**Dynamic Automatic Inspection of Signs and Panels using Computer Vision**

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Generating knowledge about the state of road signalization infrastructure

**Dynamic Automatic Inspection of Signs and Panels using Computer Vision**

**INTRODUCTION**

The present invention refers to an Automatic Inspection Equipment of traffic signs and panels. It is based on light retroreflection principle and traffic signs and panels contrast, by using as pattern generator an active illumination device based on infrared light pulses and High-resolution cameras. The Equipment will be used in nightly conditions to guarantee that the main lighting source used to measure retroreflection is the one generated by the equipment infrared illumination device, and consequently. Thus, the maximum homogeneity in lighting conditions will be obtained in different roads and routes. The invention aim is to minimize lighting effect in a test regarding retroreflection and contrast measurements of signs and panels, through luminance extraction measured in consecutive images.

**SYSTEM DESCRIPTION**

Up to now, only specific Equipments (Retroreflectometers), which require signs and panels contact, and direct measurements, have been available to obtain nightly visibility measurement of traffic signs and panels. New tests have 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, but results as for luminance measurement are not suitable. 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 comparable measurement production by determined retroreflectometers.

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 depicted in Figure 1.

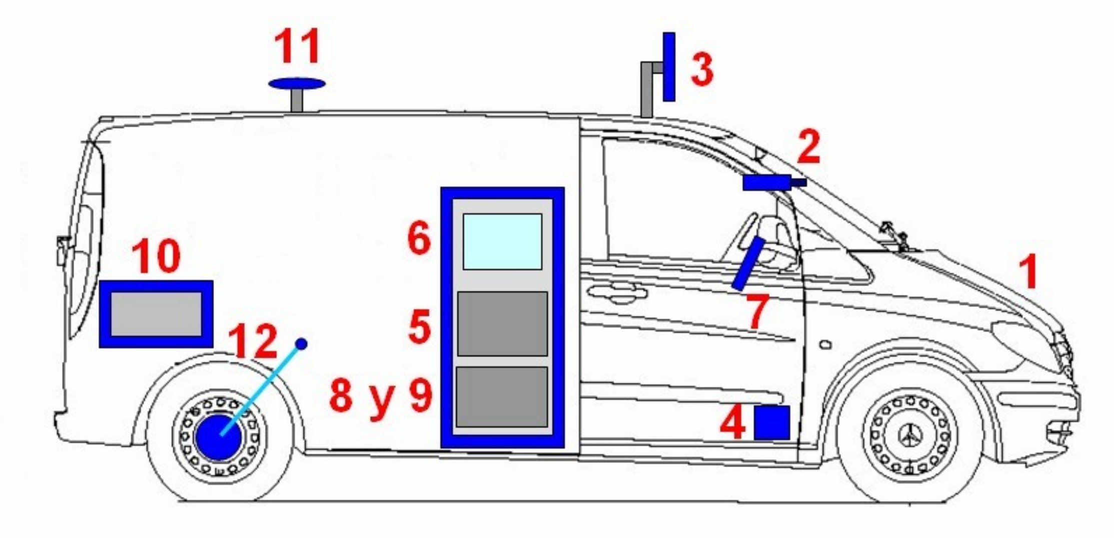



**Figure 1**. Components of VISUALISE.

| | |
|---|---|
| **1.** | Vehicle used to carry out the automatic inspection of signs and panels. |
| **2.** | High-resolution, hith-sensibility digital cameras. |
| **3.** | Infrared pulsed illumination system (synchronized with the cameras acquisition tirigger). |
| **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 disply 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). |

## 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.

### ■ *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.

■ ***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 maker 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 one of the materials a traffic or overhead sign can be made of: class 3, class 2 or class 1. Each traffic or overhead sign will be assigned its best match among the three classes. Figure 2 depicts the three conversion surfaces obtained after calibration, as well as the class 3 pattern used in the calibration process.

