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Edge-Based Tracking of an LED Traffic Light for a Road-to-Vehicle Visible Light Communication System

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Abstract

We propose a visible light road-to-vehicle communication system at intersection as one of ITS technique. In this system, the communication between vehicle and a LED traffic light is approached using LED traffic light as a transmitter, and on-vehicle high-speed camera as a receiver. The LEDs in the transmitter are emitted in 500Hz and those emitting LEDs are captured by a high-speed camera for making communication. Here, the luminance value of each LED in the transmitter should be found for consecutive frames to achieve effective communication. For this purpose, first the transmitter should be identified, then it should be tracked for consecutive frames while the vehicle is moving, by processing the images from the high-speed camera. In our previous work, the transmitter was identified by getting the subtraction of two consecutive frames. In this paper, we mainly introduce an algorithm to track the identified transmitter in consecutive frames. Experimental results using appropriate images showed the effectiveness of the proposal.

Keyword : Visible light communication, High-speed camera, LED traffic light, Edge detection

I. INTRODUCTION

DEVELOPMENT of traffic vehicles serves great support for humans in different ways. The number of the motor vehicles in the world increases every year. According to this, the number of traffic problems such as environment pollution, traffic jams, and traffic accidents have also increased. In last few decades, lots 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. On 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 while they assist the driver for making decisions in driver assistant systems, by providing the external and internal information of the vehicle. In both systems, image processing is one of the key technologies for detecting information. In many of these systems, cameras capture the images of external or internal environment of the vehicle

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and necessary information is 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 and so on[1][2][3][4][5][6]. In this study, we propose road-to-vehicle visible light communication system using on-vehicle high-speed camera as a receiver and LED traffic light as a transmitter. Here, the LEDs in the transmitter emit light in 500Hz and the images, which include those emitting LEDs are captured by a high-speed on-vehicle camera in 1000fps, while the vehicle is moving. These images are processed to gain the luminance value of each LED for conducting communication. For this purpose, first the transmitter should be identified, then it should be tracked for each consecutive frame, and the luminance value of each LED in the transmitter should be captured to achieve effective communication. Here, we applied the method used by Iwasaki et al. [3] for identifying the transmitter. In their method, the transmitter is identified getting the subtraction of two consecutive frames. In this paper, we mainly introduce a new edge-based method to track the identified transmitter in consecutive frames for certain moving distance of the vehicle. In this paper, we approached to track the transmitter almost starting 70m away from transmitter and stop at almost 20m away from transmitter. The experiments were conducted to confirm the effectiveness of the proposal under different conditions. According to experiments, the proposal was very effective in tracking the identified transmitter for certain moving distance of the vehicle.

This paper consists 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 introduce the proposals for identifying and tracking the LED traffic light for proposed 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 them 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 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: there are no legal limitation for any existing light source, such as room illuminations and displays to be used. It can be used at the places where radio waves cannot be used, for example hospitals and areas around precision machines.

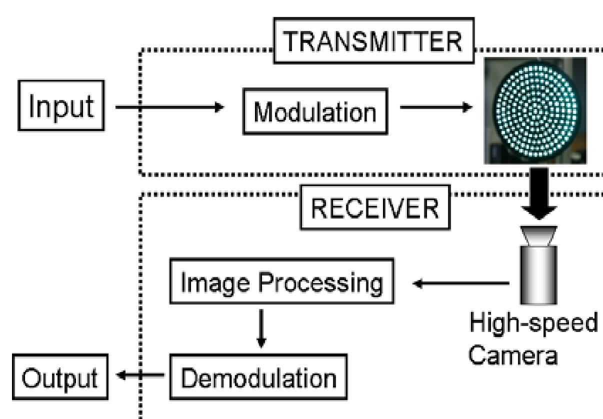


Fig. 1. Proposed visible light communication

Komine and Nakagawa[7] have achieved visible light communication using illumination light. It is a communication between PCs and illumination light, and considered as an alternative method for the wireless LAN. As latest application of visible light communication (VLC), Suzuki et al. [8] introduced a support system for visually impaired person by utilizing visible light communication technology at signalized intersections. In that system, when a pedestrian receives visible light from a pedestrian traffic signal via a portable receiver, pedestrian can listen to sound information on earphone or headphones. Here, the correct moving direction for visually impaired person is guided by changing the hearing sound.

