum of 16 hard disks of 500 GB each one.
9. Processing equipment for the estimation of the retroreflection values of every signal.
10. Diesel generator, mounted onboard the vehicle, that is able to supply an alternating current of 230 V and a power of 3500 W.
11. Differential GPS of 12 channels and a frequency of 10 Hz, with real-time submetric accuracy and decimetric accuracy at a post-processing stage, that allows to know the global position of the vehicle.
12. Odometer, installed on one of the wheels of the vehicle, that supplies 20000 pulses.

Figure 2: VISUALISE system components

The illumination system is activated by an external synchronism signal. This signal allows to synchronize the illuminator with the cameras, so the illumination of the scenario is taken out at alternative frames, which means that the light source is active while acquiring an image and it is disactivated in the following frame. Therefore, each sequence consists of pairs of illuminated stereoscopic images and pairs of non-illuminated stereoscopic images. The external synchronism signal is provided by a microcontroller. This signal is not only used to synchronize the infrared illumination system with the cameras, but also to synchronizing the acquisition times of the two cameras in order to avoid temporal derives between them.

In order to minimize the effect of the environmental lighting, a substraction of the luminance values measured by the two cameras in two consecutive frames is taken out. So, practically the whole luminance of the signs and panels comes from the illumination emited by the vehicle itself (headlights and infrared illuminator). This novel approach guarantees the maximum homogeneity on the measure conditions.

During this on-line stage, a touchscreen is used to manually add information related to the road, such as milestones or the type of road whose vertical signaling is being inspected. This information has to be taken into account on the following image processing stage.

Therefore, the computer mounted onboard the vehicle receives the images from the cameras, the position

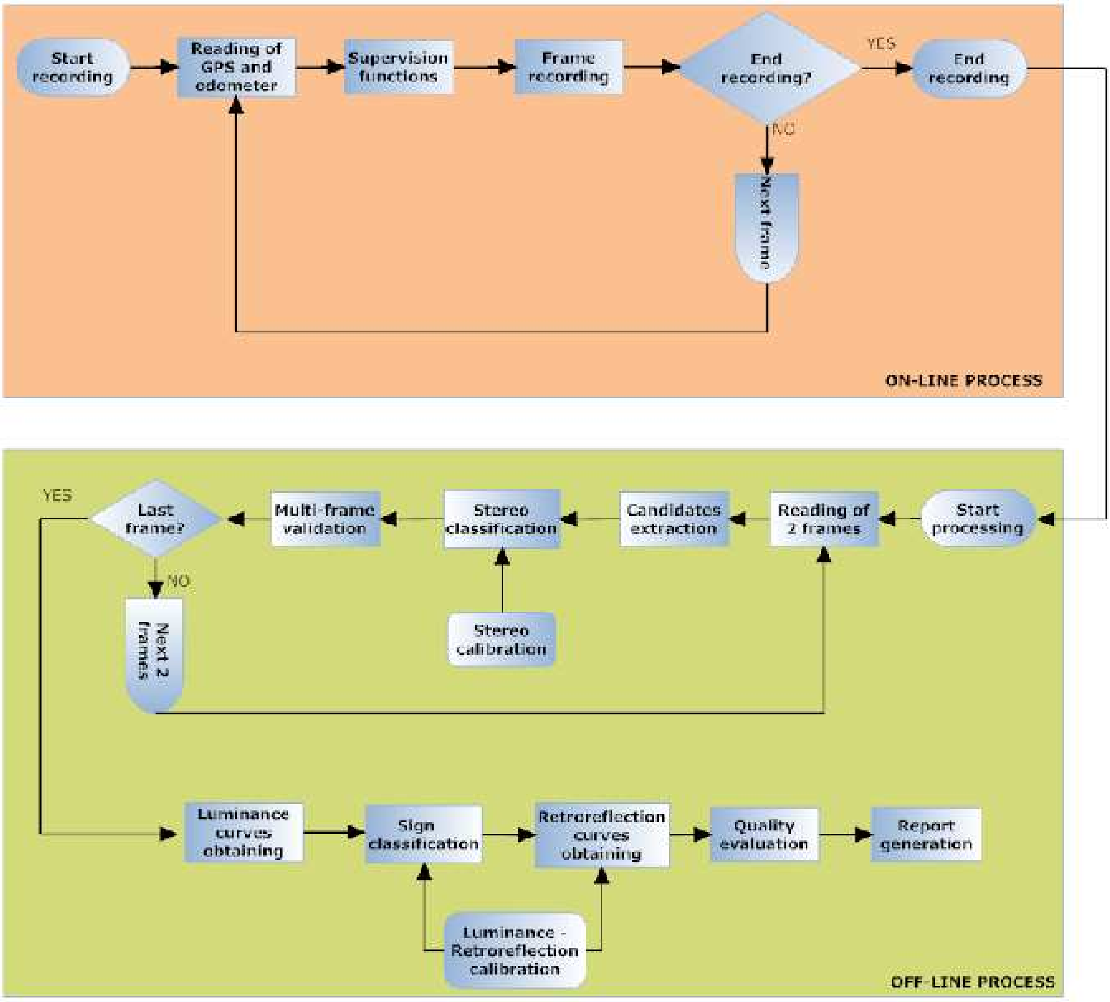


Figure 3: Diagram of blocks of the inspection process

coordinates given by the GPS receiver, the distance measure provided by the odometer and the information supplied with the touchscreen. All this information is structured and stored on disk for each pair of images. In consequence, all the information received by the computer is stored with a minimum frequency of 18 times per second.