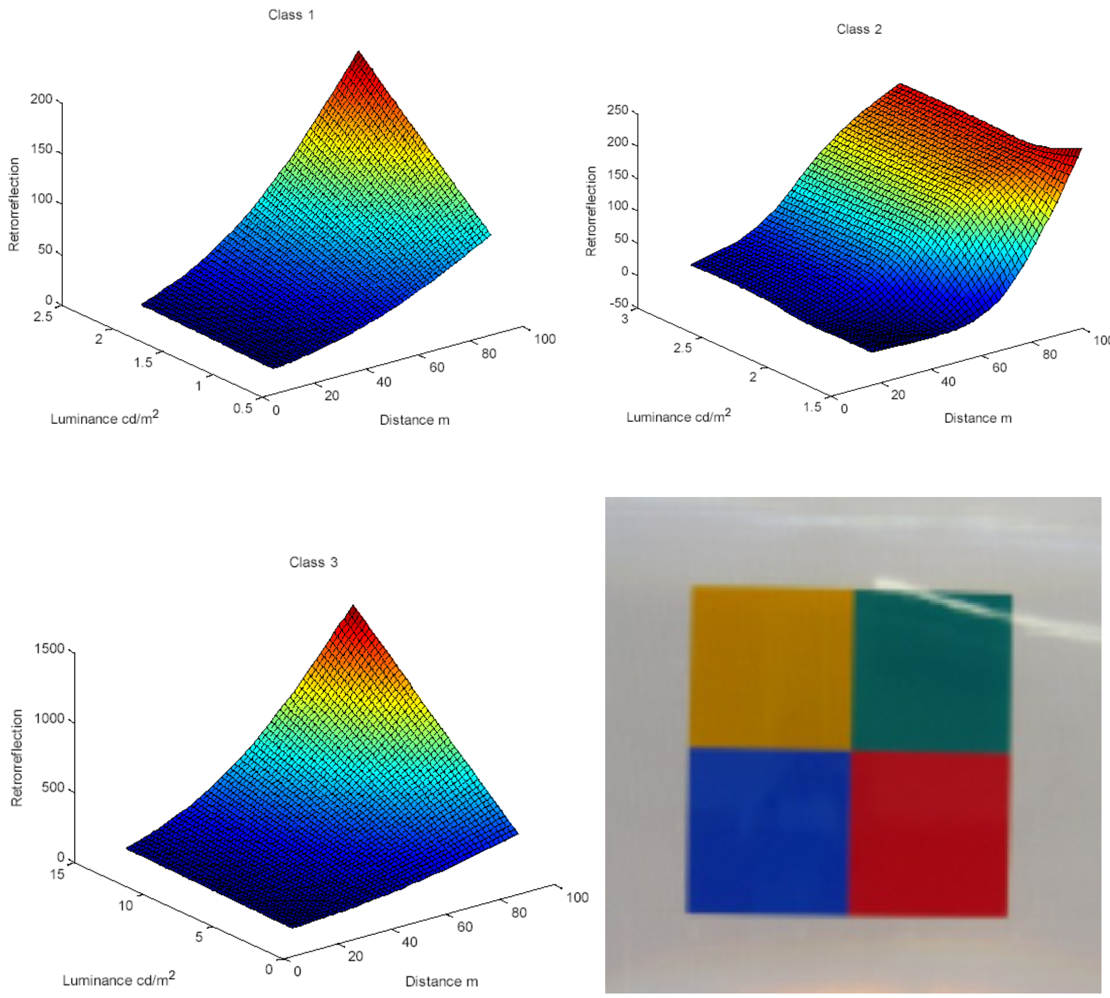



**Figure 2**. Calibration curves obtained for class 1 (top, left), 2 (top, right) and 3 (bottom, left); class 3 pattern material (bottom right).

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 3 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.

