DETECTING A LED TRAFFIC LIGHT FOR VISIBLE LIGHT COMMUNICATION SYSTEM

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ABSTRACT

In this paper, 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 the transmitter, and on-vehicle high-speed camera as the receiver. The LEDs in the transmitter are emitted with 500Hz and those emitting LEDs are captured by a high-speed camera for making communication. The images from the high-speed camera are processed to get luminance value of each LED in the transmitter. For this purpose, first transmitter should be found, then it should be tracked for each frame, and the luminance value of each LED in the transmitter should be captured. In our previous work, transmitter was found by getting the subtraction of two consecutive frames. In this paper, we mainly introduce an algorithm to detect the found transmitter in consecutive frames. Experimental results using appropriate images showed the effectiveness of the proposal

Keywords: Visual light communication, Traffic light, Edge detection, ITS

1. 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 lastest 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) was 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 information. In both systems, image processing is one of the key technologies for detecting external information. Many of these systems, cameras capture the images of external environment 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][3]. In this study, we propose road to vehicle visible light communication system using on-vehicle high-speed camera as receiver and LED signal 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 tracked for each frame, and the luminance value of each LED in the transmitter should be captured. In our previous work[3], transmitter was found by 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 distance.

This paper is consisted of five main sections explained as below. The section 2 makes a brief explanation about visible light communication and section 3 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 4. The section 5 concludes the paper.

2. 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 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, for example hospitals and area around precision machines.

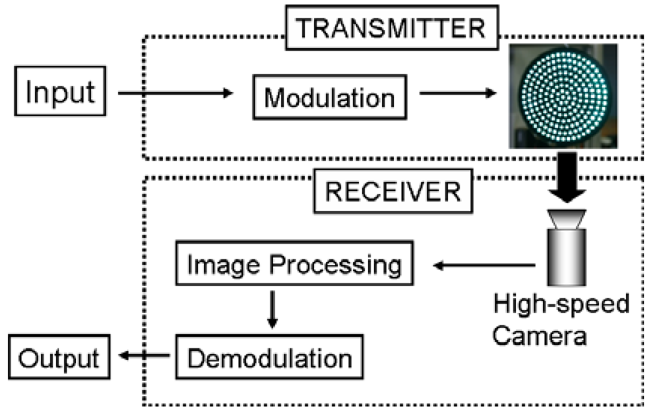


Fig. 1: Proposed visible light communication

T. Komine and M. 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 signal 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 signal 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 when high-speed camera is used. 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

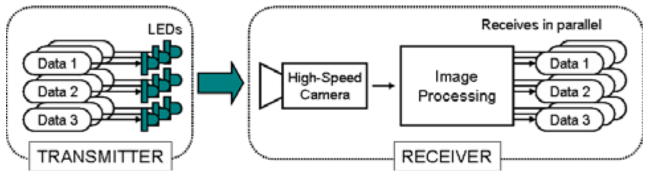


Fig. 2: Parallel communication

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

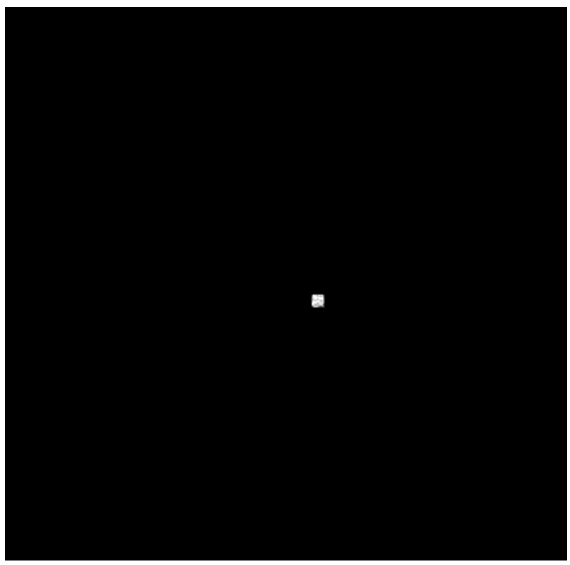


Fig. 4: The result of transmitter finding for the arbitrary frame shown in Fig. 3 using subtraction

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 each frame for achieving communication. In this paper, we mainly focus on finding and detecting of the transmitter. Emitting patterns and method for finding and detecting the transmitter is detailed in next section.

3. EMITTING PATTERN AND METHOD FOR FINDING AND DETECTING THE TRANSMITTER

3.1 Emitting Patterns of Transmitter

The transmitter used for the experiments is square in shape and it 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 3.3.

