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Enhanced Traffic Light Detection Method Using Geometry Information

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***Abstract*—**In this paper, we propose a method that allows faster and more accurate detection of traffic lights by a vision sensor during driving, DGPS is used to obtain physical location of a traffic light, extract from the image information of the vision sensor only the traffic light area at this location and ascertain if the sign is in operation and determine its form. This method can solve the problem in existing research where low visibility at night or reflection under bright light makes it difficult to recognize the form of traffic light, thus making driving unstable. We compared our success rate of traffic light recognition in day and night road environments. Compared to previous researches, it showed similar performance during the day but 50% improvement at night.

***Keywords*—**Traffic light, Intelligent vehicle, Night, Detection, DGPS (Differential Global Positioning System).

I. Introduction

IN recent years, a number of studies on object recognition based on vision have been conducted in the research area of intelligent vehicles [1]. Among them, fast and accurate recognition of traffic lights, which are required to regulate the vehicle traffics on roads, has been studied actively [2]-[4]. Traffic lights help smooth vehicle traffic. However, it may also create grave consequence to driver's life if traffic lights are not observed correctly. Therefore, accurate recognition of traffic lights is required in intelligent vehicles.

In intelligent vehicles, vision-based systems have been mainly studied for traffic light recognition. Although various sensors are mounted in intelligent vehicles, vision sensors have been widely used because they are suitable for determination of colors and signal types as they can replace the vision function of real drivers.

Recognition of traffic signals using vision sensors has been studied in various ways. A process can be divided into three steps in various traffic signal recognition methods. The first step is to set up the candidate area for traffic signal detection or highlight the characteristic of traffic signal from images acquired via vision sensors. The second step is to extract signal color and type to determine the type of traffic signal. The last step is to determine the meaning of the signal based on the extracted signal type. However, there exist environmental factors that can be difficult to overcome even if such image processing procedure is done.

The most fatal environment factor is distortion of color due to changing illumination thereby having a problem of incorrect recognition and determination about target objects. For example, a recognition algorithm, which can work well at day time, may not work well at night time. This problem occurs because recognition of objects can be difficult due to the effect of surrounding lights during night time.

The recognition of traffic lights is more difficult in the night environment. A shape of traffic light is a black square, which may cause difficulty to be recognized at night time through image processing when illumination is insufficient. Furthermore, tail lights of vehicles, surrounding street lights, and neon sign of red and green colors make the recognition of traffic lights more difficult.

Until now, a large number of studies have been conducted on detection of traffic lights and signs, and objects on roads at night based on vision-based systems. As the most important factor for the vision-based detection of traffic lights, traffic signs, and objects on roads, robustness to illumination absence or change has been proposed as follows.

A traffic sign recognition algorithm proposed by Rubel Biswas used the MSRCR (Multi Scale Retinex Color Restoration) to detect sign boards via the shape extraction of sign boards [5]. This method is based on the morphological analysis method of objects not colors which are sensitive to illumination change.

A vehicle detection method proposed by Jose M. Mossi traced the headlight and the trajectory of the headlight reflected off the road surface to determine the location of vehicles and recognized them as objects [6].

Based on such studies, locations and morphological information of traffic lights are stored in a database using the DGPS (Differential Global Positioning System) location information. In this paper, a method of locating the area of traffic light is proposed through the continuous search and comparison of current location of intelligent vehicle and database (DB) information.

II. Proposed Method

Traffic signals are important for vehicle driving because they provide road information. They are the most basic means to control traffic flows, and stable traffic signal detection with high reliability must be achieved [7]-[9].

Fig. 1 shows a flow chart of how to determine traffic signal ROI (Region of Interest) regions proposed in this paper. In contrast with existing image processing-based ROI region determination methods, this study developed location information of traffic lights via DB thereby determining the presence of surrounding traffic lights through the comparison

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with real-time location information of intelligent vehicles. Once the presence of traffic lights is identified through the information exchange with DB, ROI region can be determined via the relationship model between physical location of vehicles and traffic lights proposed in this study.