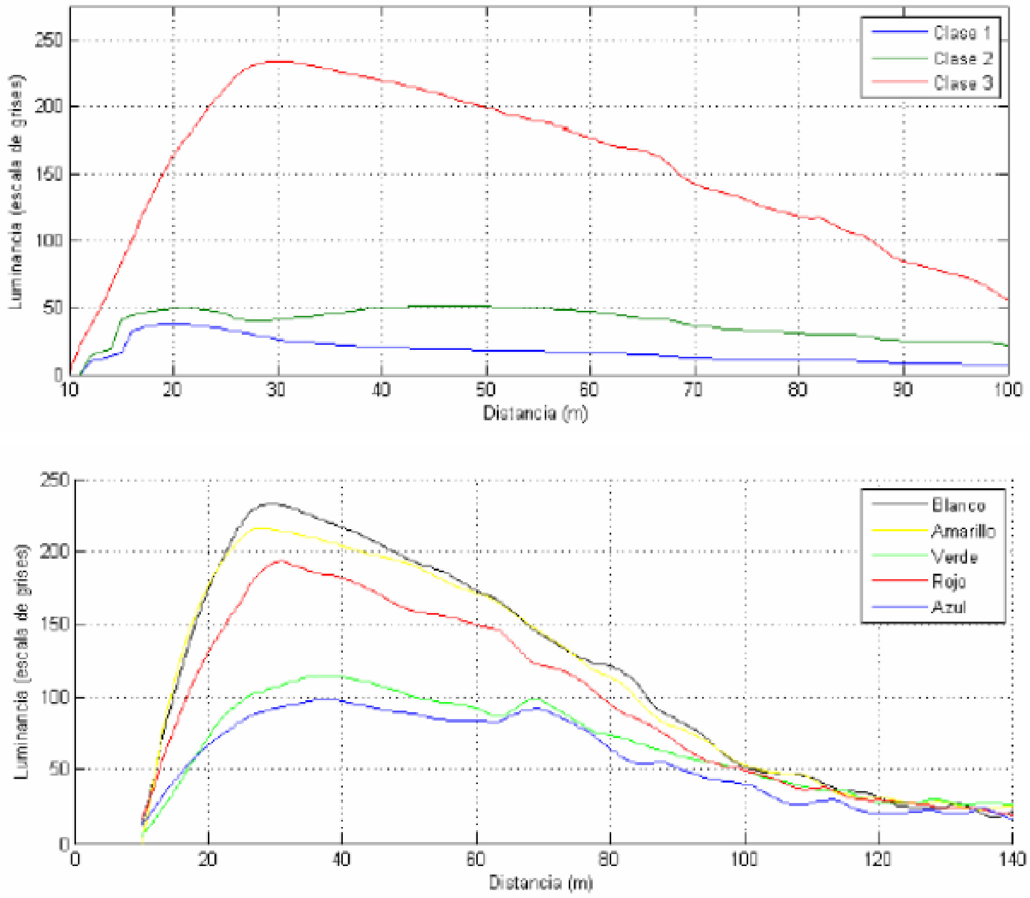



**Figure 3**. Luminance curves measured on white colour in the three different materials used in the calibration process (top); luminance curves measured for the different colours present in the class 3 material (bottom).

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 as a function of distance measured by the cameras. Figure 4 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.

