Detection of LED Traffic Light by Image Processing for Visible Light Communication System

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Abstract— **We propose a visible light road-to-vehicle communication system at intersection for ITS. In this system, the communication between vehicle and a LED traffic light is approached using LED traffic light as the transmitter, and on-vehicle high-speed camera as the receiver. The LEDs in the transmitter are emitted with 500Hz and the images of those emitting LEDs are captured by a high-speed camera for conducting communication. In this communication, it is extremely necessary to find the transmitter and detect it for consecutive frames while vehicle is moving. In this paper, we introduce proposals for finding and detecting it for consecutive frames by image processing. Experimental results using appropriate images showed the effectiveness of the proposal.**

I. Introduction

DEVELOPMENT of traffic serves great support for humans in different ways. The number of the motor vehicles in the world increases in every year. According to this, the number of traffic problems such as environment pollution, traffic jam, and traffic accident have also been increased. In latest few decades, there are a lot of researches have been conducted to give solutions for these traffic problems. Specifically, the electrical motor vehicles and hybrid vehicles which exhaust less Carbon dioxide, were already introduced to control the environment problem. In the other hand, Intelligent Transport System(ITS) has been introduced to decrease traffic jam and traffic accidents with the development of information technology. The advancing areas of ITS technology can be divided into two main groups, as automatic driving systems and driver assistant systems. The computers make all the decisions in automatic driving systems and the computers assist driver for making decisions in driver assistant systems, by detecting the external and internal information of the vehicle. In both systems, image processing is one of the key technologies for detecting information. Many of these systems, cameras capture the images of external or internal environment of the vehicle and necessary information are extracted by image processing. The cameras are installed according to desired capturing area, either external environment or on the vehicle.

In many driver assistant systems, on-vehicle cameras are used to capture images of external environment. Some studies have been conducted for detecting obstacles, traffic signs, and signal lights so on[1][2]. In this study, we propose road to vehicle visible light communication system using on-vehicle high-speed camera as receiver and LED traffic light as a transmitter. Here, the LEDs in the transmitter are emitted for 500Hz and the images, which include those emitting LEDs are captured by high-speed on-vehicle camera for 1000fps, while the vehicle is moving. Those images are processed to gain the luminance value of each LED for conducting communication. For this purpose, first transmitter should be found, then it should be detected for each consecutive frame, and the luminance value of each LED in the transmitter should be captured. Here, we applied the method used by Iwasaki et al.[3] for finding the transmitter. In their method, transmitter is found getting the subtraction of two consecutive frames. In this paper, we mainly introduce an algorithm to detect the found transmitter in consecutive frames for certain moving distance of the vehicle.

This paper is consisted of five main sections to explain our project work. The section II makes a brief explanation about visible light communication and section III and IV introduces the proposals for finding and detecting the LED traffic light for proposed visible light communication system. The experimental results and discussion are described in section V. The section VI concludes the paper.

II. Visible Light Communication

Visible light communication is one of wireless communication methods using light sources. It is able to transfer data by emitting light source, and able to receive by light sensor. There are several advantages in this communication method. One is that visible light is not harmful to human body. And it is able to transmit with high

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power. Other common wireless communication methods, such as radio waves and infra-red light are concerned to be dangerous to human body. Compared to radio waves and infra-red light, it has more advantages: No legal limitation for any existing light source, such as room illuminations and displays to be used as transmitters. It can be used at the places where radio waves cannot be used,

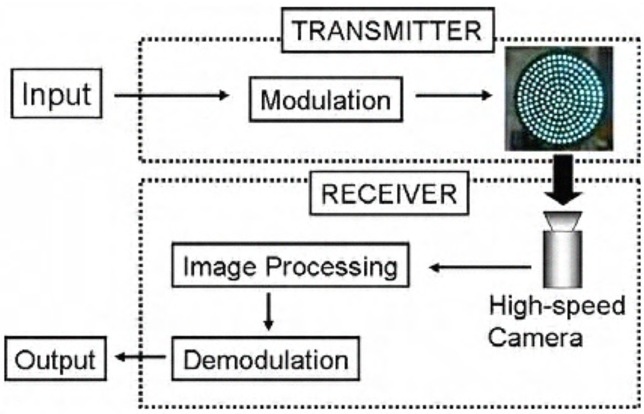


Figure 1: Proposed visible light communication

for example hospitals and area around precision machines.

