INNOVATIVE METHODOLOGY TO MAINTAIN THE NIGHTTIME VISIBILITY OF ROAD TRAFFIC SIGNS AS PART OF AN INTEGRATED APPROACH FOR ROAD SAFETY

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ABSTRACT

Improving road safety is a key element of road networks management. Any organization in charge of the management and operation of road networks should be able to diagnose problems related to drivers safety.

Mobile inspection systems for horizontal road markings are established since decades and support road authorities in their aim to maintain minimum visibility levels and road safety. Similar mobile systems for the assessment of vertical traffic sign conditions are not available, or only in embryonic stage. To date, the inspection and measure of vertical traffic signs is done with handheld equipment (retroreflectometers), which limits their use to a few number of signs in a certain stretch of road.

This paper discusses the development and features of the 'VISUALIZE' system as a solution to the traffic sign inspection process focused on visibility and the safety of drivers. It is a tool that allows us to know the traffic sign condition, in respect to the corresponding traffic code or regulation.

The system is a dynamic inspection method for traffic signs, which can perform inspection tasks from a moving vehicle at normal driving speed by using computer vision techniques. First it will provide a better knowledge about sign condition in the complete road network, second it will improve safety planning and decision making.

1. PURPOSE OF TRAFFIC SIGNS

Traffic signs are intended to keep traffic flowing safely, efficiently and smoothly under both day and night conditions. They must alert drivers to hazards and provide precise information. Therefore, they must be visible, and drivers must be able to read their message during daytime conditions, but above all at night.

The visibility of the sign will depend on its location, state of repair or cleanliness, the type of material and size, the driver's visual acuity and whether or not the surrounding area is lighted. Visibility must be ensured with diffuse light during the day. In order to achieve suitable sign brightness during night, traffic signs are typically manufactured with retroreflective technology. Retroreflection redirects a majority of the car headlamp illumination back towards the car, making the sign brighter for the driver at night.

As night-time conditions are more demanding, visibility of the signs must be ensured by maintaining certain minimum retroreflection values over the lifetime of the sign.

2. MAINTENANCE AND MONITORING OF TRAFFIC SIGNS

The publication ‘Maintaining Traffic Sign Retroreflectivity’ [1] of the Federal Highway Administration (FHWA) describes a variety of assessment and management methods normally used to maintain retroreflection levels of traffic signs in use.

2.1. Visual Nighttime Inspection Method

Means monitoring, inspection or visual assessment by a trained inspector during night-time hours. In this case, the inspector must have reference signs or sheeting material to use as a basis for comparison with actual signs.
If this procedure is used, uniformity of conditions must be ensured, i.e., the headlamps of the vehicle must be controlled and travel must be at the normal traffic speed for the road where the inspection takes place.

With this method, road signs are compared to the reference (which must have retroreflection levels similar to a minimum or established threshold), and the conditions under which minimum retroreflection was calculated should also be maintained (older inspector, using a car and dipped headlamps whose intensity is adjusted appropriately).

The advantage of this method is that the signs are evaluated under actual conditions at night allowing to detect visibility problems not only related with retroreflection; however the inspection method is very subjective.

2.2. Measured Retroreflectivity Method

Means measuring the coefficient of retroreflection on the sign itself with a retroreflectometer. The result can be directly compared to the minimum level in the appropriate standard.

This method is completely objective and is actually the one that is used in the laboratory to approve retroreflective materials. However, making measurements on installed signs in the road can be difficult and sometimes hazardous due to traffic. Also certain resources and auxiliary elements must be used with it, especially when overhead gantry and cantilever signs are to be measured. Furthermore, other features associated with the visibility or legibility of the signs are ignored with this method, as this is a spot measurement over a very small area.

For this method, there are usually national standards that establish the number of spots to be tested on the signs and the notes to be made regarding their overall condition (scratches, dents, rust, and so forth).

Figure 1 - Measuring with a hand-held retroreflectometer

2.3. Expected Sign Life Method

In this method, an analysis of the estimated useful life of a specific type of sheeting in a region or area is made; signs are replaced based on the estimates for each type. The basis for calculating useful life might be the manufacturer's warranty period and natural ageing tests.

The main advantage of this method is that it can be systematised with bar codes or a similar procedure. However, the disadvantages are that signs must be monitored one by one and all installation (not manufacture) dates must be reviewed, and actual visibility conditions are not evaluated.

For this method, a GIS-based sign inventory system is essential, in which all information for a network is in a common database. The system must have good cartographic references so that all signs can be seen in plan view, and must be able to be queried via the Internet, for example.

2.4. Blanket Replacement Method of signs

At a certain time in a specific area, all signs are replaced, regardless of their individual condition. Replacement intervals may be established based on the estimated useful life.

This is a very simple method and can be done without tracking the age of individual signs or performing measurements. The disadvantage of blanket replacement is that with this strategy, signs that are in good condition may be discarded, resulting in wasted resources.

