LED Acquisition Methods for Image-Sensor-Based Visible Light Communication

(Invited Paper)

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Abstract—This invited paper focuses on a high-speed image sensor as a visible light communication (VLC) reception device to develop the intelligent transport systems (ITS) application using VLC technique. We refer to the VLC using a high-speed image sensor as image-sensor-based VLC. A major advantage of the image sensor is the ability to spatially separate multiple sources. Based on this ability, we proposed several methods for the image-sensor-based VLC in our previous researches. Especially, we focused on unique characteristics of the image sensor and proposed the hierarchical coding and the overlay coding to improve the data reception performance. However, to perform the image-sensor-based VLC in an actual environment, the receiver has to acquire the VLC transmitter from captured images before recovering data. Namely, the VLC transmitter acquisition and tracking are critical problem. the image-sensor-based VLC technique. This invited paper introduces two proposed methods to acquire the VLC transmitter from images captured by the image sensor.

I. INTRODUCTION

Light-emitting diode (LED) offers a new and revolutionary light source since it has several superior advantages: an energy-saving, long life, good visibility and so on. Moreover, we can easily control the intensity of LED (i.e. luminance) at high speeds that are undetectable to the human eye because LED is a solid-state lighting device. Many researchers in the field of communication systems focus on these advantages and have interest in visible light communications (VLC) using LED [1]–[3]. VLC, which is one of novel optical communication techniques, can not only provide light but also broadcast data. Widespread use of LEDs in traffic applications and growing interest in intelligent transport systems (ITS) present an opportunity for the application of VLC [4]–[14]. Infrastructure-to-vehicle visible light communication (I2V-VLC) and vehicle-to-vehicle visible light communication (V2V-VLC) are typical applications for ITS. These systems contribute to exchange a safety information between roadway infrastructure (or vehicle) and vehicles.

In our previous researches, we have considered using a high-speed image sensor as the VLC reception device to develop the ITS application using VLC technique. We refer to the VLC using a high-speed image sensor as image-sensor-based VLC. A major advantage of the image sensor is the ability to spatially separate multiple sources. Thanks to the ability of the spatial separation, the image sensor can individually recognize LED light of the transmitter composed many LEDs. Here, let us consider that 1 bit data is allocated to 1 LED. In this case, a transmission data rate increases with increasing the number of LED on the transmitter since the image sensor can recognize each LED light. Namely, the parallel data transmission is possible by modulating each LED independently. The ability of the spatial separation also brings benefits to distinguish only the pixels that sense LED transmission sources and to discard other pixels, including those sensing noise sources such as the Sun. In addition, the image sensor can recognize multiple information sources thanks to this advantage.

We have focused these advantages and have proposed several methods for the image-sensor-based VLC to develop the ITS applications [6]–[14]. Especially, we focused on unique characteristics of the image sensor and proposed the hierarchical coding [6] and the overlay coding [9] to improve the data reception performance. However, to perform the image-sensor-based VLC in an actual environment, the receiver has to acquire the VLC transmitter from captured images before recovering data. Namely, the VLC transmitter acquisition and tracking are critical problem to achieve an implementation of the ITS applications using the image-sensor-based VLC technique. This invited paper introduces two proposed methods to acquire the VLC transmitter from images captured by the image sensor [10], [11]. This paper also shows our key ideas and experimental results.

II. UTILIZATION OF SPATIO-TEMPORAL IMAGE FOR LED ARRAY ACQUISITION [10]

In [10], we proposed the single VLC transmitter acquisition based on a spatio-temporal image and a spatio-temporal cross-section image. The spatio-temporal image is three-dimensional space image made by arranging captured images in time series (1), as shown in Fig. 2(a). From this spatio-temporal image of Fig. 2(a), let us create a 2D plane, as shown in Fig. 2(b). This cross-section image is called the spatio-temporal...
Fig. 1. Example of successive captured images in time series.

Fig. 2. Spatio-temporal image (a) and Spatio-temporal cross-section image (b).

cross-section image. When the blinking LED changes its own luminance value rapidly, LEDs of the transmitter have high partial differential value (gradient value) in time-domain of the spatio-temporal image and the spatio-temporal cross-section image. On the other hand, when each of LEDs changes its status simultaneously from on to off or off to on, LEDs of the transmitter have low partial differential value (gradient value) in space-domain of the spatio-temporal image and the spatio-temporal cross-section image. Based on both characteristic values in time-domain and space-domain, we propose the single VLC transmitter acquisition method that can prevent both true-negative and false-positive. As the results of the experiment in driving situation, we achieved that true-negative does not occur although the vehicle is vibrating.

III. MULTIPLE LED ARRAYS ACQUISITION USING BLOCK MATCHING [11]

In [11], we proposed the multiple-VLC-transmitters-acquisition method to distinguish whether the VLC transmitter or not for I2V-VLC. To achieve a robust detection of the transmitter, we employed the block matching algorithm [15], which is a way of finding a corresponding position between two successive frames, for the proposed method. Figure 3 shows a block diagram of I2V-VLC system model with multiple VLC transmitters. In addition, we also show a block diagram of VLC receiver algorithms, as shown in Fig. 4. Let us focus on the header image processing unit in Fig. 4. Our VLC system sends data as a packet, which consists of a header part and a data part. We include a Baker sequence of length 13 in the header part to acquire multiple VLC transmitters using the block matching. Here, we explain an operation of this multiple-VLC-transmitters-acquisition method along the header image processing unit in Fig. 4. The first unit divides a captured image into \( m \times n \) blocks to partially scan the image. The second unit extracts candidate areas of LED arrays from \( m \times n \) blocks and detects blocks including LED arrays. Specifically, this unit divides a captured image into a number of small blocks and determines if the LED array is present or absent using the block matching, as shown in Fig. 5. The third unit connects extracted blocks in the second unit and its neighboring extracted ones. When the block size is smaller than the size of transmitter on the captured image, each LED array area on the image consists of multiple extracted blocks. Namely, we make a large area including one LED array by connecting extracted blocks. Moreover, to improve an acquisition property, each connected area is expanded until its circumscribed area. Finally, each expanded area is clipped as each LED array area.

As one of advantages of using the block matching, the sub-pixel estimation is possible to find the corresponding position between two successive captured images. Namely, the proposed method robustly extracts each LED array even if a pixel-to-pixel fluctuation between two successive images is caused depending on a vehicle vibration.

This section explains the experiments of the I2V-VLC system. We performed the experiments of the I2V-VLC system evaluated a performance of the proposed acquisition method. As results, we confirmed that a false-negative (\( FN \)) and a false positive (\( FP \)) rates of the proposed method simultaneously approaches zero without limit. Here, \( FN \) and \( FP \) rates denote a missing rate of LED arrays and a rate when any things other than LED arrays are acquired, respectively. It means that the vehicle receiver using the proposed method can avoid the influence of the fluctuation between frames depending on the vehicle vibration. Moreover, it has been observed that the proposed method can perform almost 100% success of the clipping of LED arrays. Therefore, we have achieved the robust acquisition of multiple-LED arrays.

IV. CONCLUSIONS

This invited paper has introduced two proposed methods to acquire the VLC transmitter from captured images for the
image-sensor-based VLC. As future works, we would like to perform the real time and robust communication in the imagesensor-based VLC system using our proposed method.

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