3.2 Proposal for Finding the 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 signal light area. Figure(3) shows arbitrary frame with transmitter, and Fig. (4) shows found signal light 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.

3.3 Proposal for Detecting the Found Transmitter

After transmitter being found, it is necessary to detect it in every consecutive frame for making efficient communication. At the beginning step of this research we apply pattern matching for this purpose[3]. Pattern matching consumes high processing time. 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. Some studies related to object detection have conducted using edge information[5]. In our proposal, we use canny edge detector for detecting edges[6]. In this proposal, transmitter area is detected in consecutive frames while vehicle moving for certain distance, after finding it. Figure (5) shows the flow of detection and each main steps are detailed in next sub sections

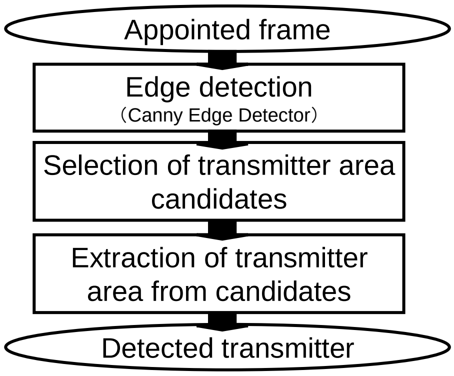
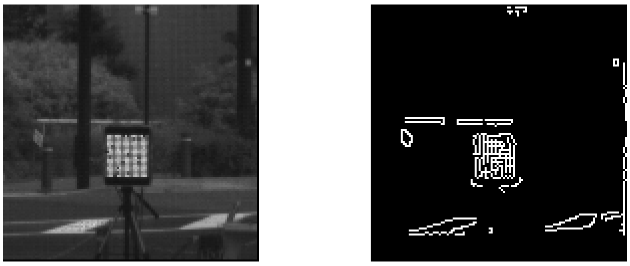


Fig. 5: Flow of proposed transmitter detection method

3.3.1 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 in 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 gradient value, greater than *Cthres1* is selected as edge points and the gradient value, less than *Cthres2* 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 gain the clear edge components by varying these two thresholds. In this paper, we determined these two thresholds experimentally as

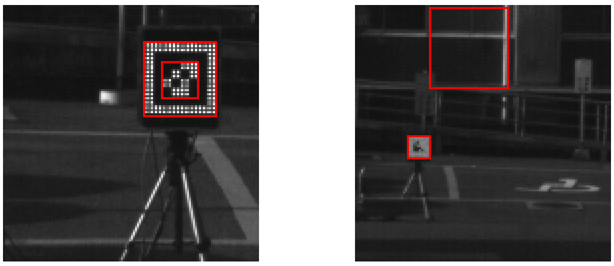


(a) Arbitrarily frame (b) Edge image

Fig. 6: Edge detection

(a) Circumscribing rectangles (b)Transmitter area candidates

Fig. 7: Calculation of circumscribing rectangle and selection of transmitter area candidates



(a) Overlapped candidates (b) Individual candidates

Fig. 8: Appearing of multi transmitter candidates

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.

3.3.2 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 following the below conditions.

$$8\,pixels < c_w, c_h < 42\,pixels$$

$$|\,c_w - c_h\,| < 3\,pixels$$

c_w and c_h means the width and height of the circumscribing rectangle respectively. These conditions mean that, if a circumscribing rectangle of the edge component is greater than 8pixels and less than 42 pixels, and the different between height and width is less than 3 pixels, that circumscribing rectangle is selected as transmitter area candidate. In this study, communication is conducted from 100m to 20m away from the transmitter. Above conditions are experimentally decided to include transmitter area as a candidate while vehicle being moved in this distance. 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. 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.

3.3.3 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. If single candidate is appeared, that candidate is taken as Transmitter area. While experiments being conducted, we found that there are two types of appeared multi transmitter candidates. In one case, the candidates are appeared overlapping the another candidate as shown in Fig. 8(a). This happened, when the vehicle reached to near the transmitter, the transmitter got bigger size, and a group of emitting LEDs inside the transmitter could create candidates. We extracted the bigger candidate as transmitter in this situation. As another case, candidates exist individually(away from each other) as shown in Fig. 8(b). The reason is that the edge component of objects in the background could also create circumscribing rectangles as same selection conditions as transmitter candidates. I this case, extraction is conducted comparing the size and middle point of the candidates with same data of extracted transmitter in previous frame. Here, the distances(M_{diff}) between the middle point of extracted transmitter in previous frame and the middle point of each candidate are calculated following Equation(1), then the differences(A_{diff}) between area of extracted transmitter in previous frame and each candidate minimum value are calculated following the equation(2). The candidate, which has minimum average value of M_{diff} and A_{diff} is taken as transmitter. In Equation (1), (M_{pre_x}, M_{pre_y}) and (M_x, M_y) are the middle point of the transmitter in previous frame and middle point of searching candidate respectively. A_{pre} and A in the Equation (2) mean area of extracted transmitter in previous frame and area of searching frame. In both Equation(1) and (2), i indicates the number of searching candidates.

