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A Study on Traffic Light Detection (TLD) as an Advanced Driver Assistance System (ADAS) for Elderly Drivers

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ABSTRACT

In this paper, we propose an efficient traffic light detection (TLD) method as an advanced driver assistance system (ADAS) for elderly drivers. Since an increase in traffic accidents is associated with the aging population and an increase in elderly drivers causes a serious social problem, the provision of ADAS for older drivers via TLD is becoming a necessary(Ed: verify word choice: necessary?) public service. Therefore, we propose an economical TLD method that can be implemented with a simple black box (built in camera) and a smartphone in the near future. The system utilizes a color pre-processing method to differentiate between the stop and go signals. A mathematical morphology algorithm is used to further enhance the traffic light detection and a circular Hough transform is utilized to detect the traffic light correctly. From the simulation results of the computer vision and image processing based on a proposed algorithm on Matlab, we found that the proposed TLD method can detect the stop and go signals from the traffic lights not only in daytime, but also at night. In the future, it will be possible to reduce the traffic accident rate by recognizing the traffic signal and informing the elderly of how to drive by voice.

Key words*: ADAS, TLD, Elderly Drivers, Traffic Accident Rate, Black-box.*

1. INTRODUCTION

According to the national demographic structure, Korea has been aging much faster and will become a super aged society whose population aged 65 or older tops 25% by 2030 [1]. Besides, the number of traffic accidents caused by them increased from 13,596 in 2011 to 23,063 in four years, up by 69.6% [1]. A further problem is the vulnerability of elderly drivers in accident exposure situations, unlike young drivers, it can be seen that the rate of deaths among elderly drivers aged 65 and older is dramatically increasing.

Advanced driver assistant systems (ADAS) are systems developed to enhance safety and better driving for the elderly [2], [3]. Many safety features are designed to avoid collisions and accidents by offering technologies that alert the driver to avoid collisions by implementing safeguards and taking over control of the vehicle [2]-[5].

The starting point for ADAS for the elderly is to recognize the traffic lights correctly [6], [7]. Since traffic scenes can be a complex scenes and contains a lot of information, keeping a constant focus on that can be a challenging task even for a seasoned driver. The idea of using vision for ADAS in urban environments so that Traffic Light Detection (TLD) can be achieved was first introduced in the late 90's and has been studied so far [7]-[10]. By finding the local maxima and minima using morphological algorithm on the image, image dilation for red light and image erosion for green are operated and then circular Hough transform (CHT) is done to enhance the TLD performance [11], [12].

Since the conventional TLD method is difficult to implement due to its complexity of the algorithm and high cost of the hardware, we propose a simple and accurate way to recognize the traffic signals through picture from black-box (camera installed in a car).

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2. CONVENTIONAL TLD SYSTEM

The idea of applying TLD to ADAS using image processing was proposed in [6], which performs image enhancement from a grayscale image and after that using edge detection algorithm such as Sobel, Prewitt and Laplacian operators for image matching. However, such method does not successfully detect the traffic light all the time but only on clear weather.

Another approach is to use color threshold segmentation method to identify the candidate regions using a HSI (Hue, Saturation and Intensity) color space instead of RGB (red, green, blue) color space [7]. Along with noise removal filtering, two types of filtering which take account of the shape information. Finally, a template matching to eliminate false positive. Using HSI color model does create a conceptual vision similar to human vision and now many researchers are adopting this color space.

A spot light detection was adapted for detecting the candidate region and adaptive template for recognition of the traffic light [8]. This method is later compare with other standard traffic light recognition system to test the accuracy of their system.

A more advanced image processing method using color, symmetry and spatiotemporal information was proposed to adverse a variety of weather conditions [9]. They achieve it using L*a*b color space model instead of RGB (Red, Green, Blue) color model and perform color pre-processing to enhance the red and green regions in the image. The fast radial symmetry transform was utilized to detect the traffic light candidate region and to reduce any false positive information. The spatiotemporal persistency was also used for its verification. This method works generally well regardless of day or night, except on foggy days.

A similar approach proposed in using the L*a*b color space by [10]. This approach still utilizes the L*a*b as [9] but instead of performing color enhancement on the red and green color, they perform the detection of traffic lights using color histogram to separate the intensity and the color information on the traffic lights. In addition, a stereo image was used to exclude candidates that are not traffic lights, and Kalman filter was used to avoid incorrect detection.