Komine and Nakagawa have achieved visible light communication using illumination light[4]. It is a communication between PCs and illumination light, and considered as an alternative method for the wireless LAN. At present, light bulbs and fluorescent lights are the light source for dominant room illumination. LEDs, however, are also getting popular as dominant light source. Recently, LEDs are used in traffic signal light and many light decorations. LEDs have features of longer operating life, lower power consuming, and smaller in size. The emitting efficiency is also comparatively higher than the fluorescent light and thus it will surely replace the bulbs and fluorescents in the near future. There are many light emitters surrounding us and any of them could become a transmitter of this communication. For examples, PC display, TV, electric bulletin board, and cellular phone display so on.

Figure.1 shows the structure of the proposed visible light communication system using LED traffic light as transmitter and high-speed camera as receiver. Here, signal light includes 256 LEDs. If these LEDs could be recognized individually, it is possible to use each of them as separate transmitter and communicate in parallel at the same time. This is the main advantage of using camera as a receiver. Light source using LED usually contain a number of LEDs. In the proposed system, we approach to recognize each LED of traffic light(transmitter) by image processing. Thus, if we consider one transmitter with many LEDs as a set of small transmitters, we can dramatically increase the communication speed by modulating each LED individually(Fig. 2). In other words, each LED transmits different data in parallel and they are received at the same time. Moreover, we can communicate with several transmitters and receive different information in parallel. However, using camera as the receiver has some disadvantages. Camera should have high frame rate to achieve good communication speed. For this purpose, image processing in the receiver should be in real time and it might be harder on a computer when high-speed camera is used. We achieve this using hardware. Another issue is the modulation method. Since this is a unique communication method using visible light and image, it requires particular modulation method which considers the characteristics of the communication. We are considering to use hierarchical coding[6] for visible light communication, which modulates data on spatial frequency

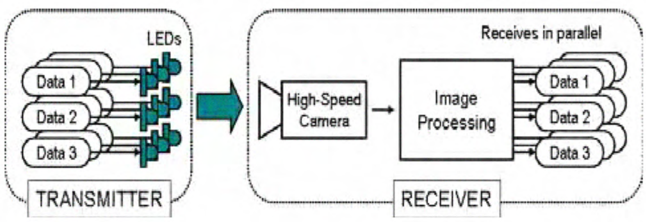


Figure 2: Parallel communication

Figure 3: An arbitrary frame captured by a high-speed camera including the transmitter in the center.

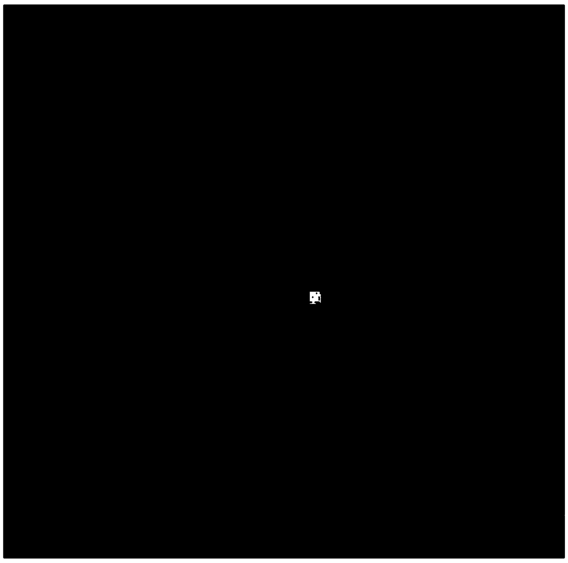


Figure 4: The result of transmitter finding for the arbitrary frame shown in Fig. 3 using subtraction

and enables long distance communication.