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 like longer operating life, lower power consumption, and smaller 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 a transmitter and high-speed camera as a receiver. Here, the traffic light includes 256 LEDs. If these LEDs could be recognized individually, it is possible to use each of them as a separate transmitter communicating in parallel at the same time. This is the main advantage of using a 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 the 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 a camera as the receiver has some disadvantages. The 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 a high-speed camera is used. We plan to 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 consid-

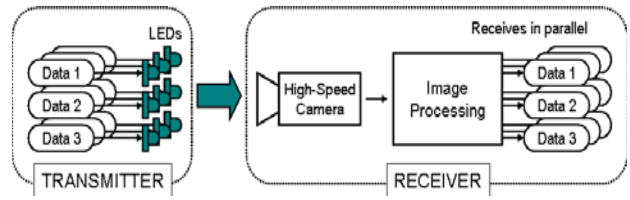


Fig. 2. Parallel communication

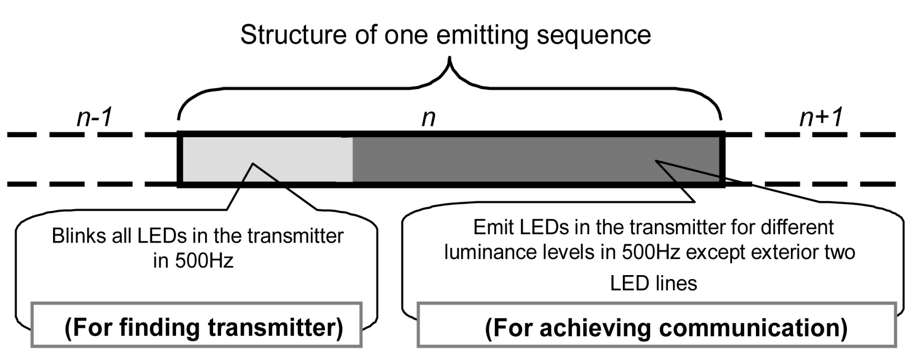


Fig. 3. Emission patterns of one sequence

ers the characteristics of the communication. We use hierarchical coding[10] for visible light communication, which modulates data on spatial frequency and enables long distance communication.

In the proposed system, the high-speed camera (Receiver) is installed on the vehicle. The transmitter (LED traffic light) is fixed on the road. In this paper, the LED traffic light which is used for experiment is specially prepared to be able to emit LEDs in 500Hz using a PC. It is not a normal traffic light. We developped image sensor to identify the LED traffic light and track it for consecutive frames by processing the images from high-speed camera, for certain moving distance of the vehicle. In the next two sections, the methods for identifying and tracking the transmitter using image processing are explained in details respectively.

Ⅲ. Identification of the Transmitter

1. Emission Patterns of Transmitter

The transmitter used for the experiments is square in shape and it consists of 256(16x16) LEDs. Communication is achieved by emitting them. They are emitted sequence by sequence and in the first half of the sequence, all LEDs are emitted (ON and OFF) at the same time in 500Hz (Fig. 3). This stage is set for identifying the transmitter by image sensor at receiver using image processing. The proposal for identifying transmitter is explained in the next section. In the second half of the sequence, LEDs in the transmitter are emitted with four different levels in 500Hz, except LEDs in the two exterior lines, and communication is conducted in this stage(Fig. 3). In this paper, these non-emitting two exterior lines are kept to make it easy to track the transmitter by image processing. The proposal for tracking the transmitter is detailed in section Ⅳ.

2. Method for Identifying Transmitter

As mentioned in above section, the transmitter is emitted (ON and OFF) in 500Hz in the first half of the sequence.

