2010 IEEE Intelligent Vehicles Symposium
University of California, San Diego, CA, USA
June 21-24, 2010

The Recognition and Tracking of Traffic Lights Based on Color Segmentation and CAMSHIFT for Intelligent Vehicles

Jianwei Gong, Yanhua Jiang, Guangming Xiong, Chaohua Guan, Gang Tao and Huiyan Chen

Abstract—**The recognition and tracking of traffic lights for intelligent vehicles based on a vehicle-mounted camera are studied in this paper. The candidate region of the traffic light is extracted using the threshold segmentation method and the morphological operation. Then, the recognition algorithm of the traffic light based on machine learning is employed. To avoid false negatives and tracking loss, the target tracking algorithm CAMSHIFT (Continuously Adaptive Mean Shift), which uses the color histogram as the target model, is adopted. In addition to traffic signal pre-processing and the recognition method of learning, the initialization problem of the search window of CAMSHIFT algorithm is resolved. Moreover, the window setting method is used to shorten the processing time of the global HSV color space conversion. The real vehicle experiments validate the performance of the presented approach.**

I. Introduction

In recent years, more and more attention has been paid to intelligent vehicles driving in urban environments. The intelligent vehicle must comply with traffic rules in an urban environment, and traffic lights are important signals for a vehicle driving in an urban environment.

Depending on the installation and usage of the camera, the detection and recognition method of traffic lights can be either static or dynamic traffic lights recognition. In the former, the camera is installed in a static place and detects crossing traffic conditions. For the latter, the camera is installed on the vehicle to provide important information for the vehicle.

Yung and Lai put forward a automatic red light runner detection on a video [1]. Chung used the color model and morphological operation to obtain the candidate region of the traffic light [2]. According to the information of the space and the time, it can get recognition results. Pang and Liu made use of a CMOS camera to carry on a recognition experiment of an LED light [3]. In these references, the traffic light detection methods are based on the intelligent transportation system, and the cameras are installed in a static place. Therefore, these algorithms are not very applicable to the traffic light recognition for intelligent vehicles.

With the development of intelligent vehicle technology, a few traffic light recognition methods based on the vehicle-mounted camera have been proposed. Tu and Li proposed a kind of recognition method of the traffic light based on the theory of Markov Chain Monte Carlo: MCMC [4]. This method can not only complete the recognition task of the traffic light, but also get the position of the traffic light. However, the real-time performance of this method is not good.

Frank adopted different methods to identify the traffic light in an urban environment and make comparisons among these methods [5]. Shen made use of the vehicle-mounted camera to carry out the video sequence processing and realize the traffic signal recognition for each image frame [6]. This algorithm used a hue and saturation model according to a Gaussian distribution and obtained the statistical model parameter through learning the collected samples. And then the calibration process of the recognition was completed in accordance with the feature of the shape in the candidate region. Lu completed the traffic signal recognition using detection and classification [7]. This method made use of the color space to extract the candidate region of the traffic light and mark the region. In each candidate region, the template feature matching was conducted. For this approach, the recognition distance can not be far. Raoul put forward real time visual traffic light recognition based on spot light detection and adaptive traffic light templates [8].

Generally, the traffic signal recognition methods mainly include the color-based method, the shape-based method and the method based on template matching. For a relatively simple case, such as a sky background, the color-based recognition method can effectively detect and identify traffic light. For a relatively complex situation, such as an urban road environment, false detections will appear easily using the color-based recognition method. The shape-based feature recognition method can effectively reduce the false detections of the color-based feature recognition. But, the different shape characteristic rule has to be created for the different styles of traffic lights. This limits the flexibility of the algorithm. For the recognition method based on the template matching, the different styles of traffic light templates also have to be created to realize the recognition of the different style of the traffic light.

Although the styles of traffic lights are different, they are

Manuscript received February 10, 2010.

Jianwei Gong is with the Intelligent Vehicle Research Center, Beijing Institute of Technology. (86-10-68912329; fax: 86-10-68912526; e-mail: gongjianwei@bit.edu.cn).

Guangming Xiong is with the Intelligent Vehicle Research Center, Beijing Institute of Technology (Tel: 86-10-68912329; Fax: 86-10-68912526; E-mail: xiongguangming@bit.edu.cn).