While proposed visible light communication system being developed, receiver(high-speed camera and image sensor) installed in the vehicle should find the transmitter(LED signal light). Then found transmitter should be detected for consecutive frame for achieving communication. In this paper, we mainly focus on finding and detecting of the transmitter. Emitting patterns of transmitter and methods for finding and detecting the transmitter is detailed in next sections.

III. PROCEDURE FOR FINDING AND DETECTING TRANSMITTER

A. Emission Patterns of Transmitter

The transmitter used for the experiments is square in shape and it is consisted of 256(16x16) LEDs. Communication is achieved by emitting them. They are emitted sequence by sequence and in first half of the sequence, all LEDs are emmited(ON and OFF) at the same time for 500Hz. This stage set for finding the transmitter by image sensor in receiver using image processing. The proposal for finding transmitter is explained in next section. In second half of the sequence, LEDs in the transmitter are emitted for four different levels with 500Hz, except LEDs in the two exterior lines, and communication is conducted in this stage. In this paper, these non-emitting two exterior lines are kept to make it easy to detect the found transmitter. The proposal for detection is detailed in section IV.

B. Method for Finding Transmitter

As mentioned in above section, the transmitter is emitted (ON and OFF) for 500Hz in the first half of the sequence. This stage is set to find the transmitter by receiver with image processing. Here, while vehicle is moving, the receiver(High-speed camera) installed in the vehicle takes images of the road with 1000fps. If transmitter is existed on the road and it is at first half of the sequence, it is expected to appear it on images once in two frames, since signal light emits(ON and OFF) for 500Hz and high-speed camera takes images for double value of it(1000fps). In this paper we applied the method used by Iwasaki et al. [3] for finding the transmitter. In this method, first, two consecutive frames are subtracted. The resulted image include approximate transmitter with some noise, if it being in first half of the sequence. This resulted image is processed for binarization and noise reduction to get almost exact transmitter area. Figure(3) shows arbitrary frame with transmitter, and Fig. (4) shows found transmitter using this method. After finding the transmitter, area of 125x125pixels is cut keeping the middle point of the transmitter as center(Fig.6(a)). Then the transmitter is detected in every frame only processing this area. If the transmitter is escaped from this cut area, the processing restarts from finding step. Next section explains the proposal for transmitter detection in details

IV. PROCEDURE FOR ACHIEVING CONSECUTIVE DETECTION OF FOUND TRANSMITTER

After transmitter being found, it is necessary to detect it in every consecutive frame for making efficient communication. Iwasaki et al. [3] used template matching for same kind of detection. But, template matching is highly time and memory consuming. In the case of tracking a stable object using a moving camera(on-vehicle high-speed camera), the matching mages should be updated to achieve good tracking. In this paper, we approach to detect the found transmitter introducing an edge based method. Edge information is one of the key point in object detection. Charmichael et al.[5] used edge information in shape-based recognition of wiry objects. In our proposal, we use canny edge detector for detecting edges[7]. In this proposal, transmitter area is detected in consecutive frames while vehicle is moving for certain distance, after finding it. Figure 5 shows the flow of detection and each main steps are detailed in next sub sections

A. Edge Detection

Canny edge detector is used for edge detection, since it has ability to connect edges. In the canny edge detector, Gaussian filter smoothes image, the gradient and its direction for each pixel are calculated using Sobel filter, Non-maximum suppression processing is conducted quantizing gradient direction, finally edge points are gained using hysteresis threshold method. There are two thresholds(*Cthres1* and *Cthres2*, *(Cthres1>Cthres2)*) are applied(hysteresis threshold) to gradient to gain appropriate edge points. Here, the pixels having gradient value, greater than *Cthres1* are selected as edge points and the pixels having gradient value, less than *Cthres2* are selected as not edge points. In the case of the gradient value between *Cthres1* and *Cthres2*: If these pixels are connected to edge points meaning that, they connect to pixels having (gradient > *Cthres1*) through the pixels having (*Cthres1* > gradient > *Cthres2*), are also selected as edge points. The edge points having different gradient values can be connected to have the clear edge components by varying these two thresholds. In this paper, we determined these two thresholds experimentally as *Cthres1*=250 and *Cthres2*=180. An example of one arbitrarily frame is shown in Fig. 6(a) and its edge detection results are shown in Fig. 6(b). The transmitter area candidates are selected using theses edge components in edge image as explained in next section.