2.5. Mobile Traffic Sign Assessment

Lastly, signs can be assessed with high-performance equipment from moving vehicles, now that precise systems are available. Monitoring with dynamic systems offers the following advantages over the methods discussed earlier:

- The presence of vehicles on road carriageways and persons positioned around the measuring posts is no longer necessary.
- Cumbersome auxiliary elements are not needed to take measurements (especially for overhead gantry and cantilever signs).
- A higher output is achieved in the monitoring of existing signs, and therefore, the frequency of checks or the length of the stretches of road to be inspected can be increased.

The aforementioned advantages (no need to measure directly, no auxiliary elements required, the frequency of inspections can be increased) lead to another, more significant benefit: better information about the condition of traffic signs in the road system, enhancing the ability to plan work (through decision-making based on sufficient high-quality data) and thus contributing to the constant improvement of road safety.

In the last twenty years, much work has been done toward developing high-performance systems that would make it possible to inspect pavements and road elements at traffic speed. Today's imaging systems, new lighting technologies and, in particular, computer capabilities have made it possible to develop very high-performance equipment and analysis methods. This has represented a significant step forward in the monitoring of traffic signs, and the night-time visibility of all existing elements in the same stretch of road can now be assessed at traffic speed.

At present, dynamic equipment can evaluate the night-time visibility of traffic signs (including overhead gantry and cantilever signs) to determine compliance with the applicable standards.

A clear distinction must be made between equipment used to make an inventory of traffic signs, calculating and recording their type, location, visibility distance, and so forth, usually under daytime conditions, and those that assess the night-time visibility of signs and panels, including meaningful retroreflection measurements.

The features of the latter equipment that is now used regularly to assess the condition and nighttime visibility of traffic signs are detailed below.

3. SYSTEM DESCRIPTION

As described above in the 'Measured Retroreflectivity Method', the sign assessment for nighttime visibility has been done with specific equipments (Retroreflectometers), which require sign and panel contact,. Some work has been carried out to obtain high performance measurement by means of infrared cameras, image-acquisition with visible modulated illumination (flashes) and inspection vehicles operators control. In general, all existing experimental systems require a measurement in day and night conditions to compare them, and they only evaluate subjectively signposting visibility without meaningful measurement of the retroreflection.

The "VISUALISE" equipment presented and described has been developed as a solution for the monitoring of traffic signs. It is a unit that makes it possible to inspect the condition of traffic signs (including overhead gantries and cantilevers) to measure their night-time visibility and determine their compliance with applicable standards. These measurements can also be compared to the parameters evaluated with spot-measuring equipment, either roadside or in the laboratory.

The fact that this equipment can take measurements at conventional traffic speeds means that it offers various technical advantages already described above.

VISUALISE is based on the light retroreflection principle. For this purpose, an infrared illuminator is used in order to generate a lighting pattern. The described equipment must be used at night-time conditions to ensure that the main source of light used to measure retro-reflection is the light generated by the infrared illuminator (3) and that the maximum homogeneity in lighting conditions is achieved in different roads and on different days. The incidence of infrared light on traffic and overhead signs will produce a reflection of the light on the signs. The light reflected by the traffic and overhead signs is captured by the stereoscopic system formed by two high-resolution cameras (2), being the luminance level measured by these cameras in gray scale, directly proportional to the luminance level of the traffic and overhead signs measured in candelas per square meter. In addition, there is a physical relationship between luminance and retro-reflection values as a function of distance and the angular orientation between the pattern source of light, the reflective material, and the measuring system. This relationship is computed by means of a calibration process. Due to that, for each traffic or overhead sign detected in the sequence, measures of the distance to the sign, luminance and retro-reflection levels are computed. In this way, for each traffic and overhead sign, a luminance curve and a retro-reflection curve, referred to the white part of the sign is computed. To do so, it is necessary to locate the white colour within each sign or panel using image processing techniques. Also, the different elements inside the traffic and overhead signs panels (edge, text, background) are automatically separated through image processing, enabling to carry out separate luminance and retro-reflection measures for each part of the traffic or overhead sign (edge, text, background), so that from the luminance and retro-reflection measures of each part of the signal or panel the contrast is calculated. This is defined as the background-border retro-reflection ratio or the background-foreground retro-reflection ratio, depending on which are the key elements to determine the legibility of the traffic or overhead sign. VISUALISE is composed of several hardware and software elements, as described in Figure 2.