Fig. 4. An arbitrary frame including the transmitter in the center

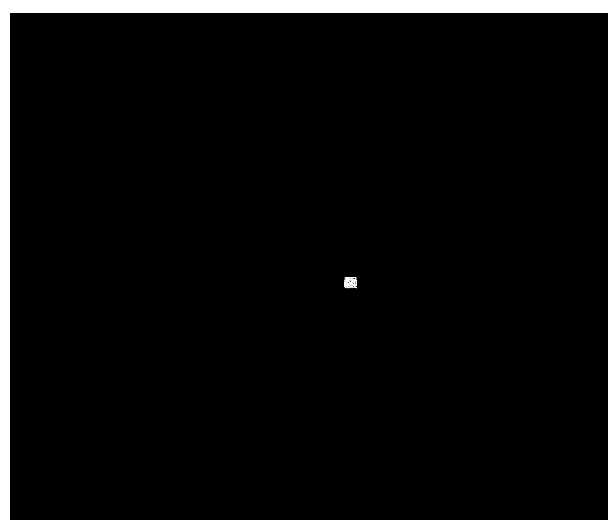


Fig. 5. The result of transmitter identifying for the arbitrary frame shown in Fig. 4

This stage is set to identify the transmitter by receiver with image processing. Here, while the vehicle is moving, the

