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A decision support system for the automatic management of *keep-clear* signs based on support vector machines and geographic information systems

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ABSTRACT

This paper presents a decision support system for automatic keep-clear signs management. The system consists of several modules. First of all, an acquisition module obtains images using a vehicle equipped with two recording cameras. A recognition module, which is based on Support Vector Machines (SVMs), analyzes each image and decides if there is a keep-clear sign in it. The images with keep-clear signs are included into a Geographical Information System (GIS) database. Finally in the management module, the data in the GIS are compared with the council database in order to decide actions such as repairing or reposition of signs, detection of possible frauds etc. We present the first tests of the system in a Spanish city (Meco, Madrid), where the systems is being tested for its application in the near future.

1. Introduction

One of the most important problems in cities of developed countries is the traffic analysis and management. This includes planning transportation policies (Arampatzis, Kiranoudis, Scaloubacas, & Assimacopoulos, 2004), traffic modeling and monitoring (Balbo & Pinson, 2005; Chong, Quek, & Loh, 2009; Fernández-Caballero, Gómez, & López-López, 2008), accident analysis (Bayam, Liebowitz, & Agresti, 2005) calculation of optimal routes (Keenan, 1998) and, of course, vehicles' parking regulation (Arnott, 2006; Arnott & Rowse, 1999; Berenger-Vianna, da Silva-Portugal, & Balassiano, 2004; Bifulco, 1993; Calthrop & Proost, 2006; Chou, Lin, & Li, 2008; Hester, Fisher, & Collura, 2002; Jones, 2006; Litman, 2006; Marsden, 2006; Shoup, 2005; Verhoef, Nijkamp, & Rietveld, 1995; Zhang, Huang, & Zhang, 2008), in which this paper is focused on. The increase in the number of vehicles in our cities has caused a dramatic reduction in the number of available parking places, mainly in large, highly-populated cities (Litman, 2006; Shoup, 2005). Thus, councils have been forced to apply strict parking restriction in certain zones, mainly the cities' downtown, to avoid traffic congestion and other derived problems (Arnott, 2006; Arnott & Rowse, 1999). In addition, there are also important parking restrictions in suburban and residential areas, related to parking places in front of private garages, official buildings, hospitals, etc. (Arnott & Rowse, 1999).

There are several systems that can be used to restrict parking in problematic areas. First, controlled parking areas, where drivers who park their vehicle at certain hours must pay a parking fee in a parking meter (Jones, 2006). Usually, residents can obtain a card which allow parking in the area at reduced prices. A system of fines for drivers who do not pay the corresponding parking fee is also implemented. These zones are usually controlled by the local police or civil servants working for the council. In the majority of cases, controlled parking zones are clearly marked with lines in the pavement, with different colors (yellow, blue, green, etc.) depending on the type of zone or fee to be paid.

The case of parking restrictions in suburban and residential areas is slightly different. Usually, those areas are not parking controlled-zones, but there are specific places where parking is not allowed, such as private garages or public building entrances, hospitals surroundings, etc. In the majority of these cases, a *keep-clear* sign is displayed in a place where it can be seen at a glance (a wall beside the garage entrance, a pole in front of a gate or similar). In this last case, the city council licences keep-clear signs to institutions or persons who apply for it and indicate the reasons why a parking restricted place is needed. In the majority of cases, a dropped kerb can be also applied for within the same application form. After studying the application, the city council decides to grant the keep-clear or/and dropped kerb or to reject the application. In the case of the application is successful, no vehicle can be parked in front the garage entrance of the applicant. On the other hand, and depending on the country, the applicant must pay fee to use the keep-clear sign in his/her property, or just for the dropped kerb. In the case of Spain, the law says that the applicant must pay a fee to display the keep-clear sign at his/her property, which will

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prevent other drivers to park in front of the entrance. This situation is, however, different in other Europeans countries such as United Kingdom for example, where the fee is paid, in the majority of cases, only for the dropped kerb, not for the keep-clear sign. In general each country has a different legislation on parking, but in many cases the problems are similar in all them.

The keep-clear sign system implemented in Spain is easy and valuable both for citizens, who are protected against vehicles which block access to their properties, and also for the city council, which obtains a very good economical profit out of it. The main problem with it is that, in the majority of cases, is the council who must manage the signs once they have been granted to citizens. After some years of use, the marks may be deteriorated, broken or simple missing due to vandalism, and it is the council who must control and repair these signs as they are part (and therefore equivalent to) road signs. In large cities, with hundreds or thousand of keep-clear signs spread out in the suburban area, this could be a formidable (and, in addition, very expensive) task.