Most of the conventional can accurately detect the traffic light candidate. However, those systems are only effective when the weather is clear and only during daytime as can be seen in [6]-[8], [10]. The systems cannot detect traffic light correctly during night time, however it is crucial to the elderly because their vision at night are drastically decreased. Plus, even on an unclear weather, some of the systems [6], [7] have difficulties to correctly identify the traffic light.

To solve this limitations, our system adopts the color pre-processing technique in [9] to Circular Hough Transform (CHT) [11], [12] due to its ability to detect the targeted colors even during night time. Plus, a much simpler mathematical morphology was used to detect the local maxima and minima. Lastly, instead of finding the traffic light box in rectangular shaped, our system detects the circular shape of the traffic light which is more effective on both in day and night time.

3. THE PROPOSED TRAFFIC LIGHT DETECTION (TLD) ALGORITHM

The considered hardware setup for the proposed system is similar to most of related application, which have a black-box (build in camera) on an elevated position on the windshield and embedded computer (navigation with CPU) in a car.

For this proposed method, we are assuming the traffic lights will always be on the top half of the image, because at the intersection the car is at the bottom level and the traffic lights are hanging in the high position.

The following are the steps for the proposed algorithm:

1) Image acquisition: Load figure file
2) Image pre-processing:
   a) Converting RGB image to L*a*b.
   b) Image enhancement on red and green color
   c) Image smoothing and filling holes in the enhanced image.
3) Traffic light detection:
   a) Image dilation to detect red color
   b) Image erosion to detect green color
   c) Circular Hough Transform to detect the traffic lights.

The steps for TLD described above are shown in Fig. 1.

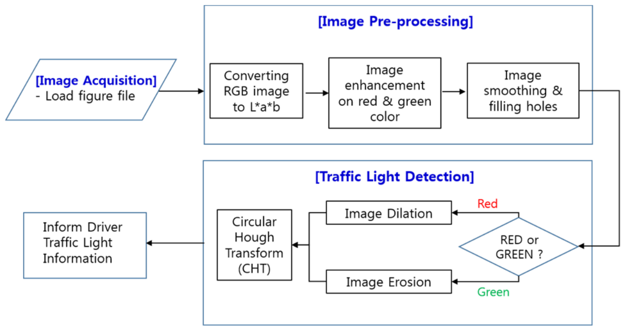


Fig.1. The proposed TLD algorithm for the elderly drivers

The proposed method will start with image acquisition and then go through image pre-processing and traffic light detection sequentially. The image acquisition will be taken from the camera based on the video frames shot by the camera. The goal of the pre-processing module is to enhance the discrimination of the red and green color which can be done through modified L*a*b color model.

The image produce in which the red traffic lights will appear as white circular blobs and the green traffic lights will appear as dark circular blobs. The image from the pre-processing module will then be used to detect the traffic light candidate which include the finding the local maxima and minima using morphological algorithm on the top half of the image. Depending on the target color, image dilation for red light and image erosion for green are operated and then circular Hough transform (CHT) is done at last.

Finally, the proposed system will inform driver the result of traffic light detection in order to assist safe driving for the elderly.

3.1 Image Acquisition

At first, we load image or figure file from the black-box (built in camera) or smartphone, when the car approach to the intersection.

3.2 Image Pre-processing

In order to perform a better traffic light detection, the difference between red and green color must first be enhanced. Only red and green colors are selected because these two colors play an important role in road traffic. The colors will tell whether a car should stop or go. Plus, these colors hold a certain duration than yellow traffic light, therefore we can ignore the yellow traffic light.

The a* from the CIELAB color space model is the red-green color component. The range of the a* color channel is from -128 to 128. The red color component lies on the positive range and the green color component is on the negative value. If a* is 0, then it becomes a neutral gray value [9-10]. The a* from the L*a*b color places positive value on red color and negative value on the green color. If we were to put a maximum positive pixel value and minimum negative value, we can achieve the ideal white circular blob for red color and dark circular blob for green color. This method aligns with the concept specify in [9]. In order to enhance the red and green color, the pixel values in a* channel are multiplied by the pixel values in channel L, producing a new enhance red-green channel defined as

$$RG(x,y) = L(x,y) \times a(x,y), \quad (1)$$

Where, the x and y variables represents the pixel coordinates of the image. The multiplication of both of these channel will impact the pixel value. This will increase the absolute pixel value on the traffic lights as it tends to exhibit a high luminosity values thus turn the advantage of multi-plying with the luminosity channel (L channel). Objects with low luminosity value will not be affected to the same degree as the traffic lights. However, if there are any lights that appears to have the same luminosity as the traffic lights, then they are affected the same way as the traffic lights. The transformation of this process can be seen from Fig. 2.