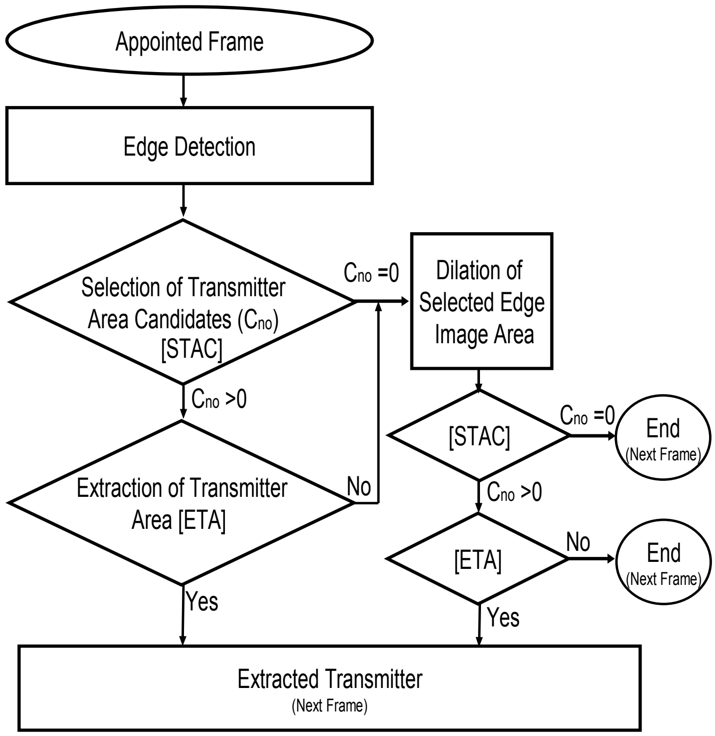


Fig. 6. Flow of proposed transmitter detection method

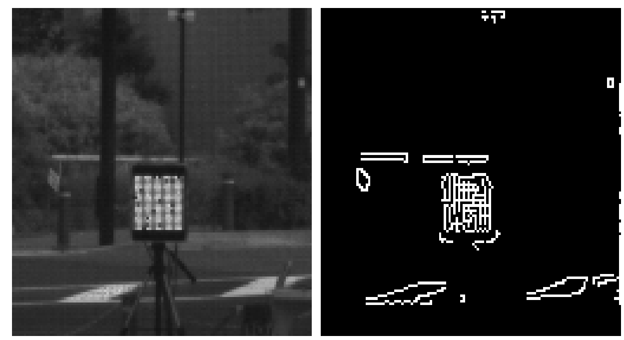
receiver (High-speed camera) installed in the vehicle takes images of the road with 1000fps. If transmitter exists on the road and it is at the first half of the sequence, it is expected to appear on images once in two frames, since traffic light emits (ON and OFF) for 500Hz and high-speed camera takes images in1000fps. In this paper we applied the method used by Iwasaki et al. [3] for identifying the transmitter. In this method, first, two consecutive frames are subtracted. The result image include approximate transmitter with some noise, if it being in first half of the sequence. This result image is processed for binarization and noise reduction to get almost exact transmitter area. Figure 4 shows arbitrary frame with transmitter, and Fig. 5 shows the identified transmitter using this method. After identifying the transmitter, area of 125x125pixels including transmitter is cut out (Fig. 7(a)). Then the transmitter is detected in consecutive frames by processing the corresponding cut out area only. If the transmitter stays out of this area, the processing restarts from finding step. Next section explains the proposal for transmitter tracking in details.

Ⅳ. Procedure for Achieving Consecutive Tracking of Identified Transmitter

After the transmitter has been identified, it is necessary to track it in consecutive frames 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 images should be updated to achieve good tracking. In this paper, we approach to detect the identified transmitter introducing an edge based method. Edge information is one of the key point in object detection. Charmichael et al. [9] used edge information in shape-based recognition of wiry objects. In our proposal, we use canny edge detector for detecting edges[11]. In this proposal, transmitter area is tracked in consecutive frames while the vehicle is moving for certain distance, after identifying it. Figure 6 shows the flow of tracking and each main steps are detailed in next sub sections.

1. Edge Detection

Canny edge detector is used for edge detection, since it has the ability to connect edges having different gradient values. And Canny edge detector can give exact edge points, since it decides edge points searching the direction of the edge points. In the canny edge detector, Gaussian filter smoothes the image, then the gradient and its direction for each pixel are calculated using Sobel filter. Non-maximum suppression processing is conducted quantizing gradient direction, and finally edge points are gained using hysteresis threshold method. There are Two thresholds(Cthres1 and Cthres2, (Cthres1>Cthres2)) are applied (hysteres is 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 not selected as 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) they 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 frame is shownin Fig. 7(a) and its edge detection results are shownin Fig. 7(b). The transmitter area candidates are selected using theses edge components in the edge image as explained in next section.



(a) (b)

Fig. 7. Edge detection, (a) Arbitrarily frame, (b) Edge image

2. 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 by the following conditions.

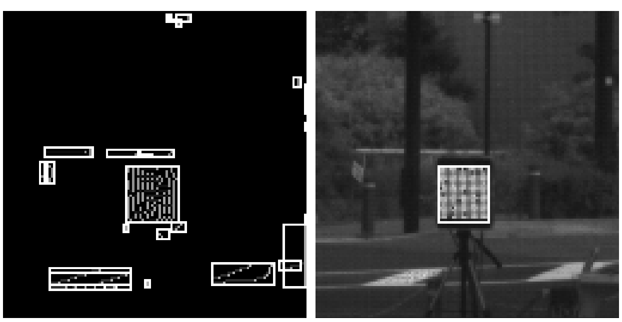
$$H_{pre} - offset < H_{now} < H_{pre} + offset$$

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

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

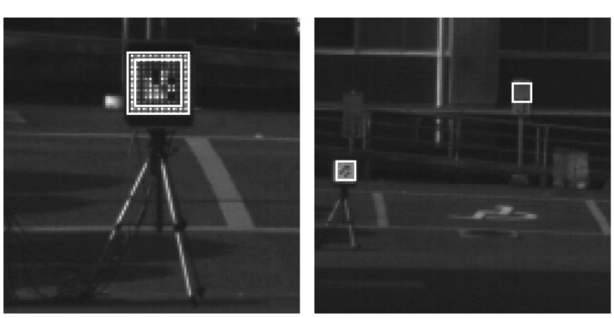
Here, W_{pre} and H_{pre} mean the width and height of the just previously detected transmitter, and W_{now} and H_{now} mean width and height of searching circumscribing rectangle. According to these conditions, if a circumscribing rectangle of the edge component is almost same in size as just previously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