In this paper, we present a decision support system (DSS) for the management of keep-clear signs, based on a robust Support Vector Machine (SVM) module (Hearst, Dumais, Osman, Platt, & Schölkopf, 1998; Maldonado-Bascón, Lafuente-Arroyo, Gil-Jiménez, Gómez-Moreno, & López-Ferreras, 2007) and a Geographical Information System (GIS) (Arampatzis et al., 2004; Keenan, 1998). The system is based on a detection and recognition tool which uses SVMs (Maldonado-Bascón et al., 2007) as the automatic recognition part of the system. The whole system includes a process to obtain images of houses from a vehicle, using two synchronized cameras. These images are processed using SVMs in order to locate possible keep-clear signs. After the recognition part by the SVMs, a database with GIS is compared with the database of the council, and the results show possible problematic points of actuation, in which human intervention must be required in order to repair or repose signs. The system can be also used to discover false keep-clear signs or infractions related to existing but non-paid signs. This paper discusses a case of real application in a Spanish city (Meco, Madrid), where the system is being tested for real implementation.

The rest of the paper has the following structure: in the next section we describe in detail the proposed system. The subsystems of image acquisition and sign recognition are specially treated and described. The actions for sign management derived from the system are also discussed. In Section 3 we show a real application of the system in Meco, a city in Madrid, with 10,000 inhabitants, where the system is being tested. Finally, Section 4 closes the paper summarizing the main conclusions of the work.

2. System description

The proposed DSS for keep-clear sign management follows the structure shown in Fig. 1. The system consists of a core, managed by a human operator, formed by a database of sign images and a GIS. The human operator must decide the route in which images will be acquired, and mark this route on the GIS. The route will be transferred to an operator team, which will use a vehicle equipped with two synchronized cameras to obtain the images. Once the images are obtained, they have to be processed using the artificial intelligent part of the system. Specifically, the recognition process is carried out using SVMs (Hearst et al., 1998; Maldonado-Bascón et al., 2007), which have been previously trained with a training set. The images in which a keep-clear sign is identified are marked as points in the GIS. In a final stage, this information must be compared with the information included in the database system of the council. The GIS system makes this step easy and accurate. Finally, the analysis of the images can be used to

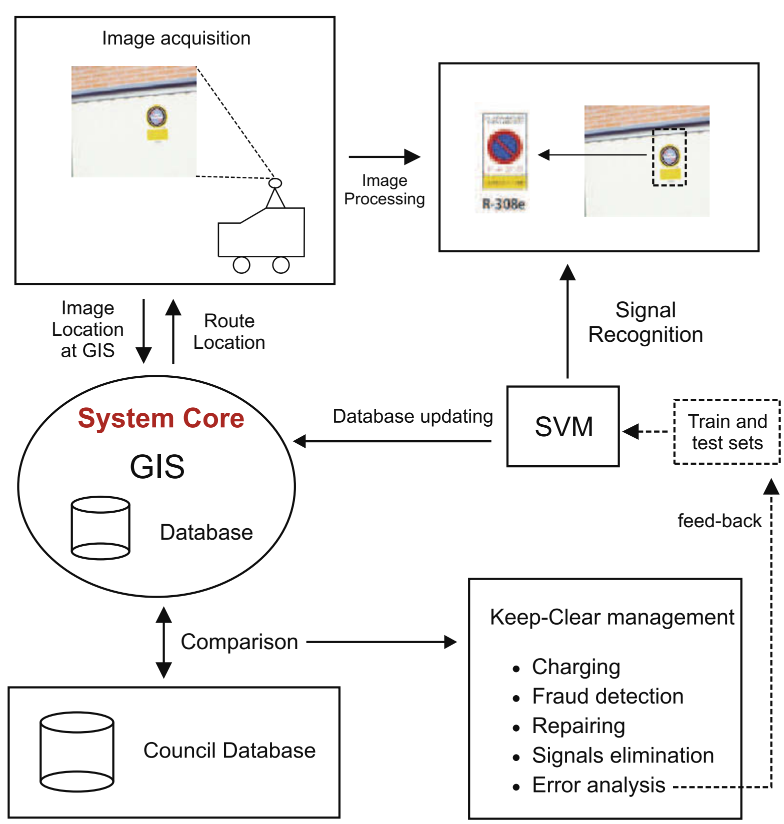

Fig. 1. Outline of the proposed DSS for keep-clear sign management.

improve the training of the SVMs since we increase the database samples for training and test processes. In the following sections we describe in detail the different parts of the system.