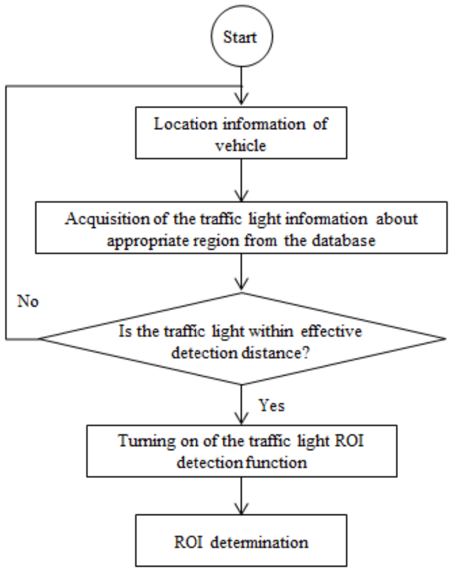

Fig. 1 System Flow

A. Configuration of the Traffic Light DB

Reference information about traffic lights shall be developed in DB in order to acquire information about location and types of traffic lights. In order to generate the physical location relationship with intelligent vehicles, the following information is required: location coordinate information of latitude and longitude, direction denoted by signal in traffic lights for the comparison with vehicle's driving direction, and information about traffic signal type.

The location coordinate information of latitude and longitude is created on the basis of three-dimensional coordinate system based on the DGPS information. For the direction denoted by signal in traffic lights, 380 degree is used to indicate its direction relative to north. For the information about traffic signal type, the number of lenses in traffic light is stored.

This DB configuration is a critical factor that helps to determine whether traffic lights are present through real time information comparison with vehicle location.

B. Analysis of Location Relationship between Traffic Signal and Vision Sensors

To determine ROI regions for traffic signal detection, analysis on the physical location relationship between traffic signal and vision sensors mounted in vehicles are necessary. In addition, analysis on the relationship between images acquired via vision sensors and recognized real region is conducted, which is a basis to determine ROI regions for traffic signal detection.

Physical relationship of location information between traffic signal and vision sensor mounted in a vehicle can be derived through the mathematical analysis. First, location information of vision sensor mounted in a vehicle is acquired through latitude and longitude coordinate and a height from the ground. In addition, information about traffic signal is acquired from DB. Both of the location information acquired from DB and vision sensor is represented via the three-dimensional coordinate system. The physical relationship of acquired location information between vision sensor and traffic signal can be determined through the mathematical analysis.

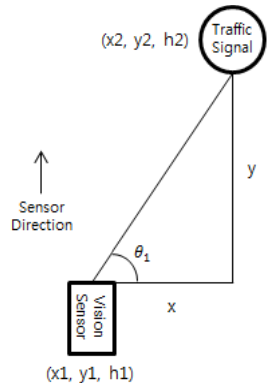

Fig. 2 The relative positions of traffic light and vision sensor (Front)

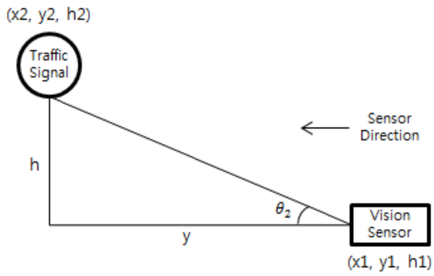

Fig. 3 The relative positions of traffic light and vision sensor (Side)

Figs. 2 and 3 represent the relationship of front and lateral sides using traffic signal and vision sensor, respectively. From the front side relationship, a gap between traffic signal and vision sensor, left-right direction, and angle information can be acquired whereas from the lateral side relationship, a gap between traffic signal and vision sensor, a height and angle information can be acquired. The following equation can represent the relationship information between traffic signal and vision sensor. (x: x-axis distance between vision sensor and traffic light, y: y-axis distance between vision sensor and traffic light, h: height between traffic light and ground, θ_1: horizontal angle between vision sensor and traffic light, θ_2: vertical angle between vision sensor and traffic light, $x1$: vision sensor x coordinate, $y1$: vision sensor y coordinate, $h1$: camera z coordinate, $x2$: traffic light x coordinate, $y2$: traffic light y coordinate, $h2$: traffic light z coordinate)

$$x = |x_1 - x_2| \tag{1}$$

$$y = |y_1 - y_2| \tag{2}$$

$$h = |h_1 - h_2| \tag{3}$$

$$\theta_1 = \tan^{-1}\left(\frac{y}{x}\right) \tag{4}$$

$$\theta_2 = \tan^{-1}\left(\frac{h}{y}\right) \tag{5}$$

The above (1)~(5) represents an ideal location relationship between traffic light and vision sensor without error of location information. The following equation is used to derive the location relationship between vision sensor and traffic light considering real location errors. (e_x : vision sensor x coordinate error, e_y: vision sensor y coordinate error, e_h: vision sensor z coordinate error, e_1: horizontal angle error between vision sensor and traffic light, e_2: vertical angle error between vision sensor and traffic light)

$$x = |(x_1 + e_x) - x_2| \tag{6}$$

$$y = |(y_1 + e_y) - y_2| \tag{7}$$

$$h = |(h_1 + e_h) - h_2| \tag{8}$$

$$\theta_1 + e_1 = \tan^{-1}\left(\frac{y}{x}\right) \tag{9}$$

$$\theta_2 + e_2 = \tan^{-1}\left(\frac{h}{y}\right) \tag{10}$$

The above (6)~(10) considers errors that can occur due to the effect of the error in the vehicle on the location information of the vision sensor. The equation includes a realistic interference factor. The error occurred due to the interference factor can influence the performance that determines the traffic signal detection. By giving a margin to the size of the ROI region, the error is compensated in the determination of the ROI region.