During the image acquisition and sequence recording process, the computer displays the acquired images on the computer screen together with an indicator that shows the real value of the frequency of the store process on disk, thus revealing if the system is working properly. As if that were not enough, a enjoyable user interface allows the operator to manage the names of every recorded sequence and the specific disk where such sequence is going to be stored.

Each removable hard disk has a capacity of recording nearly 2.5 hours, which is equivalent to inspect up to 250 kilometers. Owing to the conditions under which the system must work (inside a running vehicle), the whole system must be resistant to vibrations and it must have a good thermical and mechanical insulation. For this reason, the image acquisition and sequence recording systems are installed over a shock-absorbered industrial rack which is stabilized against vibrations. During the recording process, the vehicle can drive at the maximum speed allowed for the road under inspection.

The vehicle must drive along the right lane with the aim of keeping the input angle of the light reflected by the signs and panels, not exceeding the maximum values of the materials used on the calibration process and guaranteeing that the signs and panels are correctly illuminated by the infrared illuminator.

The files generated by the onboard computer constitute the input data to the off-line process.

4.2. Off-line process

The off-line process takes the files generated by the onboard computer as input data. These files consist of sequences of stereoscopic images, GPS coordinates, distance measures provided by the odometer and information supplied by the operator by means of a touchscreen. Then, the image processing algorithm is run in order to carry out the detection of signs and panels, as well as the corresponding measures of retroreflection and contrast (just in case this one is required).

4.2.1. Candidates extraction

The aim of the first step of the image processing algorithm is to detect the precise location of the signs and panels at both sides of the road. In order to achieve this goal, an analysis of the shapes obtained from an edge-image is carried out. A Hough transform for straight lines is used to detect triangular, rectangular signs and arrows, and also a Hough transform for lines is applied to detect circular signs as well as the Stop sign [18].

The algorithm used for edge detection is the Canny method. This method preserves contours, what is very important for detecting traffic signs using shape information because they are usually closed contours. The contours obtained applying Canny method are codified using the chain code [19]. By making use of this codification the area and perimeter are obtained, and it can also determined whether a contour is closed or not. The contours are accepted if they are closed contours, or almost closed contours. In addition they must also fulfil a certain aspect-ratio constraint. Actually, the Hough transform is only applied to accepted contours after filtered with this kind of restrictions. If all the contours in the image were analyzed the computational cost would be prohibitive, so all those contours that do not meet some requirements, supposed to be typical of traffic signs, will be removed from the image, so that the computational time is reduced.

A straight line in the xy-plane with a distance to the origin ρ and the angle of the normal line with the abscissa axis θ, can be expressed as (1).

$$x \cdot \cos(\theta) + y \cdot \sin(\theta) = \rho \tag{1}$$

Where the parameter space, $p = (\rho, \theta)$, must be quantized and expressed in a 2D accumulation matrix a, whose elements are initially set to zero. So, an element $a(\rho, \theta)$ is incremented by 1 for every feature point (x_i, y_i) in the image-domain, contained in the straight line with parameters (ρ, θ) as expressed in (2), where a precision margin ϵ is introduced to compensate for quantization error when digitizing the image [22].

$$|x_i \cdot \cos(\theta_t) + y_i \cdot \sin(\theta_t) - \rho_r| < \epsilon \tag{2}$$

The aim is detecting three, four or five straight lines intersecting each other, forming a triangular, rectangular or arrow sign. Different algorithms have been proposed in order to decrease the computational time of the Hough transform, a multi-dimensional quadtree structure for accumulating is suggested in [20] (coarse-to-fine method), or in [21] a method based on the fact that a single parameter space point can be determined uniquely with a pair, triple, or generally n-tuple of points from the original picture (many-to-one mapping method). In this work a constrained accumulation matrix a is proposed as a method to decrease the computational time, as it can be seen in figure 4. The strategy is to apply the Hough transform to every contour, one after the other, hence every straight-line-parameters estimation is calculated by means of equation 3 and 4, where (x_1, y_1) and (x_2, y_2) are points belonging to the contour under study.