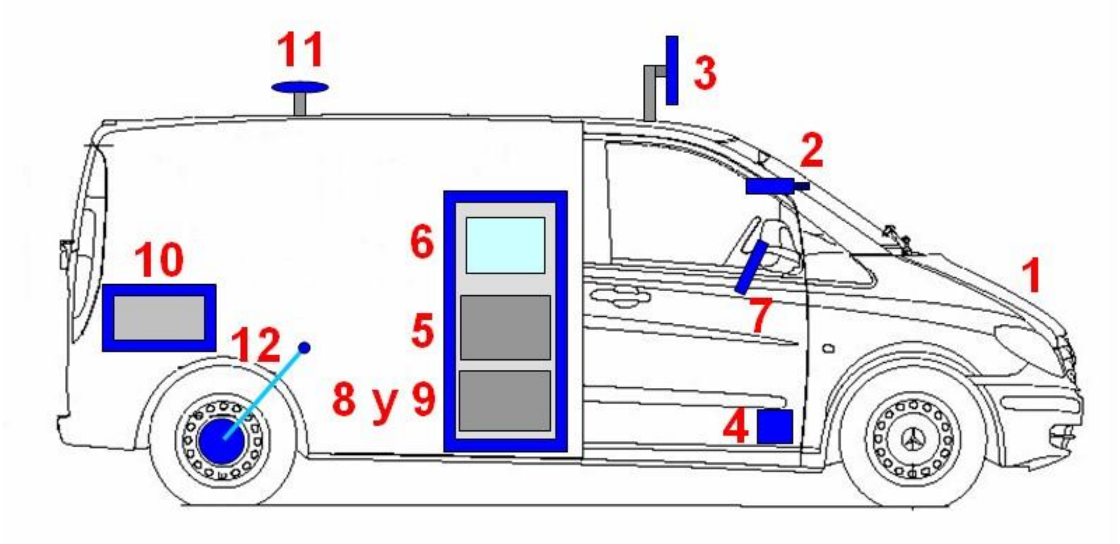

Figure 2 – Components of VISUALISE.

1. Vehicle used to carry out the automatic inspection of signs and panels.
2. High-resolution, high-sensibility digital cameras.
3. Infrared pulsed illumination system (synchronized with the cameras acquisition trigger).
4. Hardware control board for synchronization between cameras and illumination system.
5. Hardware processor based on an industrial computer installed on an industrial damped and rugged rack.
6. TFT display for visualization of results.
7. Keyboard for online introduction of incidences during the acquisition and recording process.
8. Industrial rack for storing the sequences of stereoscopic images. Capacity for 16 500 Gb removable disks.
9. Equipo de procesamiento de imágenes estereoscópicas, para la medida de la retrorreflexión de todos los elementos de señalización vertical existentes en el tramo de carretera auscultado.
10. Diesel generator (230 v, 3.500 W).
11. Differential GPS (12 channels, 10 Hz, submetric accuracy in real time).
12. Odometry system (20.000 pulses).

4. INSPECTION PROCESS

The whole inspection process is carried out in two steps. The first phase or process is called Online Process. The inspection system takes the sequences recorded in the Online Process as inputs and generates a report that contains the retro-reflection and contrast values for all the recorded traffic and overhead signs in the analyzed road stretch. This part of the process is called Offline Process.

4.1. Online Process

The goal of the Online Process is to carry out the acquisition and recording of stereoscopic sequences in removable hard disks. These sequences contain images of road sections illuminated by the infrared lighting system (3) installed onboard the inspection vehicle. The cameras (2) are located inside the vehicle, being their optical axes in parallel with regard to the vehicle longitudinal axis, with a baseline of 35 centimetres in order to ensure maximum accuracy in range measurements (distance), especially at long distances.

The location and angular aperture of the cameras (2) allows covering a minimum area of lateral visibility of up to 10 meters, both to the right and to the left, with regard to the vehicle longitudinal axis for longitudinal distances above 20 meters. Thus, visibility of all traffic and overhead signs in the image plane is guaranteed, even for shoulder-mounted signs. The cameras (2) are pre-programmed with fixed gain and shutter aperture values. The illumination system (3) emits infrared light at a maximum emission power of 60 W. This power emission level permits to ensure that no harm will be caused to drivers of incoming vehicles. The infrared-based illumination system (3) is configured with an angular aperture of 30 degrees, reaching a range of 160 meters. The illumination system (3) is installed on the roof of the vehicle (1), so that its longitudinal axis is set in parallel to the vehicle longitudinal axis and equidistant from the cameras. Thus, perception of the road scene, in terms of illumination, is similar from both cameras. The illumination system is driven by an external synchronism signal in order to guarantee that acquisition from both cameras (2) is by-hardware synchronized with road scene infrared-based illumination. Illumination of road scene is done in alternative image frames. To achieve this, the infrared-based illumination system (3) is triggered at even frames and deactivated at odd frames, yielding a set of illuminated road scene images and a set of non-illuminated road scenes images. Based on these sets of images, luminance values measured in a given non-illuminated road scene image are subtracted from luminance values measured in the next illuminated road scene image. By means of this subtraction technique, the effect of external ambient illumination is mitigated. Thus, signs luminance measured by the system is mostly due to the infrared-based illumination system and the vehicle lighting system. This novel technique allows achieving great homogeneity in luminance measurement conditions. The external synchronism signal is provided by a hardware electronic board (4). The external synchronism signal is used to synchronize the triggering of the infrared-based illumination system (3) and the cameras (2) acquisition times. An operator manually introduces information concerning the kilometric marker post or the kind of road where the vehicle is, by using an incidence keyboard (7). This information is further used in the off-line processing phase.