Thus, the circumscribing rectangle of edge component corresponding to the transmitter should almost be square in shape. The gained circumscribing rectangles for Fig. 7(b) image are shown in Fig. 8(a). The transmitter candidate selection results are shown in Fig. 8(b). There is only one candidate for this image. The $offset$ is set for 2 pixels in the experiments. Figure 9(a) and (b) are some examples for appearing multiple candidates. It might be possible to have a few candidates depending on the environment, where transmitter is installed. For this reason, we conduct transmitter extraction from candidates and the extraction method is detailed in next section.



(a) (b)

Fig. 8. Calculation of circumscribing rectangle and selection of transmitter area candidates, (a) Circumscribing rectangles, (b)Transmitter area candidates



(a) (b)

Fig. 9. Appearing of multi transmitter candidates, (a) Overlapped candidates, (b) Individual candidates

3. Extraction of Transmitter Area from Candidates

As mentioned above, in some cases it is possible that a few transmitter candidates ($C_{no} > 1$) appear at the transmitter candidate selection stage. Even if a single candidate is appeared, it is necessary to confirm whether that candidate is a real transmitter or not. In the case of a single 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 conditions are defined using side length and middle point as below, considering just previous detections.

- The side length difference of the transmitter between three consecutive frames does not decrease more than 1 pixel, and it does not increase more than 2 pixels in three consecutive frames.

- The middle point movement of the transmitter does not exceed 5 pixels in three consecutive frames.

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

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

$$P(L) = P(L_{diff})$$
$$L_{diff} = \sum_{n=1}^{i} L_{diff}(t-(1-n), t-n) \quad (2)$$

$$P(M) = P(M_{diff})$$
$$M_{diff} = \sum_{n=1}^{i} M_{diff}(t-(1-n), t-n) \quad (3)$$

In Equation (2) and (3), L_{diff} means the side length difference of the consecutive detected transmitters, and M_{diff} means the middle point difference of the consecutive previously detected transmitters. t is time sequence and i is the 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.

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

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

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

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

4. Dilation of Appointed Edge Image Area

In some cases, it is not possible to 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, but they appeared as several components.

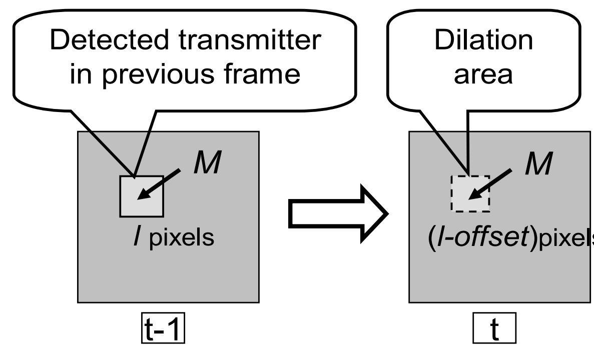


Fig. 10. Selection of dilation area

This happened when images of the transmitter got blurred in certain situations. But, according to the experiments so far, these kinds of cases are comparatively less. To solve this problem, if the candidates or extracted transmitter did not appear in candidate selection step [STAC] or Transmitter extraction step [ETA], the appointed edge image area is dilated. This dilating edge image area is selected considering the corresponding area of just previously detected transmitter as indicated in Fig. 10. The rectangular area, having height and width as $(H_{pre} - offset)$ and $(W_{pre} - offset)$, respectively 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 1 pixel. After the dilation, candidate selection step [STAC] and transmitter extraction

