Automatic Traffic Light Recognition for Mobile Robot Applications

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***Abstract*—In this study, we present a method to enhance the quality of traffic light images captured by a webcam using hardware filters for mobile robot applications. The images are processed through pre-processing, detection, and recognition steps to recognize the status of traffic lights. The results show that the status of traffic lights is recognized successfully; the overall recognition rate is about 99% while the recognition time is about 41ms to 76ms per frame. By using the method of support vector machine (SVM), the recognition rate is higher with the cost of a larger processing time.**

Keywords-traffic light; image processing; HOG; SVM; filters.

I. INTRODUCTION

With the growing concern about the traffic accidents around the world yearly, the big auto industry set the goal of achieving automatic driving by the year of 2025. However, with the progress being made, now the target time is moved forward to the year around 2020 or 2021. The ambition is admirable and the challenge is by no means simple. Researches on Advanced Driver Assistance System (ADAS) are becoming deeper and more extensive in recent years. A tremendous amount of efforts have been put into developing related techniques. Among them, real time recognition of traffic lights in the street is of a necessity. Automatic traffic light recognition plays an important role in traffic safety and traffic flow smoothness. However, traffic lights are hard to detect just by image processing in urban driving conditions due to the complex backgrounds and different illuminations. A worse situation is that some objects may even have visual features similar to traffic lights. Therefore, it is difficult to develop a universal real-time and robust traffic light recognition system for different environments, illuminations, and weather conditions.

Because of its importance, various traffic light recognition algorithms based on image processing have been proposed in the literature [1]-[6], even with machine learning [7] via Adaboost algorithm [8]. In general, researchers are usually divided into traffic light detection and traffic light recognition for the whole recognition algorithm of traffic lights. This is because traffic lights are very small as compared to other objects in the road environment, which may have street lights of similar geometric shapes. Thus, it is necessary to detect the region of interest for traffic lights first to exclude unnecessary background objects to verify the status of traffic lights more easily.

Since the goal of this study is traffic light recognition for mobile robot applications, all of the information has to be processed by the on-board computing facility without relying on external extensive computing powers. That is, an on-board notebook computer was used for all of the image processing task. The images were captured by a webcam (Logitech C525).

Following this Introduction section, Section II describes the methodology, Section III presents the results and discussion, and Section IV draws the conclusions. Details are as follows.

II. METHODOLOGY

As mentioned above, Logitech Webcam C525 was used to capture the traffic light images for the present application. Its resolution is 1280 by 720 pixels with a frame rate of 30 frames per second. In capturing the images, two types of filters were applied. One is a Circular Polarizer (CPL) filter and the other is a Neutral Density (ND) filter. The CPL filter was used to enhance the color contrast and to reduce light reflection to improve the image quality. The ND filter [9] was used to avoid image over exposure and to remove the halo around the traffic lights due to improper background lighting conditions, especially in the evening situations.

The effects of CPL and ND filtering can be clearly observed from the photos shown in Figures 1-4. The former two for CPL filtering; whereas the latter two for ND filtering. By comparing the original and the corresponding filtered photos, it is clear that the CPL filter enhances the color contrast to make the objects in the photos more distinguishable. For the ND filter, both light effect and halo around the traffic light are removed; the traffic light shows its complete round shape. Thus, by these two filters, the image quality captured by the webcam is improved greatly to ease and facilitate subsequent image processing.

Figure 1. Original photo without CPL filtering.

Figure 2. CPL filtered photo of Figure 1.

Figure 3. Original traffic light photo.

Figure 4. ND filtered photo of Fig. 3.

After the image was filtered and captured by the webcam, it is processed to determine whether it is a traffic light. If it is a traffic light, its status is further determined. All of this processing was performed by using Visual Studio C++ and OpenCV function libraries, executed by the notebook computer on the mobile robot designed for validating the recognition methods.

As shown in Figure 5, the traffic light recognition from the images captured by the webcam consists of mainly three steps in sequence: One is the pre-processing, the second is the detection of the traffic light, and the third is the recognition of the status of the traffic light. For the first step of image pre-processing, the red, green, and blue components (referred to as RGB colors hereafter) of the color image captured by the webcam is converted into H (hue), S (saturation), and V (value) color space as the latter is less sensitive to the environmental lighting conditions. Then, the region of interest, which contains the traffic light, is selected to increase the speed of processing.

For the second step of traffic light detection, typical image operations were conducted, including erosion/dilation, open/close operations to remove the noises embedded in the image. Thus, connected regions of interest can be deduced. Then, morphological operations taking care of the geometry, size, and aspect ratio of the traffic light were performed to segment out the traffic light for its status recognition.