Huiyan Chen is with the Intelligent Vehicle Research Center, Beijing Institute of Technology. (86-10-68912526; fax: 86-10-68912526; e-mail: chen_h_y@263.net).

mainly composed of red, yellow and green. In the urban environment, the vehicle has to comply with the instruction of the traffic light. Therefore, this study aims at the recognition and following of the traffic light based on vehicle-mounted cameras. A kind of traffic light recognition algorithm combined with color segmentation and machine learning for a complex urban environment is presented to accomplish recognition. Moreover, the tracking method of a traffic light based on CAMSHIFT is given.

II. Recognition of traffic light based on color space

2.1 Extraction of candidate region based on color segmentation

Color segmentation algorithms include the histogram threshold method, the feature space clustering method, the region-based method, the edge-based detection method, the fuzzy set method, the neural network, the method based on the physical model and so on [9]. Of which, the threshold method has a good real-time performance, and the hue of each kind of light is basically fixed. When a light turns on, its intensity is largely fixed. Therefore, the threshold segmentation method based on the HSV color space is suitable for recognition of traffic lights.

HSV color space is a color model based on human vision, and many researches have used color threshold with the HSI color model [10]. It can be used as a measure for distinguishing predefined colors of traffic lights [11]. In this work, the segmentation method in HSV color space was used.

150 samples with different lighting conditions, different background environment, and different brightness were selected to calculate the H, S & V statistical curves of the red, yellow, and green light. The characteristic parameter of the threshold segmentation in HSV color space was obtained according to the statistics curves [12]. The impact of the minimum risk factor and the minimum error rate is taken into account in these parameters. The characteristic parameters were expanded to prevent the loss of the detected target, and then the false detection was removed through the following recognition. There was an overlap region of the parameters between the red light and the yellow light, which can be completely separated through the following recognition.

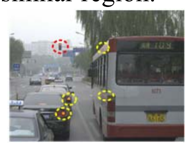
2.2 Morphological processing

After color segmentation, the binary image can be obtained. But some noises are possibly produced. Morphology [13] can resolve the noise problem of the binary image and can carry on the region mark in the connected region which is useful for establishment of the region of interest.

The pre-processing work of noise removal can be quickly completed through the operation of the erosion and dilation. The amount of erosion and dilation is determined on the basis of the resolution of the original image and the focal length of the lens. With high-resolution image acquisition, the size of the traffic lights in the image is relatively large, and the noise removal process is conducted through the operation of a second erosion and dilation without the removal of the target in the erosion stage. For low-resolution images, the operation of erosion and dilation is performed only once, because the traffic light would be removed as noise in the operation of a second erosion and dilation. If the focal length of the camera is larger, the size of the traffic light in the image is relatively large, and the noise removal process can be completed through a second erosion and dilation. Otherwise, the operation of one-time erosion and dilation is needed.

2.3 Region Labeling

According to the mentioned-previously color segmentation and morphological operation, the extraction of a traffic light's candidate region can be completed preliminarily, as shown in Figure 1. Fig.1 (a) is the original image; Fig.1 (b) is the result through the threshold method and morphological processing. The red dot circle is the recognition target and the yellow circle is the similar region.


(a)


(b)

Fig.1 Extraction of the candidate region

From figure 1, some interference is taken as the candidate regions, such as brake lights of other vehicles. Generally, there are often two or more candidate regions in practical applications. In order to remove these noises, the connected region labeling method is used to help further recognition. Using region labeling, the parameters of the central position, the width and height of the external rectangle, and the pixel area in these candidate regions can be obtained. It reduces the detecting area for the following traffic lights recognition.

2.4 Traffic lights recognition based on machine learning

In order to carry on effective recognition for a variety of traffic signals, machine learning method was adopted after mentioned-previously pre-processing. The samples of signal lights were collected to make the classified training. The classifier training was completed by Haar feature and AdaBoost algorithm [14].

III. Tracking of traffic light based on CAMSHIFT algorithm

At a crossing, the speed of the vehicle is generally lower and the position of the traffic light in the collected image changes relatively slowly between each frame. When the traffic light is confirmed by multiple frames, it is not necessarily to conduct the pre-processing and complex validation for the whole image. In order to reduce processing time and ensure the real-time performance, the tracking after the recognition of a traffic signal was performed.

The images collected by a vehicle-mounted camera in an intelligent vehicle are a continuous image sequence. During autonomous driving, the relative position and size of a target in the image constantly change. Moreover, there are some blocks from the front vehicle for traffic lights. Therefore, CAMSHIFT (Continuously Adaptive Mean Shift) [15] which takes the color histogram as the target mode is adopted to avoid false negatives and tracking loss. Combining with the traffic signal pre-processing and learning recognition result, the initialization problem of the search window from the CAMSHIFT algorithm is solved. Furthermore, the window setting method [16] is used to shorten the processing time where HSV color space conversion is conducted only in the region of interest within the window but not in the whole image. It improves the real-time performance of the system.