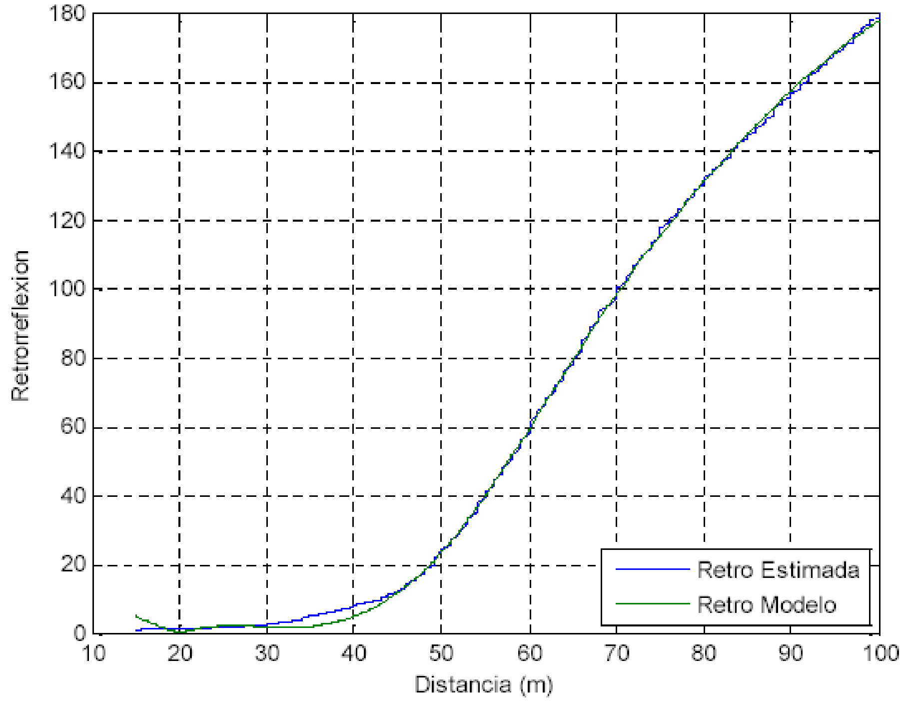



**Figure 4**. Theoretic Retroreflection curve estimated for class 2 (blue) used as pattern in the calibration process; Retroreflection curve (real) obtained with VISUALISE (green).

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 class of a traffic or overhead sign is the required by the current regulation according to the type of road in which it is located.

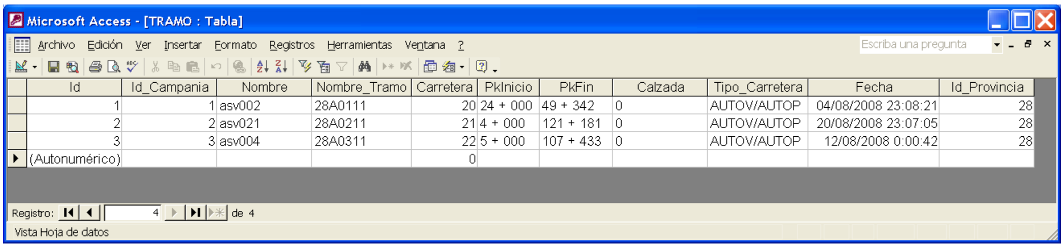
Finally, the measured retro-reflection and contrast levels for its class are checked according to the current regulation. A final report is delivered by the system consisting of the following information for each traffic or overhead sign:

- 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 the inspection 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.

## PRESENTATION OF RESULTS

A database is generated as a result of the measurement 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. In the following table, general data related to recording identification are depicted, such as: road, lane, province, kilometric begining and ending points, date. Figure 6 shows an example of such table.



Microsoft Access - [TRAMO : Tabla]

| Id | Id_Campania | Nombre | Nombre_Tramo | Carretera | PkInicio | PkFin | Calzada | Tipo_Carretera | Fecha | Id_Provincia |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | asv002 | 28A0111 | 20 | 24 + 000 | 49 + 342 | 0 | AUTOV/AUTOP | 04/08/2008 23:08:21 | 28 |
| 2 | 2 | asv021 | 28A0211 | 21 | 4 + 000 | 121 + 181 | 0 | AUTOV/AUTOP | 20/08/2008 23:07:05 | 28 |
| 3 | 3 | asv004 | 28A0311 | 22 | 5 + 000 | 107 + 433 | 0 | AUTOV/AUTOP | 12/08/2008 0:00:42 | 28 |
| (Autonumérico) | | | | 0 | | | | | | |