The on-board processor (5) receives the images acquired by the stereo-vision system, the global coordinates provided by the GPS (11), range distance measurements provided by the odometer (12), and the information coming from the incidences keyboard (7). All this information is bound together in a special format and stored in removable hard disks at a frequency of 18 Hz. At acquisition time, the processor (5) shows the stereo acquired images and the real acquisition frequency in a TFT display (6), providing an indication of correct performance to the operator. A graphical software application is run on the processor (5), supporting the operator in the management of names and location of files in the hard disks corresponding to acquired stereo sequences. Each removable hard disk has capacity to store 2.5 hours of recording. Since the whole system is installed in a moving vehicle, it must be resistant to vibrations and must be well isolated from the thermic and mechanical points of view. For this purpose, the hardware acquisition and storage system (8) is installed in an industrial dumped rack, which is vibration-proof. During the measurement process, the vehicle can be driven at normal driving speeds (up to 120 Km/h) or at the maximum allowed speed according to the current traffic regulations. It is advisable that the vehicle (1) is driven at all times on the right utmost lane in order to guarantee that the entrance measurement angle does not exceed the maximum values used in the calibration phase and that the signs and panels are correctly and entirely illuminated.

4.2. Offline process

The file sequences generated by the on-board processor (5) and stored on the hard disks are the input to the off-line part of the process. These files contain road scene sequences acquired by the stereo-vision system, global GPS vehicle coordinates at all acquired frames, range distances provided by the odometer (12) and information manually keyed in by the operator at acquisition time using the incidences keyboard (such as kilometric marker post, road type, number of lanes, etc). Off-line processing of images contained in the road scene sequences is then carried out, with the goal of detecting traffic and overhead signs and to provide their respective retro-reflection values. The first step is to detect the location of the traffic and overhead signs in the different road scene sequences

recorded by the system. For this purpose, the Hough transform for circles is used, allowing the detection of circular road signs in the images, including the “Stop” sign. By using the Hough transform for straight lines, and adequately combining the attained result, triangular and square-shaped signs are detected, as well as arrow-shaped signs and panels.
In the next step, the stereo-vision system, that has been previously calibrated, is used in conjunction with the information provided by the odometer (12) in order to measure the relative distance between the vehicle (1) and the detected sign or panel. Likewise, by making use of the stereo-vision system, height and lateral distance of the sign or overhead sign (panel) with respect to the vehicle longitudinal axis is measured. Erroneous measures are removed using the height and lateral distance of the detected traffic signs and the normalized geometric values given by the road administration in charge of traffic and overhead signs installation.

The detected traffic and overhead signs are broken down into the following categories:
1. Stop sign
2. Circular sign white background
3. Circular sign blue background
4. Triangular sign
5. Square sign white background
6. Square sign blue background
7. Overhead sign white background
8. Overhead sign blue background.

For each traffic or overhead sign, a segmentation process consisting in the separation of its main elements is performed. The main elements, which are looked for, are: the sign background, border and text. The average luminance of the gray scale image and its distance for each one of the previous elements are computed at every frame. This allows for the computation of a luminance curve (measured in levels of gray) as a function of distance. A new backtracking technique is used to obtain luminance measures up to 100m for traffic signs and to 170m for overhead signs. This technique consists in analyzing the image sequences in the opposite way as they were recorded. This way the traffic and overhead signs can be detected and tracked at further distances than with the usual techniques.

The luminance curves for each sign element are converted into retro-reflection curves as a function of distance. To do so, three different conversion surfaces are used. The inputs to these conversion surfaces are the luminance given by the camera system (2) and the distance between the cameras and the traffic or overhead sign. The output is the estimated retro-reflection for each element. As previously mentioned, three conversion curves are used, one for each performance class used in the national spanish regulation: Class 3, Class 2 or Class 1. Each traffic or overhead sign will be assigned its best match among the three classes. Figure 3 depicts the three conversion surfaces obtained after calibration, as well as the Class 3 pattern used in the calibration process.