The traffic light has a good statistical property in the HSV color space with its H, S, & V component. After the pre-processing on the traffic light, the CAMSHIFT algorithm is used to carry on the statistics for the hue component in the labeled region, and then it will conduct the tracking according to the probability distribution of the hue component. The algorithm flow is shown in Fig.2. CAMSHIFT algorithm was performed as the following steps.

a)The window was set after the pre-processing and verification of the traffic light. And then HSV color space conversion was finished inside the window.

b)The color histogram and the color probability distribution in the search window were calculated.

c)The position and size of the new search window was obtained using Mean Shift algorithm.

d)Return to step b in the next frame if the object exists, otherwise, return to recognition processing of traffic lights.

The calculation of the centroid position of the color probability distribution in the region can be obtained.

$$x_c = \frac{M_{10}}{M_{00}}, \qquad y_c = \frac{M_{01}}{M_{00}} \tag{1}$$

Where,

$$M_{00} = \sum_x \sum_y I(x,y) \tag{2}$$

$$M_{10} = \sum_x \sum_y xI(x,y) \tag{3}$$

$$M_{01} = \sum_x \sum_y yI(x,y) \tag{4}$$

$I(x,y)$ is the color probability value of the point (x,y).

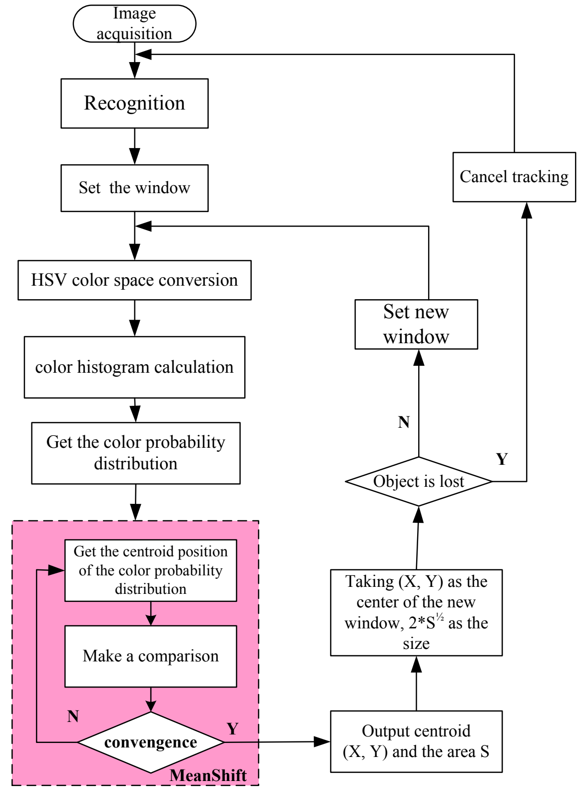


Fig.2 Flow of CAMSHIFT tracking algorithm

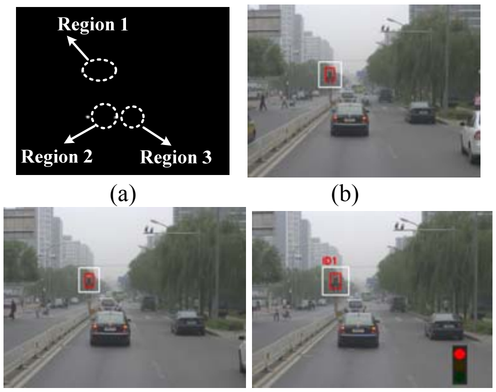
IV. EXPERIMENTS

Selecting the intersection of an urban environment road as the experiment environment, experiments were carried out for the common traffic light. As the image of the traffic light was smaller from a distance, the 780 × 580 high-resolution image format was adopted. A lens with a focal length of 15mm was selected for the camera, the processing computer had a 2.8GHz CPU and 1GB of memory, and the Visual C++ 2008 integrated development environment was adopted.

In the real vehicle experiment, the detection and recognition of the traffic signal need to be confirmed in three continuous frames, and then the initial location and recognition information are transferred to the tracking module. In order to enhance its robustness, the process of the verification was added after the multi-frame tracking. In addition, an additional thread was used for the image pre-processing to achieve the detection of a new target. When the detected target is completely concealed, the connected area of the tracking region is zero; the tracking target is regarded as being lost after three consecutive frames. In addition, when traffic lights change, the new search of the target will be carried on.