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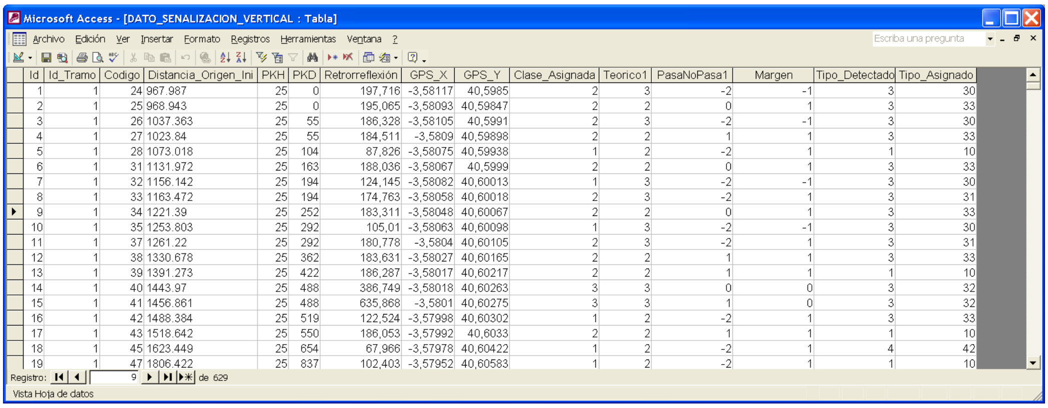
**Figure 6**. Example of table for presentation of general data related to the identification of acquired images.

In a separate table particular data related to traffic signs present in the inspect road strech are shown. Particular data include: unique identifier, kilometric point, side (left, right or top), GPS coordinates, retroreflection level, kind of sign (circular, triangular, rectangular or arrow-shaped), retroreflection coefficient at 100 metres, pass/fail value according to national regulations. Figure 7 shows an example of such type of table.



Microsoft Access - [DATO_SENALIZACION_VERTICAL : Tabla]

| Id | Id_Tramo | Codigo | Distancia_Origen_Ini | PKH | PKD | Retrorreflexión | GPS_X | GPS_Y | Clase_Asignada | Teorico1 | PasaNoPasa1 | Margen | Tipo_Detectado | Tipo_Asignado |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 24 | 967.987 | 25 | 0 | 197,716 | -3,58117 | 40,5985 | 2 | 3 | -2 | -1 | 3 | 30 |
| 2 | 1 | 25 | 968.943 | 25 | 0 | 195,065 | -3,58093 | 40,59847 | 2 | 2 | 0 | 1 | 3 | 33 |
| 3 | 1 | 26 | 1037.363 | 25 | 55 | 186,328 | -3,58105 | 40,5991 | 2 | 3 | -2 | -1 | 3 | 30 |
| 4 | 1 | 27 | 1023.84 | 25 | 55 | 184,511 | -3,5809 | 40,59898 | 2 | 2 | 1 | 1 | 3 | 33 |
| 5 | 1 | 28 | 1073.018 | 25 | 104 | 87,826 | -3,58075 | 40,59938 | 1 | 2 | -2 | 1 | 1 | 10 |
| 6 | 1 | 31 | 1131.972 | 25 | 163 | 188,036 | -3,58067 | 40,5999 | 2 | 2 | 0 | 1 | 3 | 33 |
| 7 | 1 | 32 | 1156.142 | 25 | 194 | 124,145 | -3,58082 | 40,60013 | 1 | 3 | -2 | -1 | 3 | 30 |
| 8 | 1 | 33 | 1163.472 | 25 | 194 | 174,763 | -3,58058 | 40,60018 | 2 | 3 | -2 | 1 | 3 | 31 |
| 9 | 1 | 34 | 1221.39 | 25 | 252 | 183,311 | -3,58048 | 40,60067 | 2 | 2 | 0 | 1 | 3 | 33 |
| 10 | 1 | 35 | 1253.803 | 25 | 292 | 105,01 | -3,58063 | 40,60098 | 1 | 3 | -2 | -1 | 3 | 30 |
| 11 | 1 | 37 | 1261.22 | 25 | 292 | 180,778 | -3,5804 | 40,60105 | 2 | 3 | -2 | 1 | 3 | 31 |
| 12 | 1 | 38 | 1330.678 | 25 | 362 | 183,631 | -3,58027 | 40,60165 | 2 | 2 | 1 | 1 | 3 | 33 |
| 13 | 1 | 39 | 1391.273 | 25 | 422 | 186,287 | -3,58017 | 40,60217 | 2 | 2 | 1 | 1 | 1 | 10 |
| 14 | 1 | 40 | 1443.97 | 25 | 488 | 386,749 | -3,58018 | 40,60263 | 3 | 3 | 0 | 0 | 3 | 32 |
| 15 | 1 | 41 | 1456.861 | 25 | 488 | 635,868 | -3,5801 | 40,60275 | 3 | 3 | 1 | 0 | 3 | 32 |
| 16 | 1 | 42 | 1488.384 | 25 | 519 | 122,524 | -3,57998 | 40,60302 | 1 | 2 | -2 | 1 | 3 | 33 |
| 17 | 1 | 43 | 1518.642 | 25 | 550 | 186,053 | -3,57992 | 40,6033 | 2 | 2 | 1 | 1 | 1 | 10 |
| 18 | 1 | 45 | 1623.449 | 25 | 654 | 67,966 | -3,57978 | 40,60422 | 1 | 2 | -2 | 1 | 4 | 42 |
| 19 | 1 | 47 | 1806.422 | 25 | 837 | 102,403 | -3,57952 | 40,60583 | 1 | 2 | -2 | 1 | 1 | 10 |