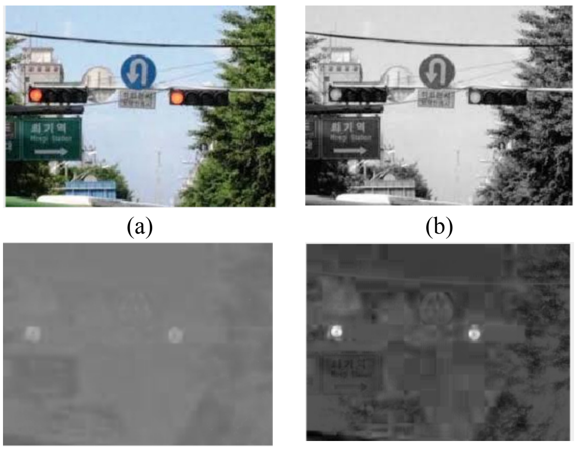


Fig. 2. Red - green color enhancement during day time (a) Original RGB image, (b) L channel, (c) a* channel, (d) L, a* multiplication result (RG channel)

The quality of the image loaded from the black-box should be suffice enough to achieve the goal of image pre-processing. However, in some cases where the condition of the road traffic is in darker side, a "blooming effect" is often produce. This can be seen from Fig. 2-(a). The blooming effect of the traffic lights can be caused by two reasons. The first one is red traffic lights often emit some orange color while green traffic lights emit blue color. The second reason is depending on the type of the camera where the camera might be sensitive to bright lights.

To overcome the blooming effect, red and green color areas are combined with the yellow and blue color. Before combining, we must first apply the same step of color enhancement for yellow and blue color (YB channel) and after that adding the resulting image to the previous enhance red and green image with the following steps:

$$YB(x,y) = L(x,y) \times b(x,y), \quad (2)$$

$$RGYB(x,y) = RG(x,y) + YB(x,y)L(x,y) \times \big(a(x,y) + b(x,y)\big) \quad (3)$$

The results of removing the blooming effect process are shown in Fig. 3. In Fig. 3(b), while the traffic light color should be red color, however it appears to be in negative values which is orange color on the inner part. This the blooming effect and can cause several issues during traffic detection method further on. By adding the YB channel to the RG channel, the blooming effect is removed as can be seen from Fig. 3-(d).

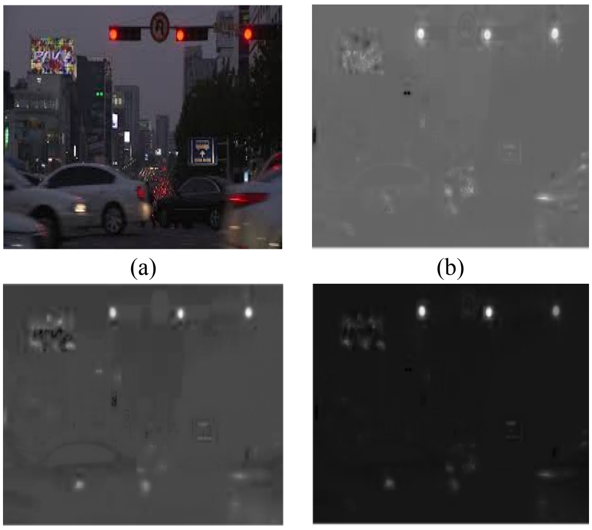


Fig. 3. Removing the blooming effect during night time (a) Original RGB image, (b) RG channel, (c) YB channel, (d) RGYB channel

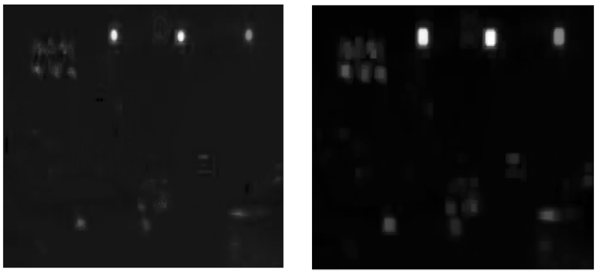
3.3 Traffic Light Detection

3.1.1 Image Dilation and Erosion

Through the method proposed in the previous section, we derived an enhancement of colors towards green and red. The green color denoted as dark pixels and red color as bright pixels.