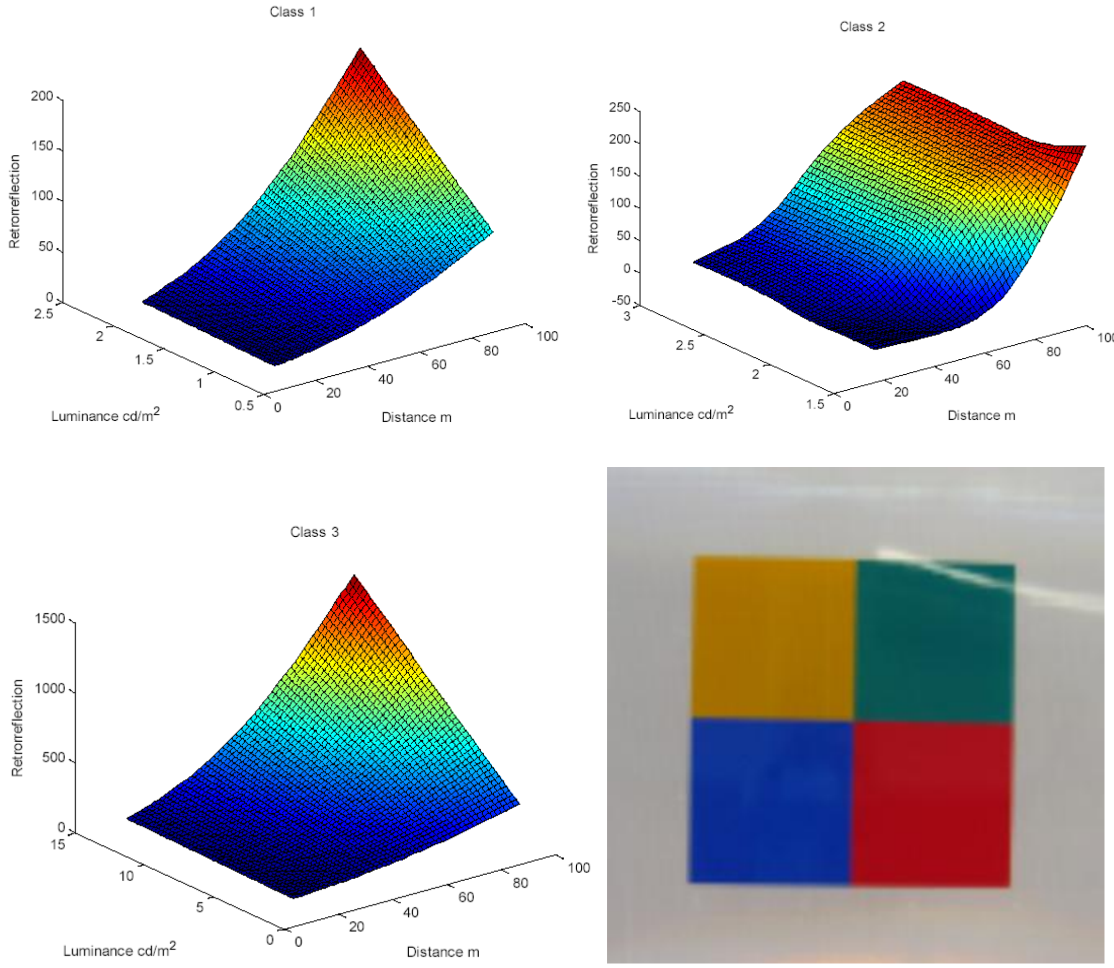

Figure 3 - Calibration curves obtained for class 1 (top, left), 2 (top, right) and 3 (bottom, left); class 3 pattern material (bottom right).

The conversion curves are obtained through an off-line calibration process, performed previously to the inspection equipment deployment in the work scenario. This conversion curves calibration is carried out using 3 pattern signs, one for each class, with known retro-reflection values. Figure 4 depicts the results obtained after a real calibration process. Luminance curves measured on white colour in the three different materials used in the calibration process are depicted in the top, while luminance curves measured for the different colours present in the class 3 material are shown in the bottom part of the figure. Each one of the patterns is recorded using the inspection vehicle (1). The patterns are fixed at 2.5 meters from the ground. During the recording process, the vehicle is driven along a lane which longitudinal axis is 5 meters away in its perpendicular direction from the pattern. The inspection vehicle starts moving 200 meters away from the pattern and it stops as soon as the pattern disappears from the cameras field of view. The recorded images are processed in the calibration process to obtain the luminance curves as a function of distance for each one of the 3 patterns.