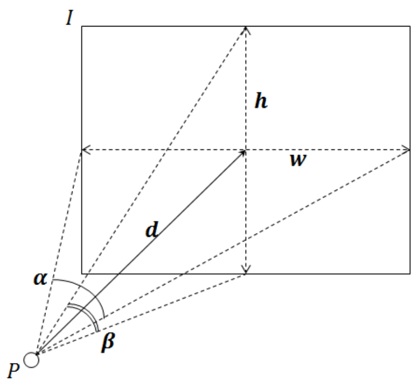

Fig. 4 The relationship between the vision sensor and image recognition

C. Relationship between Acquired Image and Actual Recognized Region

Analysis of the relationship between acquired image from vision sensor and actual recognized region can be a basis for the determination of ROI regions. Fig. 4 shows the relationship between images acquired from vision sensors and actual recognized regions. Herein, *P* is a location of vision sensor, *I* is an acquired actual recognized region, *w* and *h* are width and height of the actual recognized region, *d* is a distance between vision sensor and actual recognized region, and α and β are horizontal and vertical viewing angles of vision sensor.

The size of an image acquired from vision sensor is determined by the size of the viewing angle whereas the size of actual recognized region is determined based on *d*, which is a distance between the viewing angle of the vision sensor and recognized region. The following equation can determine the width and height sizes of the actual recognized region.

$$w = 2 \times d \times \tan\left(\frac{\alpha}{2}\right) \tag{11}$$

$$h = 2 \times d \times \tan\left(\frac{\alpha}{2}\right) \tag{12}$$

The size of the actual region that was recognized by a vision sensor can be calculated via the above (11), (12). Subsequently, the actual recognized distance of one pixel has to be known to determine the ROI region. The following equation calculates an actual recognized region that belongs to one pixel of an image derived from (11), (12).

$$\frac{w}{\#\ of\ \ horizontal\ pixels\ in\ image} = horizontal\ length\ of\ \ one\ pixel \tag{13}$$

$$\frac{h}{\#\ of\ \ vertical\ pixels\ in\ image} = vertical\ length\ of\ \ one\ pixel \tag{14}$$

Through the above (13), (14) the *width* and *height* sizes one pixel has can be determined and the ROI detection location and the size of the region can be determined accordingly.

D. Determination of the Traffic Light Region

A method of determining the ROI region can be determined by relating the physical relationship between traffic signal and vision sensor mounted in an intelligent vehicle with the relationship between acquired image and actual recognized region.

To determine the ROI region, the distance and angle between two objects, which are derived from the physical relationship between vision sensor and traffic signal, are applied to the relationship between acquired image and actual recognized region. According to (6)~(10), location information that is produced by traffic signal and vision sensor can be determined by using the values of *x*, *h*, θ_1 and θ_2. This location information is then applied to the information in Fig. 3 thereby determining the ROI region location.

The size of the ROI region is determined using the following equation according to the type of traffic signal acquired via the DB.

$$\frac{\textit{horizontal length of traffic light}}{\textit{horizontal length of one pixel}} = \#\ \textit{of horizontal ROI pixels} \tag{15}$$

$$\frac{\textit{vertical length of traffic light}}{\textit{vertical length of one pixel}} = \#\ \textit{of vertical ROI pixels} \tag{16}$$

Through the above (15), (16) the horizontal and vertical regions of the ROI can be determined.

III. Experiment and Result

To verify the proposed method, a DB of traffic light location information was constructed and experiments were conducted in a real environment. Using the DGPS mounted in an intelligent vehicle, location information was acquired in real time while the traffic light information in the corresponding region was obtained via the comparisons between DB and the location information. If a traffic light exists within the effective detection distance, the detection function of traffic light ROI region was activated to determine the ROI region.

In this experiment, acA750-30gc vision sensor from BASLER Company and a lens of 12mm focal length were used to acquire images. The image format followed the VGA standards. The equipment used to acquire the location information was a RT3002 DGPS module from OXFORD TECHNICAL SOLUTIONS.

The experiment environment was a four-lane road and the location of traffic light was placed 20 to 25m away from the vehicle stop line in the intersection. First experiment was conducted to verify the performance of the proposed method in a day time environment.