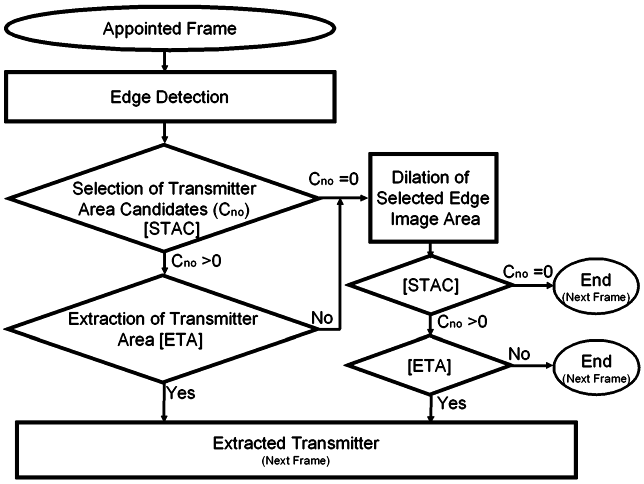


Figure 5: Flow of proposed transmitter detection method

B. Selection of Transmitter Area Candidates

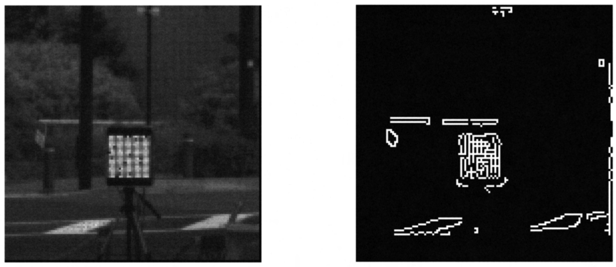
In this proposal, transmitter area candidates are selected regarding the circumscribing rectangle of edge component. First, circumscribing rectangles of each edge component are calculated. Then the transmitter area candidates(C_{no}) are selected following the below conditions.

$$H_{pre} - offset < H_{now} < H_{pre} + offset$$

$$W_{pre} - offset < W_{now} < W_{pre} + offset$$

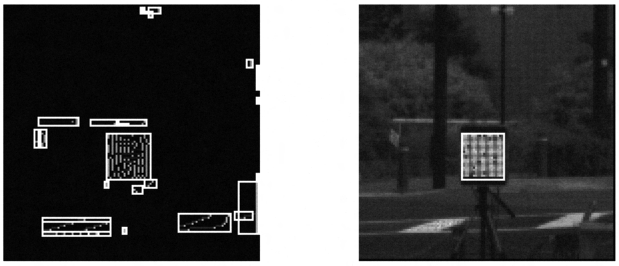
$$| H_{now} - W_{now} | \leq 2 pixels$$

Here, W_{pre} and H_{pre} means the width and height of the just previously detected transmitter, and W_{now} and H_{now} means width and height of searching circumscribing rectangle. According to these conditions, if a circumscribing rectangle of the edge component is almost same in size as just previously detected transmitter, that rectangle is selected as transmitter area candidate. Here, the transmitter which is used for experiments is square in shape. Thus, the



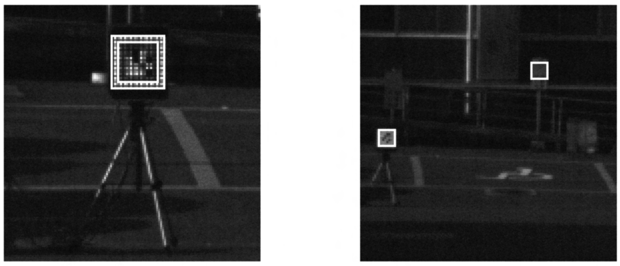
(a) (b)

Figure 6: Edge detection, (a) Arbitrarily frame, (b) Edge image



(a) (b)