$$\rho = \frac{x_1 \cdot y_2 - x_2 \cdot y_1}{\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}} \tag{3}$$

$$\theta = arctan \frac{x_1 - x_2}{y_1 - y_2} \tag{4}$$

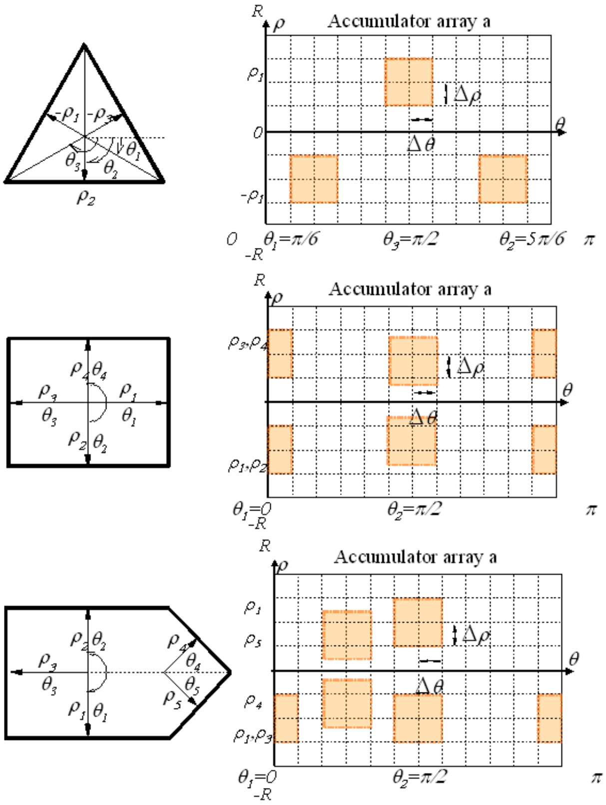


Figure 4: Constrained Hough transform applied to detect triangular, rectangular and arrow signs.

A similar strategy is followed for circular sign detection. Hough transform for circles is applied to detect circular signs and the stop sign too. A circumference in the xy-plane with center (χ, ψ) and radius ρ can be expressed as (5).

$$(x-\chi)^2 + (y-\psi)^2 - \rho^2 = 0 \tag{5}$$

Where the parameter space, $p = (\chi, \psi, \rho)$, must be quantized. For circumference detection the accumulator a will be a three-dimensional matrix with all elements initially set to 0. The element $a(\chi, \psi, \rho)$ is incremented by 1 for every feature point (x_i, y_i) in the image-domain, contained in the circumference with centre (χ_r, ψ_s) and radius ρ_t as expressed in (6), where a precision margin for the radius ϵ is introduced to compensate for quantization error when digitizing the image [22].

$$|(\chi_r - x_i)^2 + (\psi_s - y_i)^2 - \rho_t^2| < \epsilon \tag{6}$$

The circumference-parameters estimation is calculated using the direction of the contour-gradient under study, as in [23] and [24]. The search ranged into accumulator matrix a is constrained, the circumference-parameters are only searched inside shading areas, as it can be seen in figure 5.

4.2.2. Stereo classification

Sign and panel relative position. An accurate estimation of the relative position between the vehicle and the signs or panels has an important impact on further stages such as tracking, geometrical discarding and luminance-retroreflection curves computation. In order to minimize the error position, the relative distance is computed by combining the stereo vision sensor with the odometer.

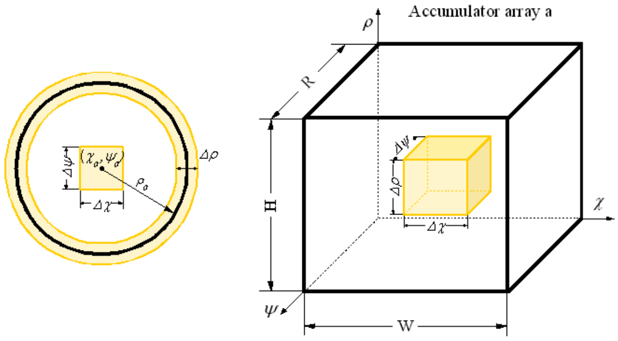
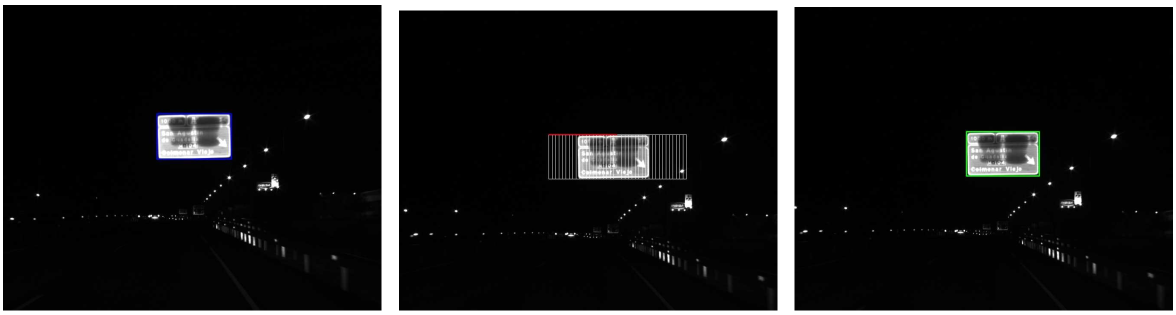


Figure 5: Constrained Hough transform applied to detect circular signs.

