A Survey on Traffic Light Detection

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Abstract. Traffic light detection is an important matter in urban environments during the transition to fully autonomous driving. Many literature has been generated in the recent years approaching different pattern recognition strategies. In this paper we present a survey summarizing relevant works in the field of detection of both suspended and supported traffic light. This survey organizes different methods highlighting main reasearch areas in the computer vision field.

Keywords: Traffic light detection survey · Advanced driver assistance systems · Intelligent transportation systems · Image recognition · Intelligent vehicles

1 Introduction

Although fully autonomous driving is a possible scenario in the future, traffic lights are active tools used to control the traffic in both urban and motorway scenarios. However, both for the current advances in autonomous vehicle and a support for the human-driving, the traffic light detection still remain an active challenge.

Another use of traffic light recognition, is to help blind pedestrian or people with some visual impairment: these systems are often developed on mobile device. In [1] is presented a system architecture based on a mobile-cloud computing. In such a paper, the authors shared promising results obtained with the system working at real-time. Another work is shown in [27]. Authors focused their work on pedestrian lights and they developed a prototype implemented on a Nokia N95 mobile phone. Finally, in [14] a software developed in a similar mobile phone was prototyped in order to be used by blind people. Authors claim that the system was tested with blind volunteer, which guarantee the successful of such method.

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Additional I2V communication can also be considered. In [19] a wireless network that periodically braodcasts traffic lights scheduling information is proposed. Traffic lights lamps can also be used as a light road-to-vehicle communication device. In [26] an high speed camera is used to allow communication between traffic lights and vehicles.

However traffic light detection has been traditionally solved with cameras, so many interesting approaches have been published in the pattern recognition field. Issues related to interpretation of suspended and supported traffic lights are the same, but suspended traffic lights detection is slightly more affected by lighting problems. Some of the most novel contributions have been summarized along this paper. This paper classifies the different works into the following issues: features extraction according to color or shape properties, classifiers and prior information through digital maps. An analysis of these phases to deal with traffic light recognition problems is presented in the following sections.

2 Feature Extraction

2.1 Color Segmentation

RGB-cameras are widely used to detect the scenario where the traffic light are present due to the utility of the color properties [35] [25] [24] [28] [31] [15] [30] [17] [20]. Different authors study the more properly combination of color. A determined color spaces or a combination of several ones are used in a same approach in order to cluster the color.

The clustering leads to analyze the color properties of different lights: while the red color luminosity from a LED spot lights have a brighter component, traditional light bulb color component are less prominent. This situation leads to systems able to integrate both sort of lamps, specially in not very modern urban environments.

Different color spaces are used in the literature. In [35] [16] a simple RGB color space is supposed to support a preliminary information of the state color. Also the normalized RGB is a color space which seems to be more robust against illumination variations or different lighting conditions [11] [25] [24] [9]. Other authors prefer a cylindrical representation of the RGB color space: we could find approaches in [31] [15] which are based on the Hue, Saturation and Value/Lightness (HSV/HLS) color space. This color thresholding model is focused on human vision and it is usually a substitution of RGB color space. Another used color space is the so called YUV color space which highlights the luminance (Y) and chrominance (UV) of images. For instance, in [28], an equalization of the image was performed by the luminance (channel Y). Then, a combination between the hue and the chorminance was carried out for the color segmentation. The LAB color space is also used for this issue in [30] [17]. In [30] a method called Fast Radial Symmetry Transform is proposed to elaborate an image that is composed by the maximum of a and b channel of LAB, reaching a good classification rate for red traffic light. In [17] a novel feature space (called V) is computed, by computing the product of the normalized gray scale, the A channel of LAB and the S channel of HSV: two different approaches are proposed for day and night, both based on Convolutional Neural Network and Saliency Map. Also in [23] the HSV color space was uased. Finally, the convenience of the YCbCr color space is discussed in [2], where authors shows a system able to work at real-time.

The color properties are often exploited by using a set of sequential rules. On the one hand, it could be seen in [25] [24] [33] [9] a simple sequential procedure for this kind of clustering. On the other hand, the integration of a fuzzy clustering combined with sequential rules in [8] seems to enhance the procedure. Another similar approach was shown in [6] where traffic lights detection was based on combination of the hue and intensity image with lighting data, then possible traffic lights were obtained by fuzzification of all this values.

Additionally, the systems should be robust to the whether (rain, fog, snow) as well as the daily hours (morning, evening or night): the color properties in such atmospheric conditions changes, this matter is also widely studied in the literature in [9] [35] [8] [7] [10].

In any case, with no additional I2V information, the current tendency to identify traffic lights and establish their state is carried out by means of a color components approach.

2.2 Shape Properties

Traffic light lamps present particular features which could be studied separately in the image. Looking for this particular features in the image is a good practice to remove whose candidates which are clearly not a traffic light. Such features are frequently based on the shape, aspect ratio, texture and size of detected objects. After studying how these features are in the real traffic lights, rules delimiting features properties is a possibility to extract the correct traffic lights, removing the false candidates.