Figure 7: Calculation of circumscribing rectangle and selection of transmitter area candidates, (a) Circumscribing rectangles, (b)Transmitter area candidates



(a) (b)

Figure 8: Appearing of multi transmitter candidates, (a) Overlapped candidates, (b) Individual candidates

circumscribing rectangle of edge component related to transmitter should almost be square in shape. The gained circumscribing rectangles for Fig. 6(b) image are shown in Fig. 7(a). The transmitter candidate selection results are shown in Fig. 7(b). There are only one candidate is appeared for this image. The *offset* is set for 2 pixels in the experiments. According to the so far experiments, one candidate was appeared except certain examples. But, it might be possible to have few candidates depending on environment, where transmitter is installed. For this reason, we conduct transmitter extraction from candidates and the extraction method is detailed in next section.

C. Extraction of Transmitter Area from Candidates

As mentioned above, in some cases it possible to appear few transmitter candidates($C_{no} > 1$) at the transmitter candidate selection stage. Even if single candidate is appeared, it is necessary to confirm whether that candidate is real transmitter or not. In the case of one candidate, the confirmation is conducted comparing the length L_{now} and middle point position (M_{now_x}, M_{now_y}) of the present candidate with same data in just previous detections.

The transmitter likelihood is defined using side length and middle point as below.

1. The side length difference of the transmitter between three consecutive frames does not decrease more than 1pixel, and it does not increase more than 2 pixels between three consecutive frames
2. The middle point movement of the transmitter does not exceed 5 pixels between three consecutive frames

In the case of one candidate, if the candidate fulfills the above conditions, that candidate is selected as transmitter. In some cases, few candidates fulfill the above conditions, it was complicated to extract real transmitter. In these cases, likelihood probability of the transmitter is defined as $\arg\max P(L,M)$. $P(L,M)$ is defined as Equation (1), and $P(L)$ means likelihood probability of the transmitter regarding the side length and $P(M)$ means likelihood probability of the transmitter regarding the middle point.

$$P(L,M) = P(L) + P(M) \tag{1}$$

$$P(L) = P(L_{diff}) \tag{2}$$

$$L_{diff} = \sum_{n=1}^{i} L_{diff}(t-(1-n), t-n)$$

$$P(M) = P(M_{diff}) \tag{3}$$

$$M_{diff} = \sum_{n=1}^{i} M_{diff}(t-(1-n), t-n)$$

In Equation (2) and (3), L_{diff} means the side length difference of the consecutive previously detected transmitters, and M_{diff} mean the middle point difference of the consecutive previously detected transmitters. t is time sequence and i is number of previous detections used for comparison. In this paper, comparison is conducted considering three $(i = 3)$ previous detections. The variation of the $P(L_{diff})$ and $P(M_{diff})$ are defined as Equation (4) ,(5), and (6). The values for m_L and m_M are set to 0.1 and 0.05 respectively, in the experiment.

$$P(L_{diff}) = -m_L * L_{diff} + 1 \qquad (0 \le L_{diff} \le 2) \tag{4}$$

$$P(L_{diff}) = m_L * L_{diff} + 1 \qquad (-1 \le L_{diff} \le 0) \tag{5}$$

$$P(M_{diff}) = -m_M * M_{diff} + 1 \qquad (0 \le M_{diff} \le 5) \tag{6}$$

The candidate having maximum value for $P(L,M)$ is selected as transmitter.

D. Dilation of Selected Edge Image Area

In some cases, it is not able get the transmitter area as a candidate in selection of transmitter candidates step, because the corresponding edges for the transmitter did not appear as one component, they appeared as several components. This happened when images of the transmitter got blurred in certain situations. But, according to so far experiments, these kinds of cases are comparatively in less. To solve this problem, if the candidates or extracted transmitter was not appeared in candidate selection step[STAC] or Transmitter extraction step[ETA], the edge image was dilated considering the almost corresponding area of just previously detected transmitter as indicated in processing flow(Fig. 5). The rectangular area, having height and width as ($H_{pre} - offset$) and ($W_{pre} - offset$), and middle point as (M_{pre_x}, M_{pre_y}) in the edge image is selected to be dilated. Here, the offset is set for 2pixels. After the dilation, candidate selection step[STAC] and Transmitter extraction step[ETA] are applied to edge image again. If transmitter is not extracted after dilation, the process move to next frame as shown in processing flow (Fig.5).