To improve the pixel intensity of both of these colors, we apply a mathematical morphology operation: image dilation and image erosion.

From the previous RGYB figure, it can be seen that the pixels with red intensity exhibits a bright intensity in the grayscale image. Applying a dilation operation will reveal brighter pixel intensity in that region, separating the brighter foreground from the darker background. Hence, we can detect more local maxima in the gray level image. In mathematical morphology, the dilation operation uses a structuring element to morph the shapes contained in the input image.



(a) (b)

Fig. 4. Local maxima detection for Fig. 3 using image dilation (a) RGYB channel, (b) Image Dilation of Fig. 4-(a)

The dilation in grayscale morphology is given by

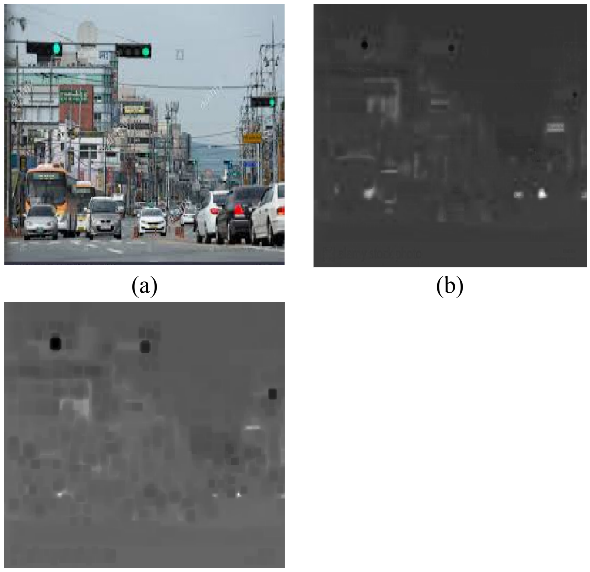
$$(f \oplus b)(x) = \sup_{y \in E}[f(y) - b(x-y)], \quad (4)$$

Where, f(x) is denoted as the image, b(x) as the structuring element, and sup is referred to supremum or also known as least upper bound (LUB). Based on Fig. 4(a), the red colors which has a bright intensity is expanded after dilating the image from Fig. 4(b). From here on, it is easier to detect the red traffic lights.

The erosion operation is the complement of the dilation operation. Applying this operation to the previous RGYB image will reveal more local minima present in the image. The bright pixels in the RGYB image is thinned and the dark pixels are more expanded. Like dilation operation, erosion operation also uses a structuring element as well. The erosion in grayscale morphology is given by

$$(f \ominus b)(x) = \inf_{y \in E}[f(x+y) - b(y)], \quad (5)$$

Where f(x) is denoted as the image, b(x) as the structuring element, and the inf is referred to infimum or greatest lower bound (GLB).



(a) (b)

(c)

Fig. 5. Local minima detection using image erosion (a) Original RGB image, (b) RGYB channel, (c) Image Erosion of Fig. 5-(b)

Based on Fig. 5(c), the pixel with bright intensity are more thinned revealing more pixels with dark intensity. This is because the value output image, Fig. 5(c), is the minimum value of all the pixels in the pixel's neighborhood in that image. It is vice versa to image dilation. Hence, using a simpler mathematical morphology will suffice in our method.