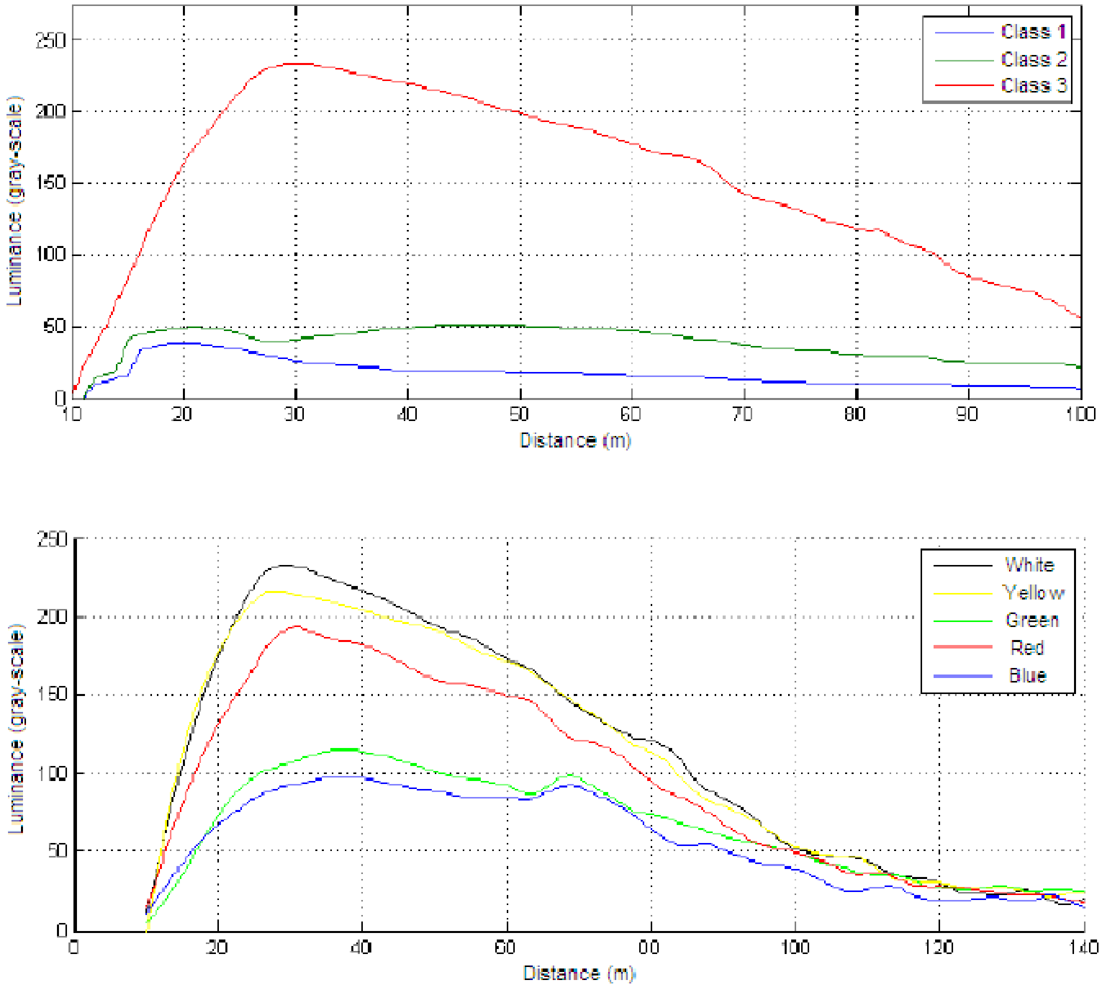

Figure 4 - Luminance curves measured on white colour in the three different materials used in the calibration process (top); luminance curves measured for the different colours present in the class 3 material (bottom).

The conversion curves values are obtained using the luminance curves from the calibration process, along with the real retro-reflection values of the 3 patterns measured at 23, 34, 67, 100 and 166 meters. The use of conversion curves allows for the computation of the retro-reflection curves as a function of distance from the luminance curves measured by the cameras. Figure 5 depicts an example of retroreflection curve measured for a class-3 material. Retroreflection curve for the model is depicted in blue, while the real retroflection curve measured by the equipment is shown in green. Given the cameras (2) and the infrared illuminator (3) position in the vehicle (1), the retro-reflection of a white element in a traffic or overhead sign measured at 100 meters corresponds to the normalized measure at 5 degrees of incidence angle and 0,33 degrees of observation angle.

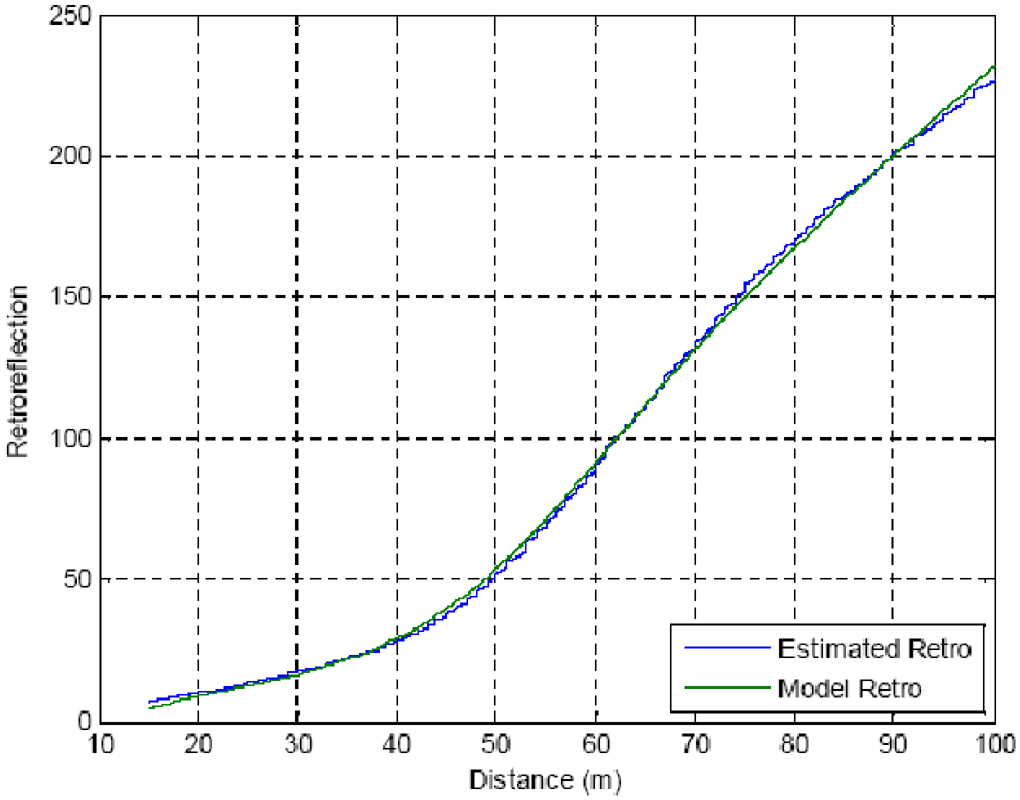

Figure 5 - Theoretic Retroreflection curve estimated for class 2 (blue) used as pattern in the calibration process; Retroreflection curve (real) obtained with VISUALISE (green).