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**Figure 7**. Example of data containing the particular data corresponding to inspected traffic signs.

Besides, other tables are built containing additional information such as manually introduced references during online operation, retroreflection curves obtained after luminance-retroreflection conversion in the image processing stage.

The information included in the tables is filtered in the database inquiring process. The kind of filtering can be very varied. Nonetheless, the following information will at least be displayed: signs located on a given road side, signs passing the pass/fail criteria based on retroreflection (at 100m) according to national regulations. Figure 8 depicts some examples showing the fore mentioned information.

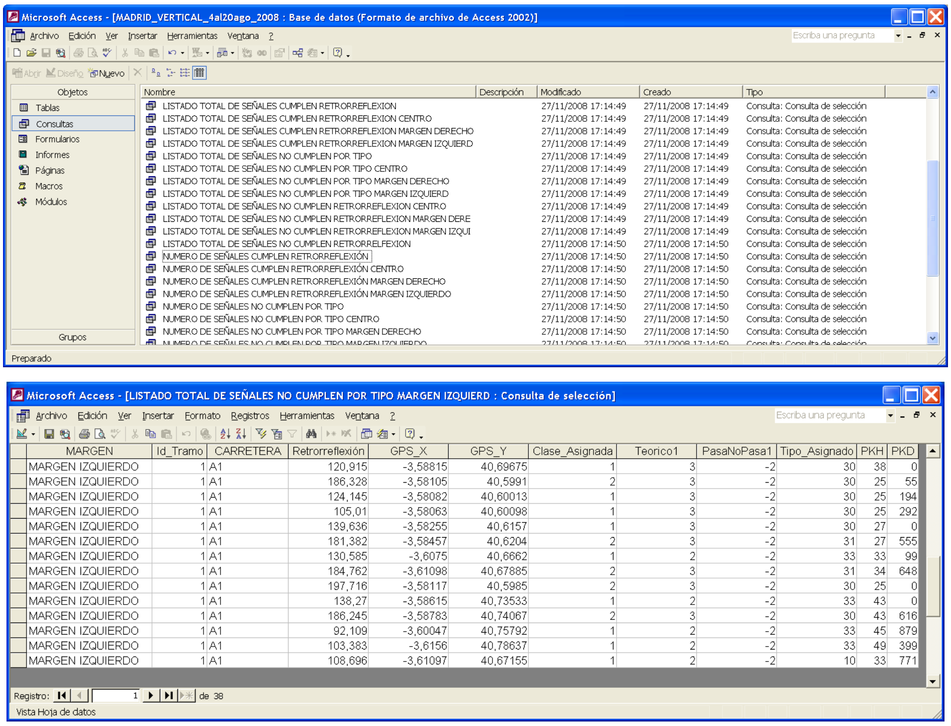


**Figure 8**. Examples of consultations carried out based on filtered information included in tables depicted in figures 6 and 7.

Due to the great amount of information obtained after inspection, VISUALISE provides a software tool so that results visualization is enhanced for end users (Visualiser). Thus, it is