In the last step of the recognition, the method of histogram of gradients (HOG) [10][11] is used to extract the features of the traffic light. A database of red, green, yellow, and non-traffic light was also established using the HOG descriptors. This database is constructed mainly for the recognition of using the approach of support vector machine (SVM) [12], which is also trained by the information in the database. That is, recognition is divided into two parts: one for daytime and the other for nighttime. For daytime traffic lights, HOG is combined with SVM for the recognition. For nighttime traffic lights, only features in the color space are used to recognition. If we detect zero or more than one candidate region, the loop will break back to the beginning of the input images for restarting. The image processing algorithm is verified by experiments using a mobile robot

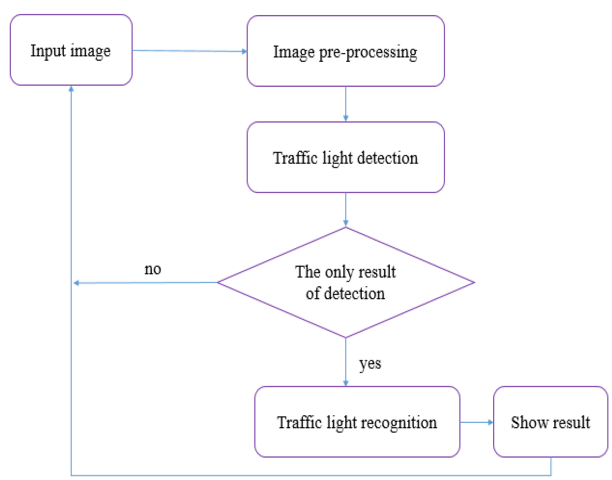

Figure 5. Flow of the traffic light algorithm.

In this study, SVM was selected for enhancing image recognition with HOG. The reasons for this choice are two. One is that the environment around the traffic light is fairly complex, especially at night when lighting sources around the street become the noise of traffic lights. The other is that SVM guarantees a convex space for classification, which can effectively avoid the trapping of the recognition algorithm to local maximum as compared to other classifiers.

III. RESULTS AND DISCUSSION

The experimental environments with traffic light images are shown in Figure 6 and Figure 7 for the red lights at daytime and nighttime, respectively. It is evident that in the daytime, surrounding objects are all captured in the image; whereas, at the nighttime, the lights have halos around them. The recognition process and result are shown in Figure 8, taking the green light recognition as a typical example. The result shows that even under a fairly complex background and illumination of the traffic light, the detection and recognition are successfully achieved.

In order to understand the details of the recognition results, we record every experimental result in different environments and the computation time from traffic light recognition. The results indicate that for the sunny daytime, the recognition rate is about 99.7%, for cloudy day about 99.8%, and 99.1% for nighttime. For the process time, it takes 76ms/frame and 41ms/frame for the daytime and nighttime, respectively. Most of the time is spent in the process of detecting the traffic light while recognition by using SVM also consumes about the same amount of time as the detection process. That is, it takes less time for the method through color recognition, but the correct rate is also slightly lower due to difficulties in distinguish the red from yellow lights.

Figure 6. Daytime traffic light captured and recognized.

Figure 7. Nighttime traffic captured and recognized.

IV. CONCLUSIONS

A notebook computer based algorithm for real-time robust traffic light recognition using images captured from a webcam is developed. The goal is to design a traffic light recognition system which can conquer influences from complex backgrounds and different illuminations for mobile robot applications. Thus, mobile robots can recognize traffic light signals automatically and work in an appropriate way. This algorithm adopts filters to enhance the captured images for detecting traffic lights.

Overall results show that the developed method performs well for image detection in a general environment. The SVM method combines with HOG feature extraction not only can reach real time but also has high accuracy for recognition. Although the recognition method with color feature takes less time than that of the SVM method, it is not efficient to recognize the difference between red and yellow lights. The experimental results show that our algorithm can detect and recognize circular lights in different environment robustly and in real-time with recognition rate around 99%. Further studies are being conducted to improve this recognition rate.

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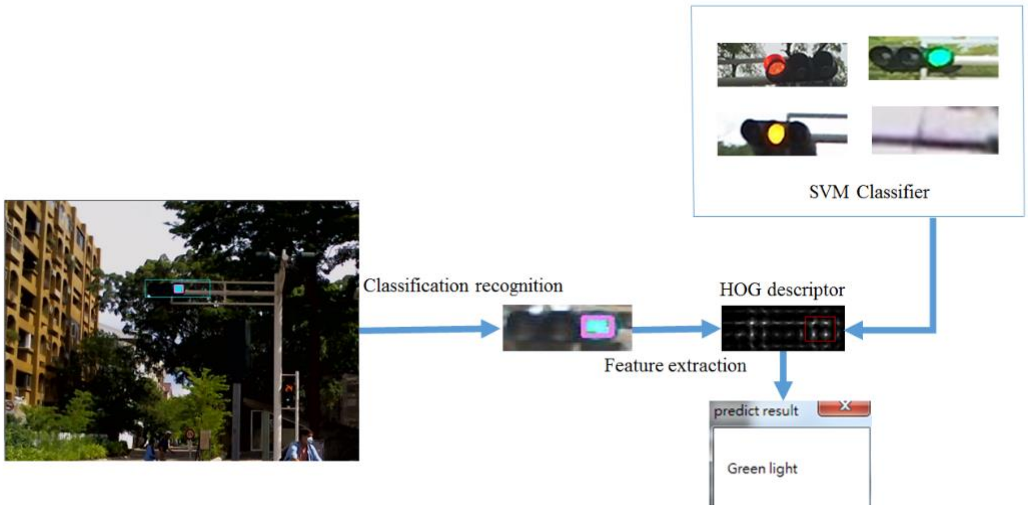

Figure 8. Overall recognition process and result.

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