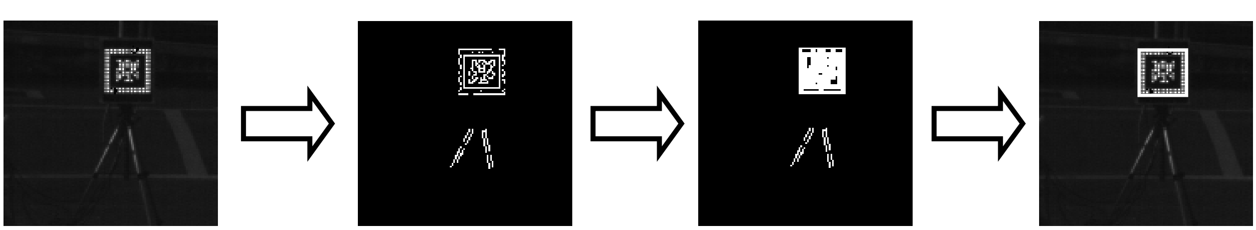


Fig. 11. Flow of transmitter detection by dilating an appointed edge image area

step [ETA] are applied to the edge image again. If the transmitter is not extracted after dilation, the process moves to the next frame as shown in processing flow (Fig. 6). An example of transmitter tracking by dilating an appointed edge image area is shown in Fig. 11. Here, the original image is processed for edge detection. In this case, the circumscribing rectangle belonging to the transmitter did not appear, because exterior edge component was split in to several components. The split edge components could be connected by dilation process and transmitter could be found by calculating the circumscribing rectangle of dilated edge component.

V. Experimental Results and Discussion

1. Experimental Results

The experiments were conducted to confirm the effectiveness of proposed transmitter tracking method. We fixed a high-speed camera on a vehicle and images were captured while driving the vehicle in more than 30km/h, towards the transmitter. Transmitter is emitted in 500Hz and images of emitting transmitter were captured by a high-speed grayscale camera which is fixed on the moving vehicle in 1000fps. The moved distance of the vehicle is from 70m to 15m, from the transmitter. In the identifying stage, transmitter could be identified effectively. The results of tracking, after identifying the transmitter are mainly explained in this paper. Figure 12(a)~(l) show some detection results of one experiment when the vehicle is away from different distance from the transmitter. Table 1 summarizes results of five experiments conducted under different conditions. Experiment 1, 2, and 5 in Table 1 were conducted under the cloudy(dark) weather condition and Exp. 3 and 4 were conducted under the sunny weather condition. The detection rate is defined to evaluate the proposal, as below Equation (7). In all experiments, there was not any error detection.

Table 1. Summary of several experimental results

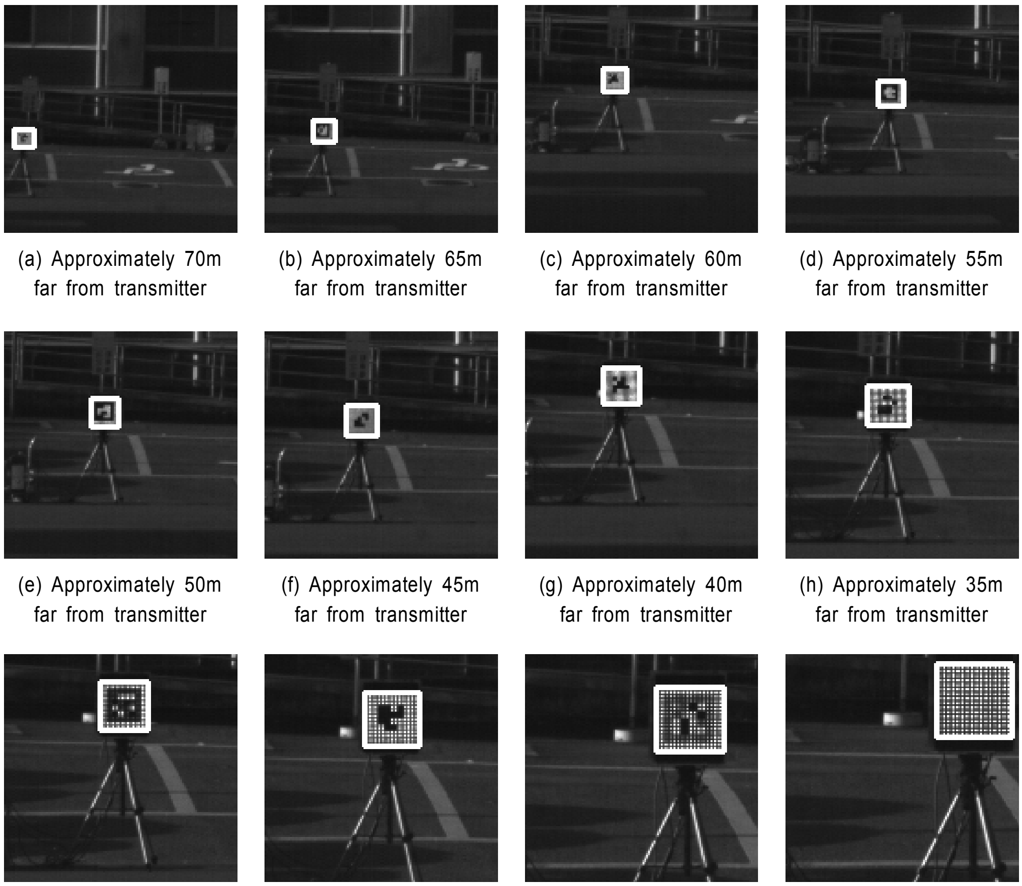
Experiment number	No. of frames in experiment video	No. of transmitter lighting frames	No. of detections	Detection rate (%)
1	6400	6373	6086	95.49
2	6400	6312	6159	97.12
3	5323	5302	5121	96.59
4	6400	6319	5966	94.41
5	4273	3948	3914	99.13