possible to graphically observe most of the obtained results. This tool loads the database generated during the processing stage and displays it in an ordered way. The visualiser can be customized according to the road administration specifications.

The results presentation software provides some buttoms for rapidly moving forward in the inspected signs set, both in automatic and manual mode. The kilometric point can also be introduced, so that the 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 9 depicts the general aspect of the results visualization software.

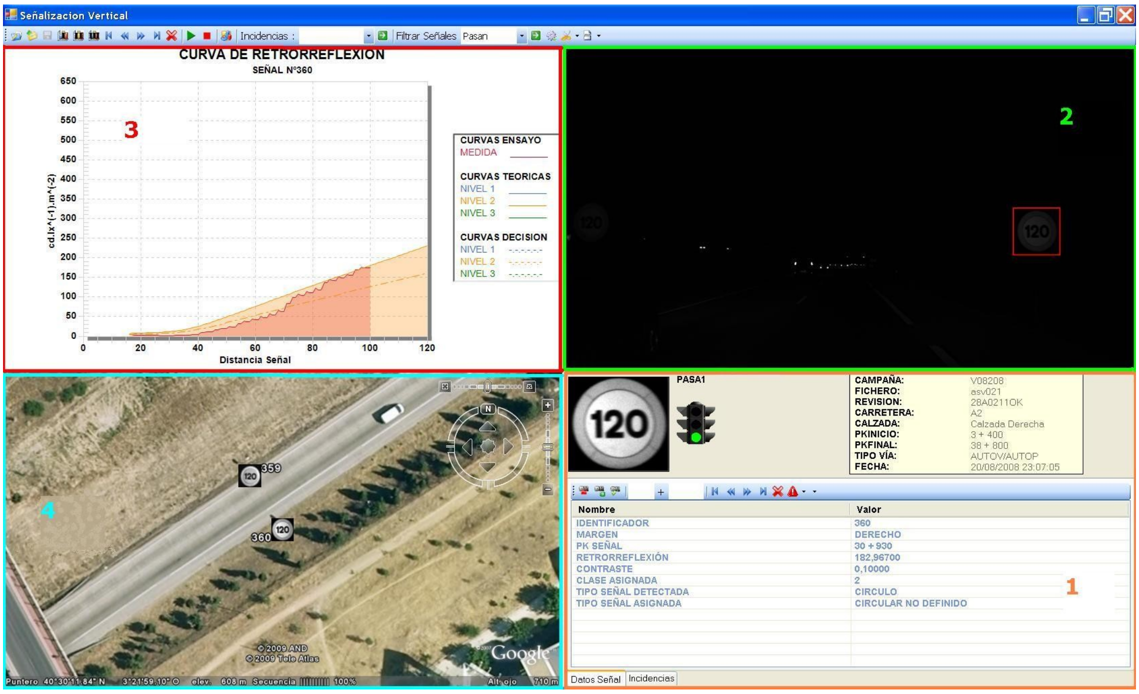


**Figure 9**. Example of visualization device for presentation of results.

In the visualiser display information is distributed in several areas (1, 2, 3 y 4), as described in the following lines:

**1.- Data Area (Figure 10):**

- 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 sing has passed the criteria, i.e., the class of the material conforms the class value 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 regulatin 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 bellow the class value specified in the regulation.