Stereo parameters such as separation between cameras, sensor focal length and images resolution have been defined to reduce the error of the stereo measurements. The calibration process is carried out on a supervised fashion in order to minimize the calibration errors. Both images are undistorted and the epipolar geometry is computed. The content of the detected bounding boxes is matched along the epipolar line on the other stereo image by using the ZNCC function (Zero mean Normalized Cross Correlation) as in [25]. The search space can be reduced considering the minimum and maximum ranges. The correlation values are obtained and the values near the optimum are approximated by a second degree polynomial in order to compute the 3D position with subpixel accuracy [26]. This process is illustrated in figures 6(a)-6(c) and 7.



(a) Right image and bounding box of the detected panel

(b) Search space along the epipolar line corresponding to the upper-left part of the bounding box on left image

(c) Final match on left image

Figure 6: Stereo correlation

The use of stereo vision involves two main drawbacks. Firstly, the computational costs are too high. Secondly, stereo errors are proportional to distance [27] so that, depth measurements corresponding to signs or panels at long distances are not reliable enough. In order to minimize these aspects we propose the use of a novel method called backtracking [1]. Accordingly, the initial appearance of the sign takes place at the minimum relative distance (once the whole sign is visible in both cameras), i.e., with the minimum possible stereo error. Thus, the relative distance between the vehicle and the sign is initialized with the best stereo measurement $d_0 = z_0$. The remainder measurements are updated by adding up the vehicle displacement dv_t which is provided by the odometer, i.e., $d_t = d_{t-1} + dv_t$. This strategy is followed for two main reasons. First, the computational cost is reduced since stereo measurements are only obtained during the first iterations. Second, even the fact that the odometry error is cumulative (1m per each 100m), considering the detection

[1]Backtracking analyses the image sequence in reverse direction respect to the recording one. This technique allows to do a more robust tracking of every sign and panel up to longer distances than typical tracking methods.

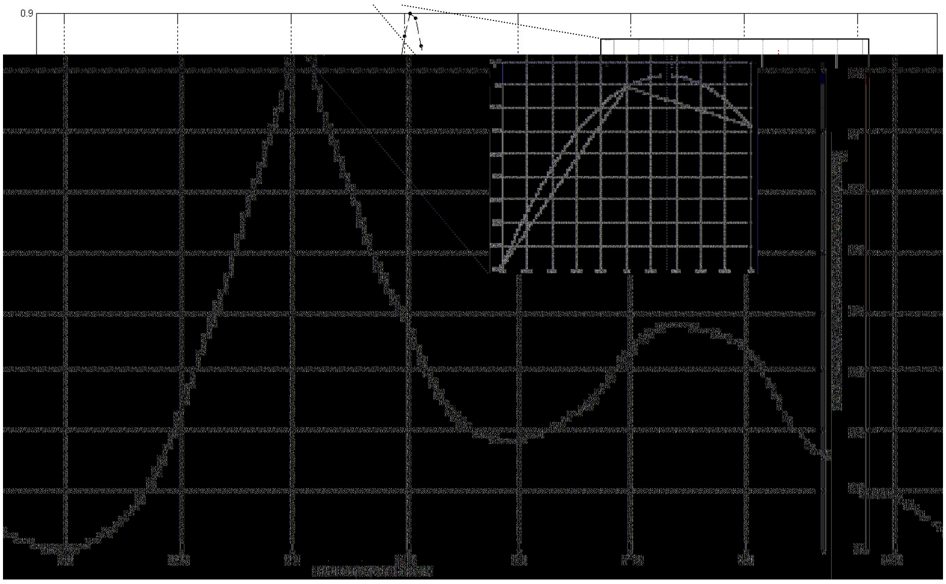


Figure 7: Correlation function along the epipolar line and second degree polynomial approximation.

range (100m for signs and 170m for panels), this error will be always much lower than the error provided by the stereo sensor at long distances.

Sign and panel global position. The vehicle global position is accurately obtained from the differential GPS. However, the GPS sample frequency is 1Hz which implies that the system obtains one GPS measurement per each 20-30m approximately. As the storage process is carried out at 18 Hz, some kind of interpolation is needed. We apply a linear interpolation between two consecutive GPS measurements using the values provided by the odometer whose sample frequency is ten times higher (100Hz).

Finally, a global reference for each one of the detected signs and panels is obtained by combining the global position of the vehicle and the relative position between the vehicle and the sign or panel. The global position of the signs and panels is extremely useful from the point of view of both inspection and inventory tasks.

4.2.3. Sign classification

Every sign and panel detected is later analysed in order to classifying it into one of the following categories, which are depicted in figure 8:

- Stop sign.
- Cicular sign with white background.
- Circular sign with blue background.
- Triangular sign.
- Rectangular sign with blue background.
- Panel with white background.
- Panel with blue background.
- Arrow panel.