2.1. Image acquisition

The image acquisition subsystem deals with the process of capturing and saving the images in an efficient and synchronized way. Since the amount of data needed for these kind of applications is pretty high, the design of the acquisition hardware must be done to get an efficient pipeline from the cameras to the media in which the images and the information from the GIS will be saved.

The image acquisition subsystem is made with two cameras, two laptops, a board with a microcontroller, an odometer and a GPS receiver. Fig. 2 shows the cameras mounted on the roof of the van.

The microcontroller gets information from the odometer, and synchronizes both cameras, which are controlled from the laptops too. Due to the vehicle is on movement while the system is recording, the cameras must work in a synchronized way to capture exactly the same scene. With each stereo pair of images, the system will build a panoramic view in which the keep-clear signs will be recognized. A software to adjust all the parameters to get a successful recording is done as well. Every image is saved together with a GPS position and the relative position casted by the odometer, so the images are related with the GIS too. The images are saved without compression, to make the capturing pipeline efficient. An average of 10 images per second can be saved in the system. The image acquisition subsystem performs the first stage of the whole system, then the signs recognition starts.

Fig. 2. Acquisition subsystem: two cameras on the top of the van.

2.2. Sign recognition

Our automatic keep-clear sign recognition system is based on a recent application for recognizing general traffic signs (Maldonado-Bascón et al., 2007). It can be described in three steps: segmentation, detection and recognition. The most important problems for automatic traffic sign detection are given by the fact that traffic signs are present in outdoor environments. In consequence, the system must overcome difficult situations such as illumination variations, changes of appearance, occlusions and aging.

The segmentation process is a key step in the recognition task. Its purpose is to isolate candidate traffic signs from the background in the scene. In our system, color information is considered to extract candidate objects from the input image by thresholding. Thus, we have implemented several algorithms, but most of them are based on HSI color space since it is strongly robust against illumination changes. Additionally, in order to increase the processing speed, we have developed look-up tables.

We can take advantage of the fact that many Spanish traffic signs (including here keep-clear signs) present different distinctive colors: red, blue, yellow and white. So, in the case we are concerned with, keep-clear signs can be considered as the sum of four contributions corresponding to the red circle, the outer yellow circle, the two blue semi-circles and the white rectangle plate. As an example, Fig. 3 shows the different segmentation masks for a captured image which contains a keep-clear sign. In this figure the background is represented by gray color for all masks. The advantage of this procedure is that the same sign can be detected by different colors and so, we increase the detection success rate.

Once blobs are extracted, a connected-components operator is applied to label the objects of interest. The detection block performs two different tasks, the identification of the shape of

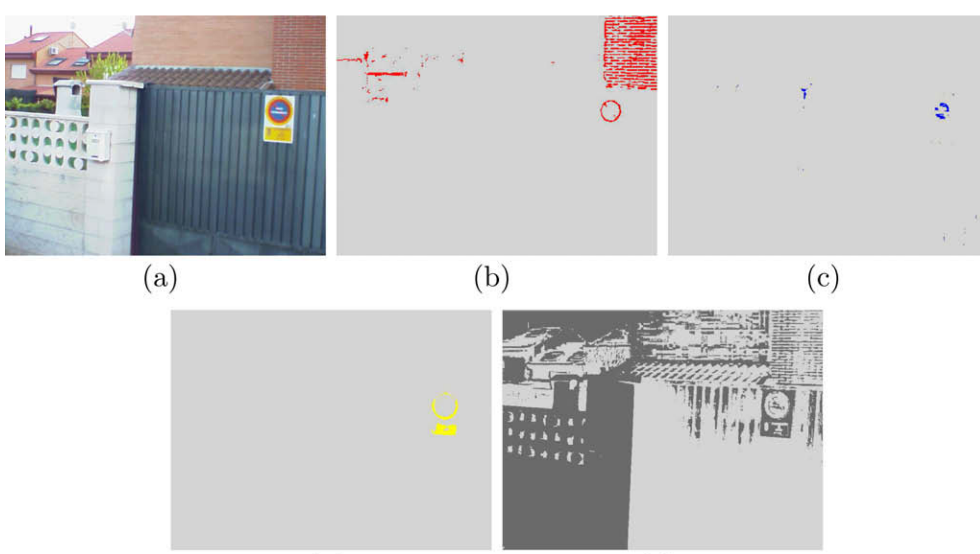

Fig. 3. Example of segmentation process. (a) Original image; (b) segmentation mask by red; (c) segmentation mask by blue; (d) segmentation mask by yellow and (e) achromatic mask.