The retro-reflection at 100 meters is used to check which traffic and overhead signs comply with the established criterion. In the same way, the contrast between the text and the border or the background is computed using the measure of retro-reflection at 100 meters. This contrast is used to establish the legibility level of the traffic or overhead sign in accordance with the normalized values fixed by the relevant authorities. The type of material a traffic or overhead sign is made of is estimated using the retro-reflection values at 23, 34, 67, 100 and 166 meters in comparison with the retro-reflection values for these distances established by the current regulation for Class 3, 2 and 1 materials. This information is used to check if the performance class of a traffic or overhead sign is in accordance with the current regulation for the respective type of road.

Finally, the measured retro-reflection and contrast levels for its class are checked according to the current regulation. A final report is delivered by the system consisting of the following information for each traffic or overhead sign:

- Retroreflection curve.
- Retroreflection at 100m.
- Contrast at 100m.
- Type of road.
- Kilometric marker post.
- GPS coordinates of sign or overhead panel.
- Height above ground.
- Lateral distance with respect to the center of the lane that the vehicle is in.

- Road name.
- Traffic direction.
- Road lane.
- Material class.
- Type of traffic or overhead sign.
- Whether the traffic or overhead sign complies or not with the current regulation for its class (pass-fail).

This information is managed by an application with a GUI which allows the visualization and management of the report for each analyzed road stretch.

5. PRESENTATION OF RESULTS

A database is generated as a result of the analysis carried out in the offline process. VISUALISE has been designed to achieve 1:1 processing capability. It means that 1 hour of processing is needed for 1 hour of recorded images.

Due to the great amount of information obtained after inspection and analysis, VISUALISE provides a software tool called ‘Visualizer’ in order to facilitate visualization of results for the end users. Thus, it is possible to graphically observe most of the obtained results. The ‘Visualizer’ tool loads the database generated during the processing stage and displays it in a structured way. Visualiser can be customized according to the road administration specifications.

‘Visualizer’ provides animated buttons for navigating through the database, both in automatic and manual mode. The kilometric point can also be introduced, so that Visualiser automatically moves to that point. Images can be filtered as a function of the retroreflection result, showing only those signs that have passed/failed the pass/fail criteria. Figure 6 depicts a typical output page in ‘Visualizer’.

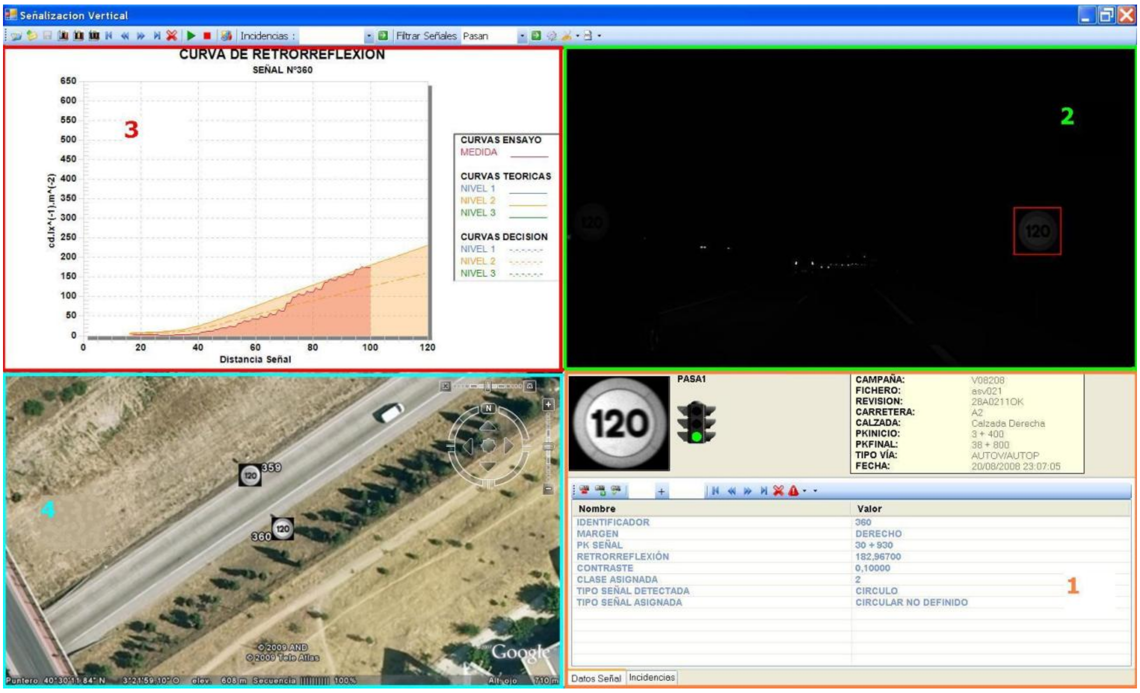

Figure 6 - Example of visualization device for presentation of results [2] and [3].