3.1.2 Modified Circular Hough Transform (CHT)

The Hough transform was designed to detect lines in edges. However, it can be designed to find circles and other shapes as well as stated in [11], [12]. As mentioned in it, the circle in parameter space yield the following equation:

$$r^2 = (x-a)^2 + (y-b)^2, \quad (6)$$

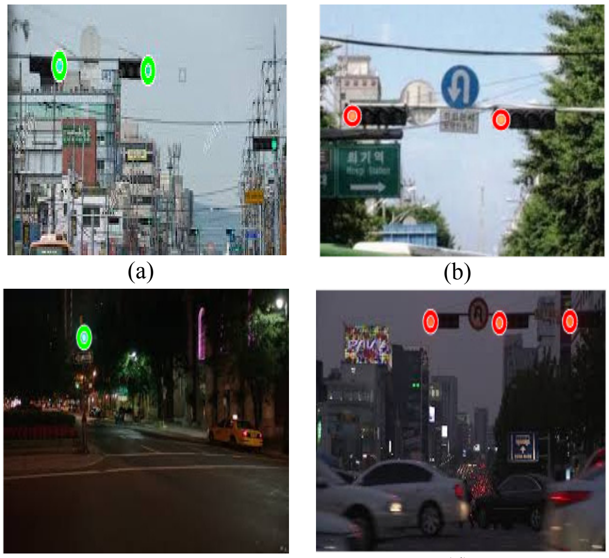
Where, r is the radius, and (a,b) is the center of the circle. If the point of (x,y) is fixed then the parameters can be found using the equation (6).

In our method, the radius of the traffic lights is varied according to the distance between the car and the traffic light. We selected the radius between 2 and 7 as it suffices to detect the circles in the input image. Firstly, all traffic light candidates are selected based on the radius and a certain threshold. This is because there is often the case that back light of the former vehicle is chosen instead, when the traffic light is very far away. So a threshold is applied to reject the traffic light that is lower than the threshold based on the pixel intensity. Next, the radius of the remaining traffic light s is compared and the highest radius is selected. Based on this, we assume that the traffic light that has the highest radius is closer to the vehicle which is what we are aiming for.

Moreover, the object polarity, which indicates whether the circular object is brighter or darker than the background. In our case, the red circular object is to bright polarity and vice versa for green circular object. To reduce false negative object being detected, an edge threshold is applied. The edge gradient threshold will detect both weak and strong edges when the threshold is close to 0 and fewer circles with weak edges are detected when the threshold is close to 1.

Since all red lights are depicted as the brightest pixel and green lights as the darkest pixel, the modified CHT is applied to detect both ends of the extrema regions. Therefore, all circular shapes of the traffic light can be detected in the end.

The implementation of the modified CHT is shown in the Fig. 6. We can find in the figure that the output of modified CHT successfully detect the traffic signals not only in the day time but also in the night time.



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

Fig. 6. The implementation of the Modified CHT (a) Green in day time (b) Red in day time (c) Green in night time (d) Red in night time

3.4 Results of Traffic Light Detection

Table. 1. shows the detection probability from the environment in which the photographs used in the test were taken, the number of pictures used in the test and the number of correctly detected ones from the test pictures.

Table 1. Simulation Environment and Detection Probability

Simulation Environments	# of Test Pictures	# of Detected Pictures	Detection Probability
Day time (clear weather)	100	99	99%
Night time (clear weather)	50	43	86%

The method that we have proposed has proven to almost correctly detect the traffic light during day time and under the normal condition during night time as well. The use of color enhancement as proposed in [9] eliminates the blooming effect which is one of the main factors that the conventional system failed to detect the lights at night. Moreover, the mathematical morphology enhances the bright pixels in red colors and dark pixels in green colors for a better circular shape identification. The proposed method utilizes a much simpler technique using a basic mathematical morphology and shape detection algorithm on the color pre-processing module that we adopt to our method. The modified Hough transform algorithm is additionally used to detect the circular object based on the results of the mathematical morphology.

4. CONCLUSIONS

In this paper, we have proposed a method for traffic light detection using a vehicle black-box camera. The proposed method utilizes a color pre-processing module, and then the output image of the pre-processing further is analyzed with a mathematical morphology algorithm. The algorithm detects the local maxima for red color pixels and local minima for green color pixels. Finally, a circular Hough transform is applied with the object polarity set to bright and dark pixels to detect the traffic light. From the computer simulation results, we can find that the proposed TDL method can detect the stop and progress signal from the traffic lights not only in day time but also, under the right condition, at night as well. By recognizing the color of the traffic lights on the black-box or smartphone camera and confirming the voice to the elderly in advance, the driver who is confused at the intersection can get a great help from traffic accidents.

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