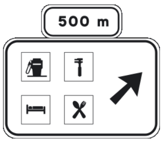
(a) Stop sign

(b) Circular sign (white background)

(c) Circular sign (blue background)

(d) Triangular sign

(e) Rectangular sign



(f) Panel (white background)

(g) Panel (blue background)

(h) Arrow panel

Figure 8: Types of signs and panels

4.2.4. Luminance and retroreflection curves obtaining

For each type of sign and panel, a segmentation process is carried out in order to separate their basic elements (border, text-pictogram, background). The mean value of the luminance in grey-scale is calculated for each part of the sign. This is done for every single image, so it is possible to obtain a luminance curve as a function of the distance measure.

The segmentation method implemented must be robust enough against a series of typical problems, such as:

- Obstructions and shadows due to other objects.
- Non-controlled lighting conditions.
- Image saturation.
- A wrong orientation of the infrared illumination system, that causes that some signs can be insufficiently illuminated.
- A wide range of variation in the appearance of the traffic signs and panels in the image

In order to ease these problems, a couple of techniques have been implemented. First of all, the use of frame subtraction to minimize the effect of non-controlled illumination, such as road illumination and car lights, so that the luminance measure only depends on the infrared illumination. Figure 9 shows the decrease of external lighting on the subtracted frame.

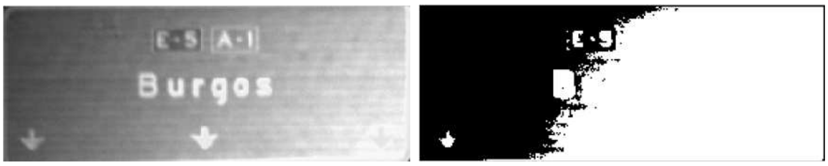
In addition, a non-uniform illumination correction method is applied in order to fix the non-uniform illumination that arises in traffic signs and panels due to the light that mainly comes from the infrared illuminator and from the residual environment light. This unintended effect causes the detection of two different classes in the segmentation process when theoretically there is also one, as can be seen in figure 10.

This difference in the grey levels of the background can be corrected before the segmentation process by subtracting from the estimated sign background, as it is shown in figure 11. Although it is a simple method, it improves the segmentation quality in high degree, as it can be seen in figure 12.

The segmentation method implemented is based on the Otsu algorithm [28], which is an automatic adaptive technique that computes the optimum thresholds by maximizing the inter-class variances. This method is applied over the subtracted frame after applying the aforementioned non-uniform illumination correction method.

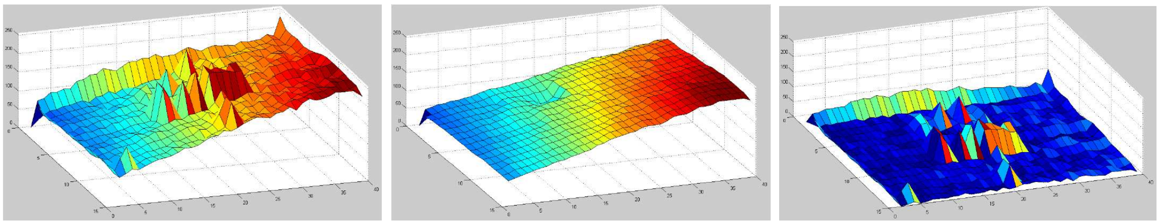
(a) Illuminated frame (b) Non-illuminated frame (c) Subtraction frame

Figure 9: Frame subtraction



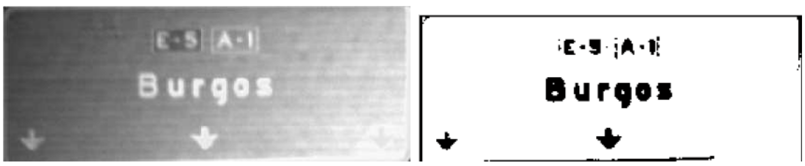
(a) Original image (b) Segmented image

Figure 10: Effect of non-uniform illumination on image segmentation



(a) Grey levels of subtracted frame (b) Grey-level background estimation (c) Background subtraction from estimated background