In the Visualiser output page, information is distributed in four areas as described in the following:

5.1. Data Area (Figure 7)

- General information that is common to all signs: campaign, file, road,lane, begining and ending kilometric point, Type of road, date of recording.
- Detailed image of the inspected sign.
- Particular data for a given sign: identifier, location side, kilometric point, retroreflection at 100m, contrast value (only if specified in the applicable regulation), class of material (based on retroreflection value), class of material (according to applicable regulation), and type of sign.
- Assessment of result regarding pass/fail criteria according to national regulation.
- A Green light in the semaphore (that in this particular case has only three lights instead of four) indicates that the sign has passed the criteria, i.e., the class of the material conforms the required class specified in the applicable regulation, and the retroreflecton value at 100 metres is above the minimum value specified in the applicable regulation. A yellow light indicates that the retroreflection value is between the minimum value specified in the regulation and a value 20% above the minimum value. Finally, a red light indicates that the sign does not meet the retroreflection (at 100m) specification or that the class of the material is below the required class specified in the regulation.

Figure 7 - Detail of data area in the Visualiser.

5.2. Panoramic Area (Figure 8)

Panoramic image of the road. The inspected sign is highlighted by a red square.

Figure 8 - Detail of panoramic image in the Visualiser.

5.3. Inspection result area (Figure 9)

Retroreflection curves (vs distance) of the inspected sign. The current version of the Visualiser displays three curves: ideal or theoretical curve, defined for a given class, inspection resulting curve, built after the luminance-retroreflection conversion, and decision curve, (pass: measured curve is above the region of interest / fail: otherwise).

Figure 9 - Detail of result presentation in the Visualiser.

5.4. Positioning Area (Figure 10)

Image of the inspected sign in an aerial picture of the zone where the experiment was conducted. The sign can be positioned on any georeferenced cartography system.

Figure 10 - Detail of positioning area included in the Visualiser.

Visualizer provides a window for display of statistics corresponding to the inspected road. A summary of the obtained results is depicted, containing data relative to the number of existing signs (measured by the system) and their distribution (inventory), and the status of signs (based on retroreflection). These data can be distributed either as a function of position or as a function of the sign type (code, informative, etc). Figure 11 depicts an example of results presentation based on the selected information after offline processing using VISUALISE.

In order to remove artifacts that can alter the final analysis (publicity panels, under construction signs, etc) the software allows manual postprocessing of the information.

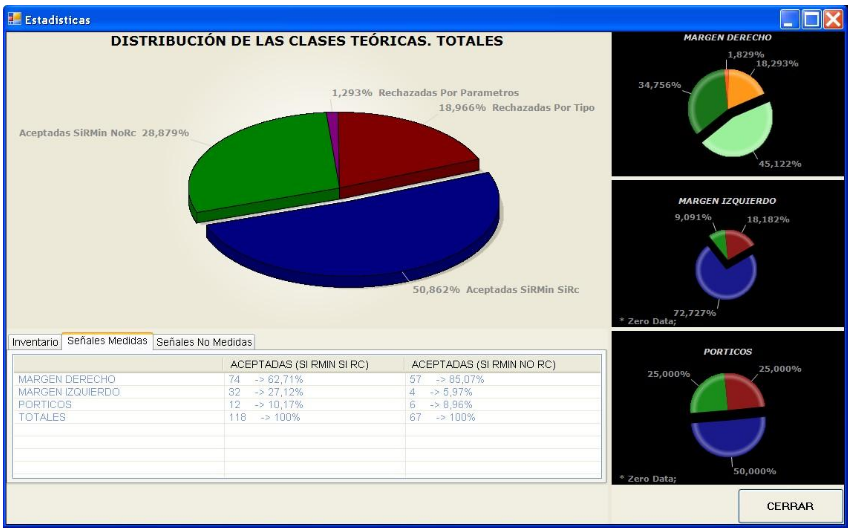

Figure 11 - Statistics presentation report corresponding to the inspected road section. The report is automatically generated

6. CONCLUSION

Dynamic devices provide a leading step, both qualitatively and quantitatively, in the inspection of vertical road signalization. In this aspect, They are an essential tool for road authorities in order to improve the service level of traffic signs.

The improvement in the accurate information about the traffic sign condition will allow for more efficient planning of maintenance and replacement operations. Resource planning devoted to this task will be optimized allowing for a better management of the budget for traffic sign replacements.

Finally, the use of Dynamic devices will contribute to a remarkable increase in road safety.

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