4.1 The experiment of detection and recognition of traffic lights

Fig.3 is the detection & recognition stage of the traffic signal, the color segmentation was carried out firstly. Fig.3 (a) is the result after the pre-processing for frame No. 8193. It shows three interested zones. As the color threshold of the brake light and the red is extremely similar, the brake light is included in the region of interest. The classifier of the traffic light was used for the target detection in those three interested regions, which can effectively eliminate interference of the brake light. The detection on the frame from No.8193 to No.8195 is carried out in accordance with the proposed method.



(a) (b) (c) (d)

Fig.3 Detection & recognition stages of traffic signal

4.2 The experiment of tracking of traffic lights

Fig.4 illustrates the window tracking. The white box is the window setting for the next frame and the blue box is the search region of the current frame. The search region is smaller and the process time of tracking is reduced using the window.

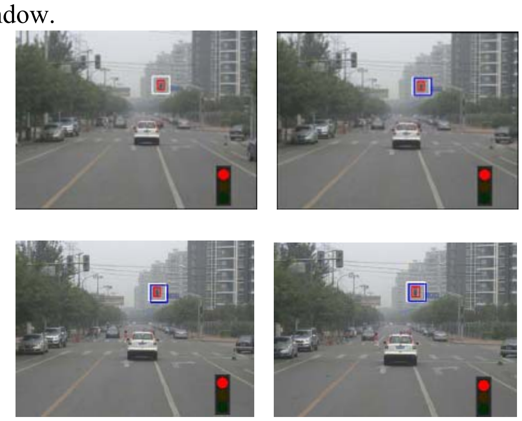
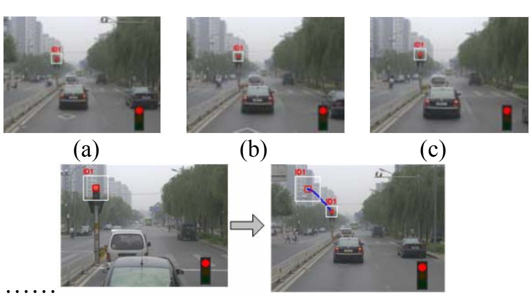


Fig.4 Window tracking

Fig.5 shows the tracking process of the traffic signal, the white box is the calculation area of the CAMSHIFT tracking, and the red rectangular box is the target area. In Fig.5 (e), the blue line is the tracking trajectory, and the tracking region is stable during the period of waiting after the vehicle stops.

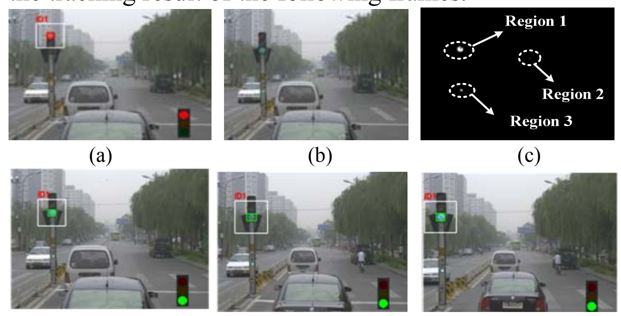


(a) (b) (c)

…… (d) (e)

Fig.5 Tracking Experiment of traffic lights

Fig.6 is the recognition and tracking experiment over color changes of the signal light. The area of the connected region of the red light is zero in the tracking of three consecutive frames, the target is regarded as lost, and then the new detection will be conducted for the calculation region of the target. Fig.6 (a) is the last frame of the red light. Fig.6 (c) is the pre-process result of the green light, and Fig.6 (d) (e) (f) is the tracking result of the following frames.



(a) (b) (c) (d) (e) (f)

Fig.6 Recognition & tracking of traffic signals

V. CONCLUSIONS

The appropriate color space was adopted and the statistical analysis of traffic lights on the various components of this color space was carried out in this paper. Then the segmentation threshold was obtained and the color segmentation was completed according to the statistics result. The morphology was used to complete the noise processing after the color segmentation and the connected region was marked as a candidate region. Through the collection of different styles of the traffic signals samples under a variety of different environments, the traffic lights sample database was established. The machine learning method was adopted to complete the verification. This method has a good adaptability and robustness and it can remove the interference of brake lights. In order to improve the performance of the stability and the real time, the window setting and the tracking based on the CAMSHIFT algorithm were added to the system. The feasibility of the algorithm was verified through the experiment.

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