Figure 11: Non-uniform illumination correction



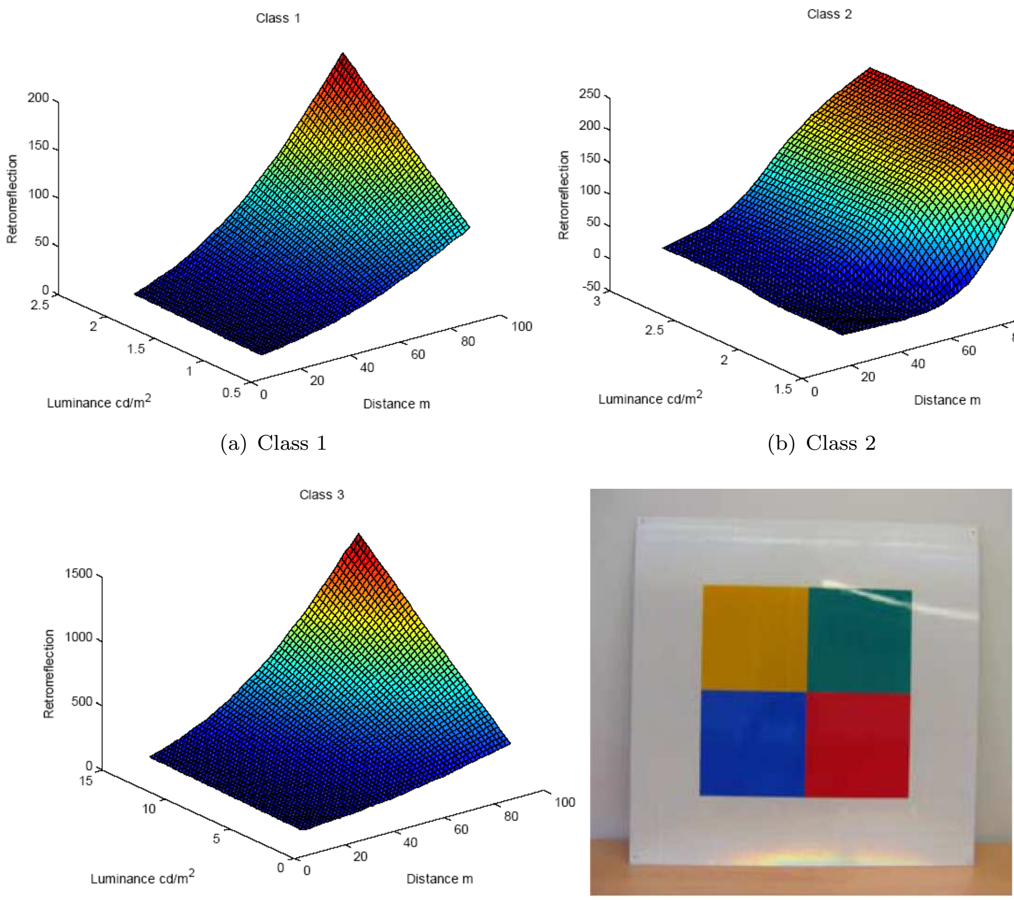
(a) Original image (b) Segmented image

Figure 12: Image segmentation after applying non-uniform illumination correction method

Later, in order to obtain the luminance curves for each traffic sign and panel, the aforementioned backtracking approach is used. It makes possible to get measures of luminance up to 100 meters for signs and up to 170 meters for panels.

These curves are turned into retroreflection curves as a function of the distance. In order to achieve this, different conversion surfaces are used. These surfaces use the grey-scale luminance and the distance as inputs, and they provide the retroreflection value estimated as output.

Three different curves are used, one for each retroreflective material with which the signs and panels can be made: level 3, level 2 and level 1. The assigned curve to each sign or panel will be that one for which a better adjustment for each hypothesis is got. These conversion surfaces are obtained trough a prior calibration process. Figure 13 shows the three different conversion surfaces and the appearance of the level-3 pattern sign used in the calibration process. This is a methodology patented by the authors.



(a) Class 1 (b) Class 2

(c) Class 3 (d) Class 3 pattern sign

Figure 13: Conversion surfaces obtained during the calibration process

Three pattern signs with known retroreflection values as function of the distance, made of level 1, level 2 and level 3 materials, are used in the calibration process. A video sequence is acquired for each pattern sign by using the vehicle to be calibrated and all its onboard equipment. Figure 14 shows the results obtained on a real calibration experiment. On the upper part of the figure, the grey-scale luminance curves of the white colour for each material are depicted, while the lower part of the figure displays grey-scale luminance curves for each colour for the level-3 pattern sign.

In the calibration process, different pattern signs are placed at the typical positions of traffic signs in a test road. The vehicle drives along the right lane at a lateral distance of 5 meters on the sign. The vehicle starts its driving 200 meters away from the sign, and it moves towards the sign until it disappears from the cameras' view. The recorded sequences are then processed in order to obtain the luminance curves as a function of the distance for each one of the three pattern signs.

The three conversion surfaces are obtained from the three luminance curves and the retroreflection values measured manually at several distances for each pattern sign. Fuzzy non-linear regression techniques have been carried out in order to obtain the surfaces. Therefore, three retroreflection curves, one for each material, as a function of the distance, are obtained from the luminance curves. Figure 15 shows the retrorreflection