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

According to total experimental results, the average detection rate with the proposal introduced in this paper was 96.55%, and the detection rate with template matching as conventional method[3] was 61.2%. These results showed that the proposal is very effective in tracking the desired transmitter (Traffic light) in consecutive frames compared to the conventional method.

2. Discussion

In this paper, a new traffic light (transmitter) tracking method was introduced for a road-to-vehicle visible light communication system with a traffic light as a transmitter and a high-speed on-vehicle camera as a receiver. This new method mainly tracks 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



(a) Approximately 70m far from transmitter
(b) Approximately 65m far from transmitter
(c) Approximately 60m far from transmitter
(d) Approximately 55m far from transmitter
(e) Approximately 50m far from transmitter
(f) Approximately 45m far from transmitter
(g) Approximately 40m far from transmitter
(h) Approximately 35m far from transmitter
(i) Approximately 30m far from transmitter
(j) Approximately 25m far from transmitter
(k) Approximately 20m far from transmitter
(l) Approximately 15m far from transmitter

Fig. 12. Examples of transmitter detection while vehicle being moved between 70m to 15m

transmitter using thresholds. In the transmitter candidate selection, the multiple candidates almost appeared when the vehicle is far from the transmitter, and the number of candidates got less when vehicle reached near the transmitter. The transmitter could be extracted from candidates mainly on the defined transmitter likelihood conditions. But, in the cases when the few candidates are almost similar, the transmitter could be extracted using the defined transmitter likelihood probability.

This extraction didn't make any error tracking. The dilation of appointed edge image area was able to connect the disconnected edge components belonging to the transmitter in edge detection step. As a result, some miss-tracking of the transmitter could be minimized. The experiments were conducted to confirm the effectiveness of the proposed transmitter tracking method under different conditions. The results of tracking transmitter in the dark environment is a little better than the results under sunny conditions. According to the overall experimental results, proposed method was very effective in tracking the desired transmitter.

Ⅵ. Conclusion

In this paper, a new traffic light tracking method was introduced for a road-to-vehicle visible light communication system with a traffic light as a transmitter and a high-speed on-vehicle camera as a receiver. This proposal is mainly tract the traffic light by calculating the circumscribing rectangles of edge components which are related to traffic light. 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 tracking.

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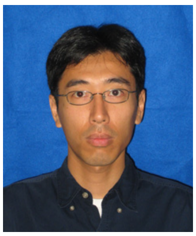

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