**Figure 10**. Detail of data area in the visualiser.

**2.- Panoramic Area (Figure 11):**

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


**Figure 11**. Detail of panoramic image in the visualiser.

**3.- Inspection result area (Figure 12):**

- 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, (pasa: measured curve is above the region of interest / fail: otherwise).


**Figure 12**. Detail of result presentation in the visualiser.

**4.- Positioning Area (Figure 13):**

- 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 13**. Detail of positioning area included in the visualiser.

The results visualization software provides a window for visualization 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 (inventary), 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 14 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 developed software allows manual postprocessing of the information.

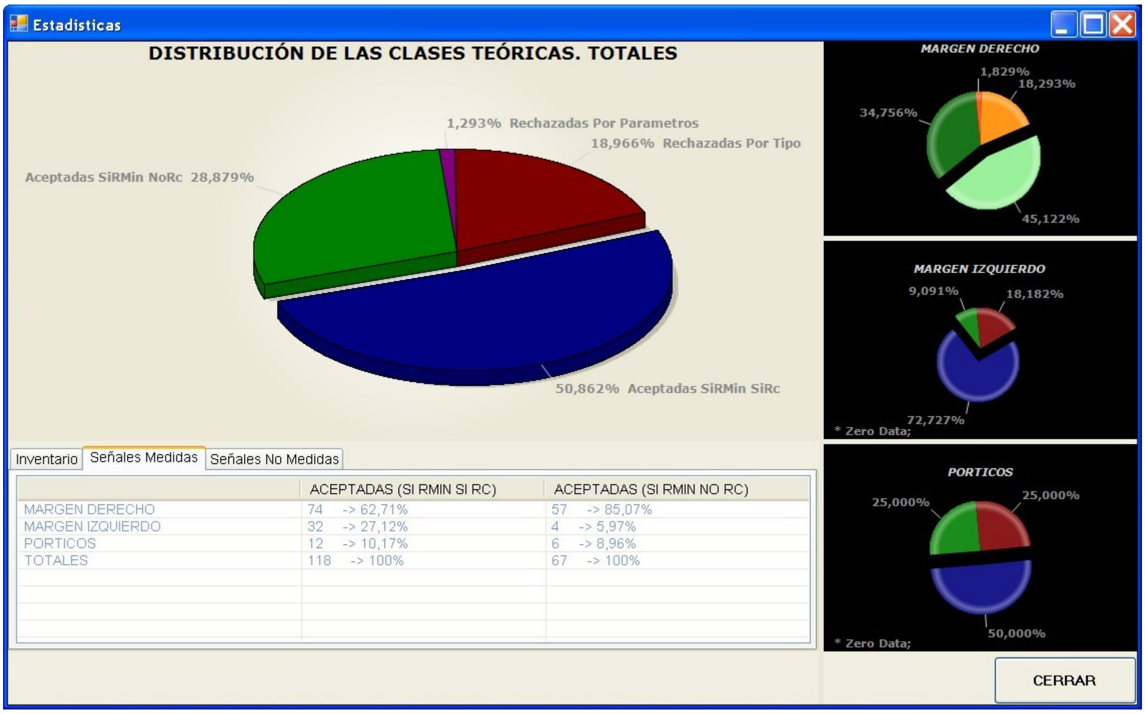


**Figure 14**. Statistics presentation report corresponding to the inspected road section. The report is automatically generated from the results visualiser.

**VISUALISE** provides a leading step, both qualitatively and quantitatively, in the inspection of vertical road signalization. In this aspect, it is bound to be a challeging element that will boost the service level of traffic signs.

The improvement in the knowledge of the traffic signs status, with appropriate reliability levels, will allow for more efficient planning of conservation operations and, as a consequence of that, resources devoted to this task will be optimized. Finally, the use of VISUALISE will contribute to a remarkable increase in road safety.