For instance, authors proposed a straightforward approach in [35] with a concurrent set of rules based on common sense. Although promising results were obtained during the day test, the success rate was quite low during the night.

The contribution [29] presents a system composed by a low cost camera and a robust algorithm written in Matlab. Once, the traffic light parameters are learned using a 2D Gaussian distribution, authors modeled the hue and saturation parameters by using a set of training images. The strongest part of this work is the recognition stage based on the traffic light shape. A weak part of this procedure is both the high computation time and the low frame rate (about 1.4 fps).

An algorithm carried out in this kind of issues is the Hough Transform, since it is able to recognize pattern and forms in an image like the circular shapes. In order to save computation time, an edge detector, commonly a Canny filter, is usually applied to grayscale images at the first stage. Thus, the search is based on detecting parameterized curve circles in the frames. In [34] a discussion about the edge detector is carried out working on traffic light detection. Then, Omachi et. al have worked with traffic lights with lenses mounted in a row. They can be typically found in countries like Japan or in cities like Miami, among others.

In their approach, authors have modified the classical Hough Transform achieving a computation time of 0.15 s and an accuracy rate of 89 %. A classical Hough Transform is used in their initial work [24] and their last approach is discussed in [25]; this new method is used after the clustering and the edge detection process.

Additionally, Circular Hough Transform (CHT) is an acceptable approach to compute the center of a circle object as well [18]. For instance, CHT is used in several traffic signs recognition, such as [13] or [3]. The weakness of this kind of techniques is the computation time, which should be carefully taken into account.

3 Classifiers

The structure of a traffic light is quite standard in many countries. It is composed mainly by a vertical structure and three circular lenses with the colors green - amber - red. Some approaches are based on cascade classifiers to detect this structures.

R. de Charette et al worked on this topic. Several classifiers, based on AdaBoost learning processes, are developed. An interesting and customized Adaptative Templates Matching helped to assay traffic lights from different countries. In their first publication [4] the method is tested in urban roads. Then, in their second publication [5], the method is evidenced in China, France and USA, where 640×480 images were processed with a 2.9 GHz single core desktop computer in real-time. The precision achieved is 95 %.

On one hand, a large set of traffic light images is used in [10] to train the proposed ADAS. In this work, two out three traffic light states were considered: red and green. On the other hand, although not in real-time, a challenging detection results are obtained by using a cascade classifier is used in [22].

The histogram of oriented gradients (HOG) features and support vector machine (SVM) are also recognizer used in this field. Their convenience was evaluated in [23]. Hence, a nearest neighbor classifier is also adopted as recognizer in [2] and a Hidden Markov Models (HMM) in [12].

3.1 Distance Estimation

Estimating the distance between vehicle and detected traffic light is an additional value for any ADAS. In some reviewed works, we could find different approaches. For instance, in [31] authors label traffic lights, their size (radius), number of lenses and height. Labelling traffic lights in a city supports robustness to computer vision system performance.

While in [9] authors dealt with the distance estimation from visual detected candidate properties, in an extension of such work in [8] the distance was computed through Bayesian filters.

Moreover, the distance could be approximated assuming a permanent diameter for the traffic lights lenses [10]. The traffic light location is also estimated through record tracking, back-projection, and triangulation combined with

Bayesian filters in the tracking stage of the algorithm [21]. In [22] [33] the maximum distance at which it is possible to detect traffic lights is presented as well.

State estimation and tracking is as well almost essential for the integration of traffic light detection in automotive systems. The use of Hidden Markov Models is proposed in [12] to filter error in state estimation, increasing the detection rate up to the 50%. In [32] the authors propose an Interacting Multiple Model filter to track the position and the status of traffic lights. Position estimation accuracy increases with the number of iterations that is closely linked to the distance from the traffic light.

4 A Priori Information

Traffic lights equipped with high technology are usually found in modern and smart cities. Among its modern properties, they can be found registered in a digital map for an urban area or can be referenced by a global navigation satellite system data.

A priori knowledge of traffic light position is very useful to filter out a large number of false candidates on the images. Also, such aids to navigation system allow to activate the traffic light detector when the vehicle reaches a fixed distance from a traffic light, i.e. 150 meters in highways or even less in urban environments.

In order to create a digital prior map, some techniques are shared in [10]. In this work, promising results were obtained thanks to the numerous mapped traffic lights in the tested areas - more than 4000 traffic light position were registered. The work published in [22] also confirms the extremely significant benefits in the recognition rate due to the use of a prior map.

Additionally, in [17] the GPS position is used to compute a Region Of Interest in the image, when the distance from the traffic light is lower than 100 meters.

Finally, the experience in Public ROad Urban Driverless-Car Test[1] 2013 by VisLab group also demonstrated the reduction of false candidates and the increase of the correct detections.

5 Conclusions

Although the fully autonomous vehicles will not need the presence of traffic light in future smart cities, detection and interpretation of traffic lights meaning remains an active problem for industries and research groups. The majority of the current advance driver assistance system related to traffic light detection are based on computer vision. In this work we have reviewed the main recently advances published in this field, highlighting phases common to most approaches.

[1] http://vislab.it/proud

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