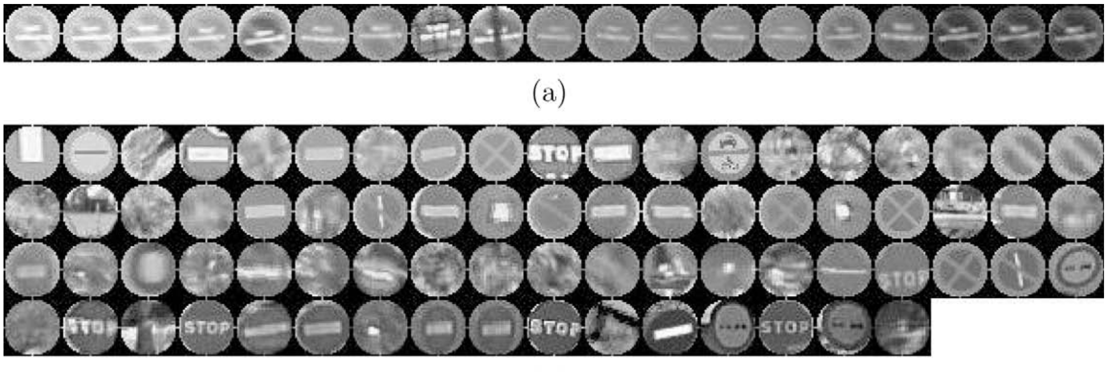

Fig. 4. Support vectors for'Keep-Clear' sign. (a) Positive support vectors; (b) negative support vectors.

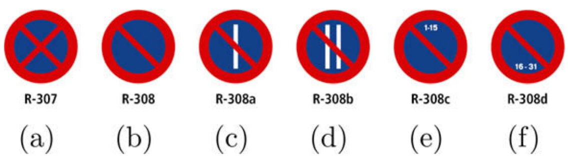

Fig. 5. Group of similar traffic signs considered as different classes to keep-clear signs.

the object, and its localization. The first task consists in classifying each object returned by the segmentation step into a reduced number of shapes: triangle, circle, rectangle, ellipse and semi-ellipse. The classification is performed by extracting the signature of the blob and comparing it with previously computed signatures of the theoretical shapes. Finally, when the shape has been correctly localized, a 2-D homography is computed to allow the system get an image of the sign placed in a reference position.

The identification of the signs is implemented with SVMs using gaussian kernel, where the input vector is a normalized gray-scale image block (Maldonado-Bascón et al., 2007). In order to simplify the recognition problem, both the training and test are done according to the color and shape of each candidate region. So, each object is only compared with those signs that have the same color and geometric properties than the current blob.

From a training process, a binary one-vs-all SVM classifier is implemented to decide if the candidate object corresponds, in this case, to a keep-clear sign. The decision is given by the output value and so, when the classifier gives a positive output, the object under study is considered as a keep-clear sign. Otherwise, the object is considered a noise object. It is important to note that only some pattern vectors of the whole training set define the decision hyperplane as support vectors. As an example, Fig. 4 shows the support vectors that define the binary decision region for the keep-clear sign from red segmentation. This figure includes positive vectors and negative vectors corresponding to other classes and noise samples. Due to size normalization of the blobs, the recognition algorithm is invariant to scale changes. It is important to note that same similar signs appear as negative support vectors. It is because we consider the six signs that appear in the Fig. 5 as different classes to keep-clear sign.