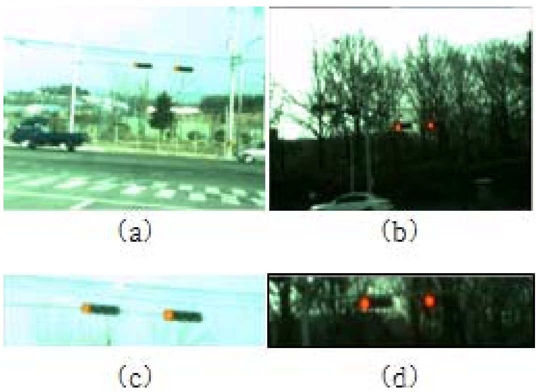

Fig. 5 Experiment image (Day time)

Fig. 5 shows images acquired from the vision sensor, to which the proposed method will be applied. Figs. 5 (a) and (b) show images acquired from the intersection on flat and uphill roads respectively. The results obtained by applying the proposed method to the acquired images are Figs. 5 (c) and (d). Smaller regions were extracted in the ROI images acquired through the proposed method than the original images where traffic light was present. Since the size of the region where the traffic light recognition method was applied was smaller and GPS information was used, more reliable ROI region can be provided.

The following description presents the comparison of the count of successful determination of ROI regions among three methods: the proposed method in this study, existing traffic light feature-based ROI region determination method, and road environment modeling-based ROI region determination method [10], [11].

TABLE I
Performance of Recognition (Day Time)

	Straight Road	Curved Road
Traffic light feature-based method	94%	92%
Road environment modeling-based method	92%	76%
Proposed method	96%	94%

Table I shows success rates of ROI determination with respect to traffic lights when 100 attempts were tried to determine the traffic light ROI region on straight and curved roads using the traffic light feature-based, the road environment modeling-based, and the proposed methods, respectively. The ratio between straight and curved roads was set as the same for the 100 attempts.

The experiment result showed that there was no significant difference in the straight road among three methods: the proposed method in this study, exiting traffic light feature-based ROI region determination method, and road environment modeling-based ROI region determination method. However, the road environment modeling-based method showed a lower success rate in the curved road than the other two methods whereas the traffic light feature-based method and the proposed method showed comparable performance. The reason for such difference was because the road environment modeling-based method had relatively more errors which occurred due to mismatch between the location of traffic lights and the curvature in the curved road.

Second experiment was conducted to verify the performance of the proposed method in a night time environment. The experiment condition was based on various road environments from six-lane to eight-lane roads while the rest of the experiment conditions were the same with the first experiment.

Fig. 6 shows images acquired from the night time environment and the results where the proposed algorithm is applied. Fig. 6 show the images acquired from the intersection in four-lane and eight-lane roads respectively. An image acquired from the four-lane road environment shows that the tail lights of surrounding vehicles are certain distance away from the red signal in the traffic light, and thus, it is expected to have no significant influence on the detection of traffic lights. On the other hand, an image acquired from the eight-lane road environment had tail lights of surrounding vehicles and signboards near the traffic lights, thereby expecting a difficulty in the traffic signal detection with general image processing methods.

Fig. 6 Experiment image (Night time)

The next describes successful recognition counts comparing between the proposed method and existing traffic light recognition algorithm.

Table II shows experiment results where the proposed algorithm and existing traffic light recognition algorithm based on shape and color features were applied 100 times over five different environments. The existing traffic light recognition algorithm showed less than 30% successful recognition rate of traffic lights. This low recognition rate showed that shapes and colors of traffic lights cannot be acquired and recognized correctly under the night time environment using image processing. On the other hand, the proposed algorithm had about 80% successful recognition rate because it determines the location of traffic lights by detecting colors and shapes in a corresponding region by the DGPS location information not by image processing.

TABLE II
PERFORMANCE OF RECOGNITION (NIGHT TIME)

	Recognition rate
Traffic light feature-based method	29%
Proposed method	80%

IV. CONCLUSIONS

This paper proposes a traffic light detection method which is robust to noise caused by surrounding illumination changes at night time. The proposed method determines and recognizes locations of traffic lights by analyzing a location relationship between traffic lights and vehicles thereby determining the location of traffic light in images acquired via vision sensors. To minimize errors of image processing occurred during the traffic light recognition process at the night time environment, this paper proposed a robust traffic light detection method under the night time environment by using a relationship between DGPS location information of vehicles and DB of traffic light location information.

For the future study, a reduction method of margin in the traffic light detection region occurred due to the DGPS location error will be pursued to extract the size similar to that of a traffic light, and in addition, a method of minimizing the surrounding illumination effect will be studied.

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