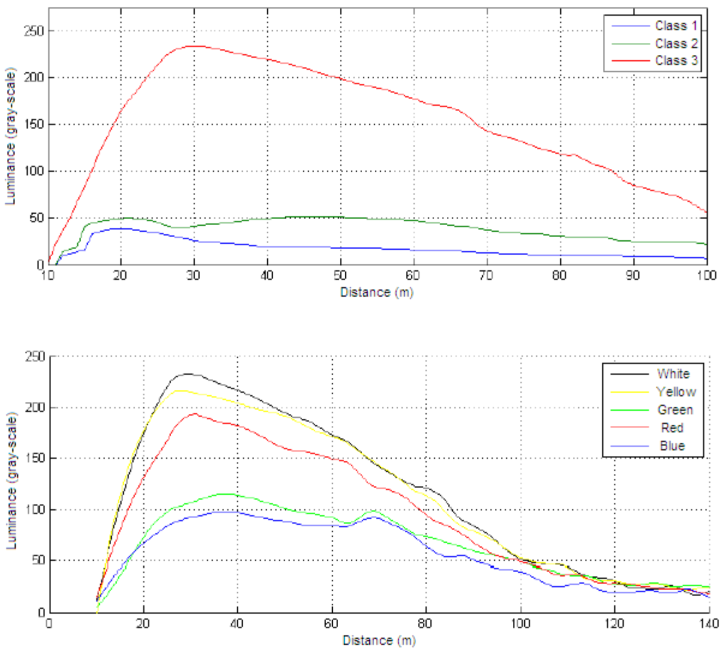


Figure 14: Luminance curves of the white colour for each pattern sign (upper) and luminance curves of each colour for the level-3 pattern sign (lower)

curves obtained after the calibration process for each material.

The retroreflection value of the white part of the sign, measured at a distance of 100 meters, corresponds to the standard measure for an input angle of 5° and an observation angle of 0.33°, because of the geometry given by the location of the cameras and the infrared illuminator. Retroreflection at 100 meters measure is used for the current manual inspection systems in order to establish if a sign fulfils the regulation relative to the minimum retroreflection value accepted for a traffic sign.

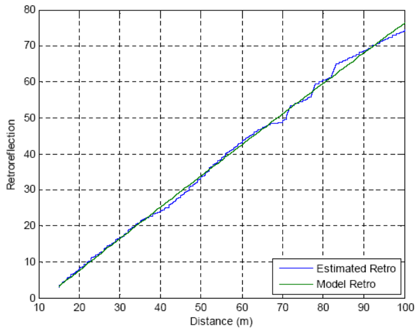
As it was said previously, the retroreflection measures of the parts no belonging to the sign background, such as the border or the text-pictogram, can be used to calculate the contrast relation between the primary colour and the secondary one of the sign. This contrast relation can be seen as an indicator of the legibility of the traffic sign.

Besides that, the retroreflection curve can be compared to the retroreflection ground truth established on the regulation for each material. This comparison allows to determine if the sign fulfils the regulation in force, which depends on the road where the sign is located.

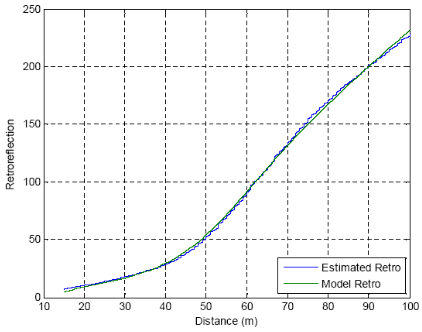
4.2.5. Report generation

Finally, the system generates a report which has the next information for each sign and panel:

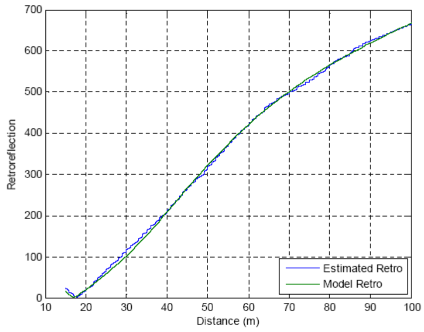
- Retroreflection curve as a function of the distance.
- Retroreflection value at 100 meters.
- Contrast relation at 100 meters.
- Type of road.
- Milestone.
- GPS coordinates.



(a) Class 1



(b) Class 2



(c) Class 3

Figure 15: Ideal and real retroreflection curves of each pattern sign

- Height above the ground.
- Lateral distance from the centre of the lane where the vehicle is moving.
- Road.
- Carriageway.
- Lane.
- Material.
- Type of sign or panel (circular, triangular, rectangular, panel, arrow).
- Fulfilment of the regulation relative to the retroreflection value depending on the material of the sign.

The whole information is managed by using an application that allows to go through the contents of the report generated for each stretch of road analysed. A screenshot of this applications is shown in figure 16.

Figure 16: Results' viewer

5. Experimental results

In order to check the reliability of the VISUALISE system, a series of different experiments have been carried out. First of all, two inspection vehicles were assembled, and more than 6000 kilometers of the Spanish road network were inspected with these vehicles in order to check, on the one hand, the reliability of the recording system and, on the other hand, the performance of the processing software in different road scenarios. These roads can be seen in Figure 17. All the measures were taken in the summer time, because it is the time of the year when the air humidity is minimum, and at nighttime, from 12 am to 5 am, because the system is been designed to work at nighttime when there is lower traffic density. On the other hand, more than 500 signs and panels from different roads have been chosen randomly as ground truth, which means that they have been measured manually, and these values have been compared to the results obtained with the VISUALISE system. Some conclusions can be drawn from these results.