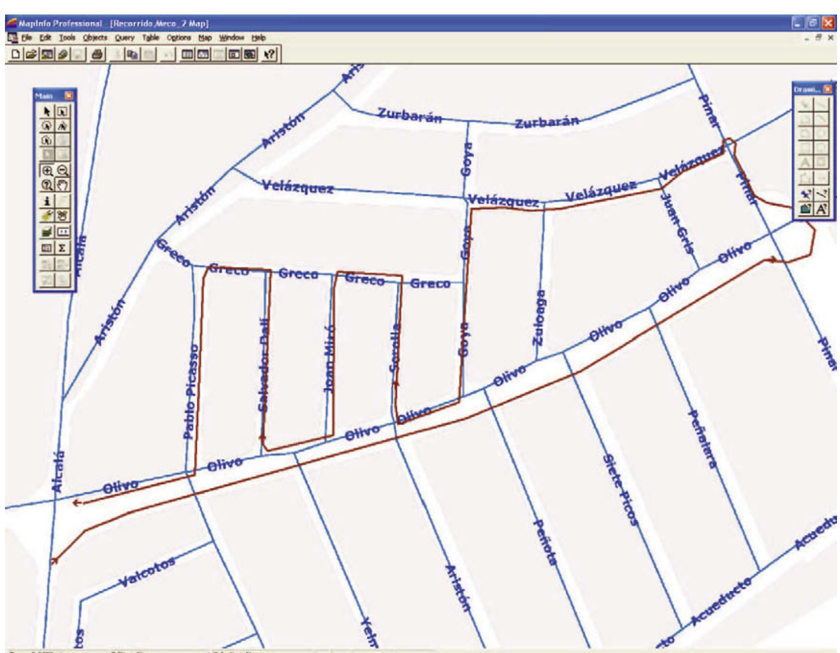

Fig. 6. Outline of one route carried out to test our system in the city of Meco (Madrid).

2.3. Sign management

Once the system finishes the automatic recognition of keep-clear signs in the images of a given route, the information must be incorporated in the system database. Then a process of comparison with the council database initiates the sign management process. This comparison allows detecting possible problems: for example, a sign detected by the system but not in the council database may be a fraudulent sign. Other possible problems such as damages in signs, missing signs due to vandalism etc., can be detected. In these cases, the system will not recognize any sign in an image, but it is in the council database. Note the importance of the GIS in this process, since the different images will be marked in the GIS as points (latitude–longitude coordinates), and used in the comparison of the information in the databases. In these cases, a human operator will check the possible problems with the signs, repairing or substituting them if needed. The proposed system may also be used to facilitate the charging process to users (normally carry out manually), to improve the management of users' complaints about parking or to accelerate the process of granting a keep-clear sign once a user has applied for it.

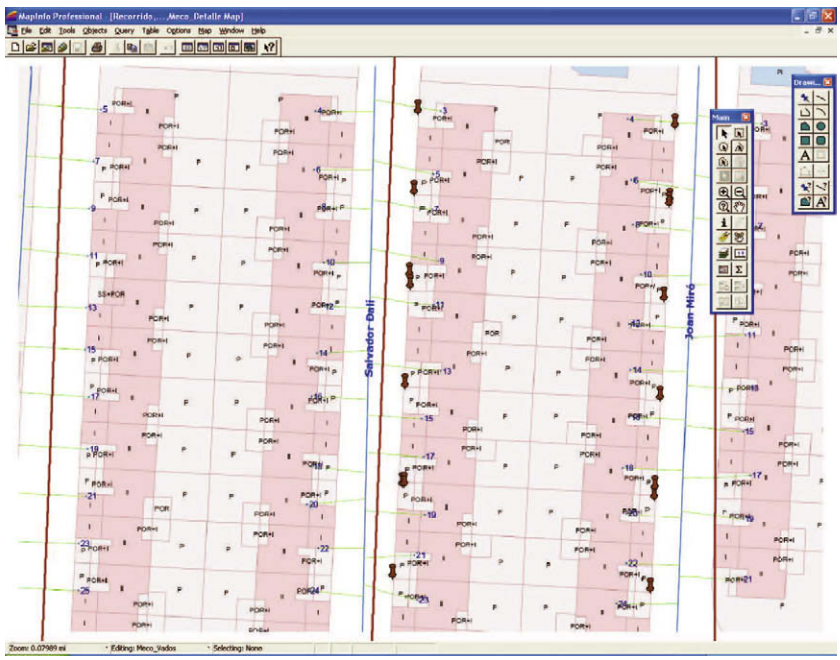

Fig. 7. Detail of streets where images were recorded at Meco (Madrid).