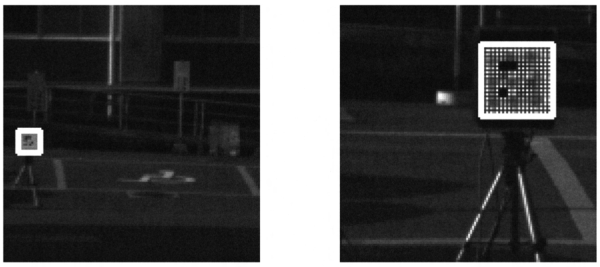
V. Experimental Results and Discussion

A. Experimental Results

The experiments were conducted to confirm the effectiveness of proposed transmitter detection method. We fixed a high-speed camera on a vehicle and images were captured while driving straight more than 30km/h, approaching the transmitter. Transmitter is emitted for 500Hz and images of emitting transmitter were captured by high-speed camera which is fixed on the moving vehicle for 1000fps with grayscale. The moved distance of the vehicle is from 70m to 20m, from the transmitter. In the founding stage, transmitter could be found effectively. The results of detections, after finding the transmitter are mainly explained. An examples of two transmitter detection results are shown in Fig. 9. The total experimental results are summarized in Table 1. The detection rate is defined to evaluate the proposal, as below Equation (7). Experiment 1 and 2 in Table 1 were conducted under the cloudy weather condition and Exp. 3 and 4 were conducted under the sunny weather condition. In all experiments, there were not any error detections.

$$Detection\ rate = \frac{Number\ of\ detections}{Number\ of\ transmitter\ lighting\ frames} \times 100 \tag{7}$$

According to total experimental results, the average detection rate with the proposal introduced in this paper was 96.0%, and the detection rate with template matching as conventional method was 61.2%. These results showed that proposal is very effective in detecting the desired transmitter(Traffic light) in consecutive frames compared to the conventional method.



(a) (b)

Figure 9: Examples of transmitter detection (a)Vehicle is moving between 40m-20m, (b) vehicle is moving between 70m-60m

Table 1: Total experimental result

Experiment number	No of frames in experiment video	No of transmitter lighting frames	No of detections	Detection rate (%)
1	6400	6373	6086	95.49
2	6400	6312	6159	97.12
3	5323	5302	5121	96.59
4	6400	6319	5966	94.41

B. *Discussion*

In this paper, new traffic light(transmitter) detection method was introduced for road-to-vehicle visible communication system with a traffic light as transmitter and high-speed on-vehicle camera as receiver. This new method mainly approach to detect an emitting traffic light detecting the edges of traffic light image and calculating circumscribing rectangle of the edge component. Here, the canny edge detector was used for edge detection, and the necessary thresholds for this detector were decided experimentally. We observed that, this detector can create appropriate edges of transmitter using with these decided thresholds. In this proposal, the multi candidates almost appeared when the vehicle is far from the transmitter, and the number of candidates got less when vehicle reached near the transmitter.

In the method of extracting transmitter from candidates, if single or multi candidates are appeared, that transmitter is extracted from them comparing length and middle point with same data in just previously detected three transmitters. This extraction didn't make any error detection meaning not detected another object as transmitter. According to the experimental results, proposed method was very effective in detecting desired transmitter.

VI. Conclusion

In this paper, new traffic light detection method was introduced for road-to-vehicle visible communication system developing with a traffic light as transmitter and high-speed on-vehicle camera as receiver. This proposal is mainly detect traffic light by using the circumscribing rectangles related to edge components of traffic light image. The experiments using appropriate images were conducted to confirm the effectiveness of the proposal. The results showed that the proposal was very effective for desired detection.

VII. Acknowledgement

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