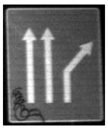
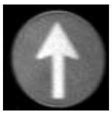
Figure 17: Inspected roads

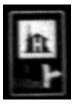
Firstly, the system is able to detect up to 99% of the signs and panels present on the road. As there are typically obstructions owing to vegetation or other vehicles, not all of the detected signs are valid to get a reliable retroreflection measure. Therefore, it has been decided to get a minimum of 10 samples at different distances from a certain sign or panel, in order to get a reliable retroreflection curve of it. As a consequence, only the 97% of the total of signs present on the road are valid to get a retroreflection curve. After comparing the measures obtained with the dynamic system to the manual measures, the main conclusion that can be pointed out is that the reliability of the VISUALISE system is up to 91% in terms of signs and panels that are correctly classified into accepted (signs that fulfil the minimum retroreflection values taken in the regulation) or rejected (signs whose material or retroreflection values are below the minimum required by law). Table 1 shows these statistics, while tables 2 and 3 contains the comparison between the manual measure and the dynamic measure of different signs with examples of hits (table 2) and misses (table 3). At this point, it is crutial to notice that each type of material has a minimum retroreflection value at 100 meters, as required by law. These minimum values are, according to the Spanish regulation, 49 cd/m^2lx for level-1, 126 cd/m^2lx for level-2 and 212.5 cd/m^2lx for level-3 signs. This is the reason why some signs are rejected although the class of material is correct.

Table 1: Performance of the VISUALISE system.

	Percentage over the total of signs present on the road
Percentage of detection	99.05%
Percentage of measured signs	97.62%
Percentage of reliability	91.66%

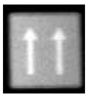
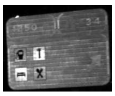
Table 2: Comparison between manual measures and the VISUALISE system. Hits.

Sign	Road	Mimimum level required by law	Level assigned by VISU-ALISE	Manual retroreflec-tion measure at 100 m. (cd/m^2lx)	Retroreflection measure by VISUALISE at 100 m. (cd/m^2lx)	Decision
	A1	2	2	191.22	218.96	Accepted
	A1	2	1	70.77	96.07	Rejected because of a lower material
	A1	2	2	206.55	225.36	Accepted
	A1	2	2	75.88	74.66	Rejected because of a lower retroreflection
	A1	2	3	453.88	513.08	Accepted
	A1	3	3	571.33	492.67	Accepted
	A1	3	3	55.00	49.84	Rejected because of a lower retroreflection
	A2	2	1	90.06	95.98	Rejected because of a lower material

	A2	3	3	447.00	503.43	Accepted
	A2	2	1	19.90	20.34	Rejected because of a lower material

As it was said before, not all of the detected signs are valid to get a reliable retroreflection measure, and a minimum of 10 samples is required. Even so, there are signs whose measures can be erroneous because of different reasons. Among the possible causes, there are graffitis, obstructions because of vegetation or other vehicles, shadows due to other signs or panels and inclined signs. This lead to misclassifying in terms of material, because certain sign or panel can be classified into a lower sign if the measures taken are erroneous. However, VISUALISE tends to give retroreflection values higher than the real ones in general, thus compensating the possible mistakes made in the classification step.

Table 3: Comparison between manual measures and the VISUALISE system. Misses.

Sign	Road	Mimimum level required by law	Level assigned by VISUALISE	Manual retroreflection measure at 100 m. (cd/m^2lx)	Retroreflection measure by VISUALISE at 100 m. (cd/m^2lx)	Decision
	A2	2	2	94.30	196.18	Erroneously accepted
	A2	2	2	159.45	97.36	Erroneously rejected because of a lower retroreflection
	A2	2	2	169.15	85.95	Erroneously rejected because of a lower retroreflection
	A1	3	2	635.66	220.53	Erroneously rejected because of a lower material
	A1	2	1	162.55	86.58	Erroneously rejected because of a lower material
	A1	2	2	158.11	99.39	Erroneously rejected because of a lower retroreflection

6. Conclusions and future work

Unlike manual devices, the VISUALISE system is able to get several luminance measures of a sign in a range from 15 to more than 100 meters. It is also capable of classifying a sign or panel into a certain class of material by comparing the luminance measures to a model obtained through a prior calibration process. In addition, unlike other automatic inspection systems, VISUALISE calculates retroreflection values from luminance measures and checks if the sign fulfils the minimum values at 100 meters required by law.

The results obtained show that the retroreflection values given by VISUALISE are really accurate, as they have a small error compared to the measures taken manually. In addition, it makes an inventory of the signs and panels.

As if that were not enough, the VISUALISE system has been designed to have a processing capacity of 1:1, which means that only one hour of processing is necessary for each hour of recording. As a consequence, this system is a good solution to the inspection problem, as it is able to analyse the majority of the signs and panels located on a road in a short period of time.

In conclusion, the VISUALISE system means a qualitative and quantitative quantum leap with regard to road signaling evaluation. It represents a boost for the improvement of the quality of the road signaling. Actually, the improvement in the awareness of road's signaling state will allow to plan more efficiently the road maintenance and, consequently, to optimize the budget gone on this purpose. This will definitely help to increase road safety.

As future work, we are planning to increase the system ratios through the experience obtained from the kilometers that are planned to be inspected in Spain (more than 30000) and to adapt the system to other countries' signaling regulations.

Acknowledgments

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