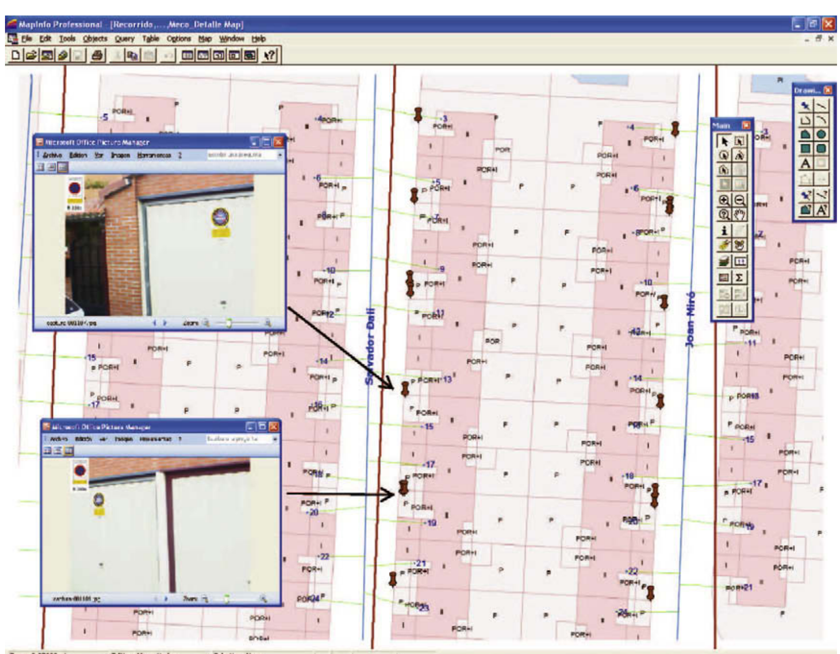

Fig. 8. Detail of streets with keep-clear signs detected at Meco (Madrid).

(a) (b) (c)

Fig. 9. Images of three different keep-clear signs detected by our system in Meco (Madrid).

3. Experimental results

In this paper we include some tests of the system in real operation, in the Spanish city of Meco, Madrid. Meco is a small size city, at the East of Madrid, with about 10,000 inhabitants. Meco is growing very fast, incorporating new residential areas with detached houses, the majority including private garages. In the majority of cases the owner applies for a keep-clear sign to prevent cars parking at the garage's entrance. Thus, the number of garages with keep-clear signs grew over a 300% in the last 3 years, and the problems in the management of the system started. The results of the initial test of the proposed system to tackle this problem in Meco are summarized in this section.

Fig. 6 shows one of the routes carried out by our recording vehicle in Meco. We have chosen a route in one of the new residential areas in which there are zones with a large number of private garages, many of them including keep-clear signs. Fig. 7 displays in the GIS the detail of two streets where images were recorded (we only show the recording of one of the vehicle's cameras). The marks in the GIS show points in which a keep-clear sign was detected by our system. It is easy to see that the majority of garages in these two streets have keep-clear signs displayed at the garages' entrances. Fig. 8 shows the images of two keep-clear sign detected in this route, pointing them out in the GIS.

Finally, Fig. 9 shows three different keep-clear signs detected by our system. These three images give an idea of the recognition problem once the image is recorded. Note that the signs may be displayed in different places around the garage entrance. For example, in the case of Fig. 9a and b the signs are displayed at the garage's gate, whereas in the case of Fig. 9c, the sign is displayed at the top of the gate. Note that this changes the background color where the sign must be detected, so the SVMs must recognize the sign under different conditions. Another interesting point is shown in Fig. 9c. In this image a complete keep-clear sign can be seen at the top left hand side of the image, and a part of a different sign can be appreciated at the top right hand side. Note that the SVM is not able to recognize the part of the sign at the top right hand side, and only the complete sign is detected. The detection of the sign at the top right hand side should be done using a previously image where the sign appears complete.

In this section we have shown the most important parts of the proposed system in operation, the recording part and the recognition part. We have shown the results displayed in the GIS. The management part of the system, in which the council database is compared with the data generated by our system is straightforward.

4. Conclusions

This paper presents a novel decision support system for the management of keep-clear signs. The core of the system is a recording subsystem, mounted over a vehicle equipped with two cameras, and a recognition subsystem formed by a support vector machine, which performs the analysis of images to locate keep-clear signs on them. The results of this process is included in a database with a geographic information system (GIS), to visualize the information. The GIS database offers the possibility of comparison with an alternative database of a client, a council in the majority of cases, which highly automates keep-clear management process. The paper presents some results of the system in operation, specifically the recording and recognition subsystems in a route in city of Meco, in Madrid, Spain.

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