$$M_{diff} = \sqrt{(M_{x_i} - M_{pre\_x})^2 + (M_{y_i} - M_{pre\_y})^2} \quad (1)$$

$$A_{diff} = | A_{pre} - A_i | \quad (2)$$

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Experimental Results

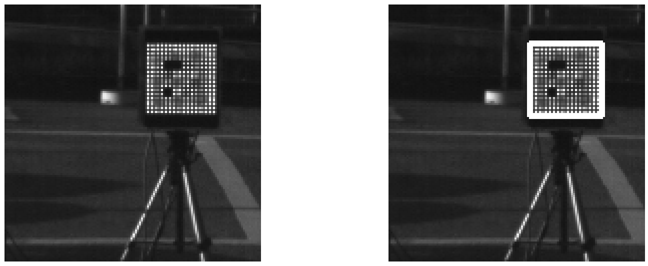
The experiments were conducted to confirm the effectiveness of proposed transmitter detection method. We fixed a high-speed camera on a vehicle and images were captured while driving straight at 30km/h, approaching the transmitter. Transmitter is emitted for 500Hz and images of emitting transmitter are 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 this paper, the results of detections, after finding the transmitter are explained.

(a) Original frame (b) Detected Transmitter

Fig. 9: An example of detection while vehicle is moving between 60m-50m

(a) Original frame (b) Detected Transmitter

Fig. 10: An example of detection while vehicle is moving between 50m-40m



(a) Original frame (b) Detected Transmitter

Fig. 11: An example of detection while vehicle is moving between 30m-20m

Table 1 Total experimental result

Exp. number	No of frames in Exp. video	No of transmitter. Lighting frames	No of detections	Detection rate (%)
1	6400	6373	6178	96.94
2	6400	6312	6131	97.12
3	6357	6332	6095	96.26
4	6400	6319	6113	96.74

Examples of some detection results, are shown in Fig. 9, 10 and 11. In each example, left image is an arbitrary original frame with transmitter and the right image shows transmitter detection result of left image. The total experimental results are summarized in Table 1. 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.

4.2 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 signal 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, detector can create appropriate edges of traffic light using with these decided thresholds.
According to the experimental results, proposed method was very effective in detecting desired traffic light. The miss detections were happened, when the corresponding edges for traffic could not be detected properly. The reason

for this is that the some traffic light images got blurred when the high-speed camera fixed on moving vehicle took images. But, the number of these kind of cases were comparatively smaller.

In the method of extracting traffic from candidates, If single candidate is appeared, that candidate is taken as traffic light area. Here there is a possibility to have error detections, since if one candidate which is related to another object was appeared. But, no error detection was happened since this reason in so far experiments.

5. CONCLUSSION

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 analyzing the edges 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. We plan to develop this algorithm to be able to detect miss detection as further step of this work.

6. REFERENCES

[1] Frank Lindner, and Ulrich Kressel et al., “Robust Recognition of Traffic Signals”, Proc. IEEE Intelligent Vehicle Symposium , pp. 49-53, 2004.

[2] Kenji Mori, an Tomokazu Takahashi et al., “Recognition of foggy conditions by in-vehivle camera and millimeter wave radar”, Proc. of IEEE Intelligent Vehicle Symposium, pp. 87-92, 2007

[3] Shinya Iwasaki, and Chinthaka Premachandra et al., “Visible Light Raod-to-Vehicle Communication Using High-Speed Camera”, Proc. IEEE Intelligent Vehicle Symposium , pp. 13-18, 2008

[4] Toshihito Komine and Masao Nakagawa, “Fundement analysis for visible-light communication system using LED lights”, IEEE Trans. of Consumer Electronics”, pp.100-107, Feb.2004

[5] Cheng Hua Zhu, and Kiyotaka Hirahara et al., “Street-Parking Vehicle Detection Based on EPI Analysis” ,Technical report of IEICE

[6] John Canny, “A Computational Approach to Edge Detection”, IEEE Trans. on Pattern Analysis and Machine Intelligence”, Vol.8, pp. 679-698, November 1986