Performance Enhancement for Image Sensor Communication in an Intelligent Transport System Using a High-speed Stereo Camera

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***Abstract*—In this paper, we propose using a high-speed stereo camera as the image sensor communication (ISC) receiver of an intelligent transport system (ITS). The stereo camera is used for front recognition of the vehicle, making it possible to estimate distances and enabling an integrative system that comprises vehicle front recognition and communication. Furthermore, several stereo images from slightly different views can be obtained at the same time, which provides diversity. Thus the proposed method enhances communication performance owing to the stereo diversity. We also provide experimental results obtained using the high-speed stereo camera and compare them with that of a conventional single high-speed camera. The proposed method improves the bit error rate (BER) performance with respect to the conventional method.**

Keywords—Visible light communication, image sensor communication, intelligent transport system, high-speed stereo camera

I. Introduction

The market for image sensors is expanding significantly [1], [2] owing to the development of advanced driver assistance systems (ADASs). At the moment, these image sensors are mainly used for application related to view assistance and image recognition. Additionally, they can be used as receivers for visible light communication (VLC) [3], which is a novel wireless communication method for transmitting data through high-speed blinking of a light-emitting diode (LED) [4], [5]. VLC using an image sensor as the receiver is called image sensor communication (ISC) [6].

In ISC, the transmitted VLC signal is spatially separated by image processing and then decoded. Therefore, multiple and simultaneous communication is easily possible [7]. Also, other image processing applications, such as collision avoidance, and lane keep assistance among others can be incorporated [8]. Owing to these advantages, ISC is expected to become an attractive application in the field of intelligent transport systems (ITSs) [9], [10].

While a single high-speed camera is used as the receiver in conventional studies [11]-[15], we now consider using a high-speed stereo camera in the proposed study. Since a notable feature of stereo cameras is the possibility to estimate distances [16], [17], they serve as a core technology in front recognition systems of vehicles such as EyeSight [18]. Additionnally, using high-speed stereo cameras as ISC receivers, both front recognition and wireless communication can be achieved. Hence, we aim to develop an integrative system for vehicles that enables front recognition and communication by utilizing a high-speed stereo camera receiver. Moreover, we expect to improve the communication performance itself by using stereo images obtained at the same time.

To do so, we propose a method for improving the communication performance by using the differences in vision of stereo cameras. In general, the images captured on the right and left side of a stereo camera are slightly different so that a diversity effect may be provided by that difference. For example, in the field of 3-D shape measurement with structured light, the precision of the measurement improves by stereo diversity [19], [20]. In this paper, we apply the diversity obtained by the difference of stereo vision to improve the communication

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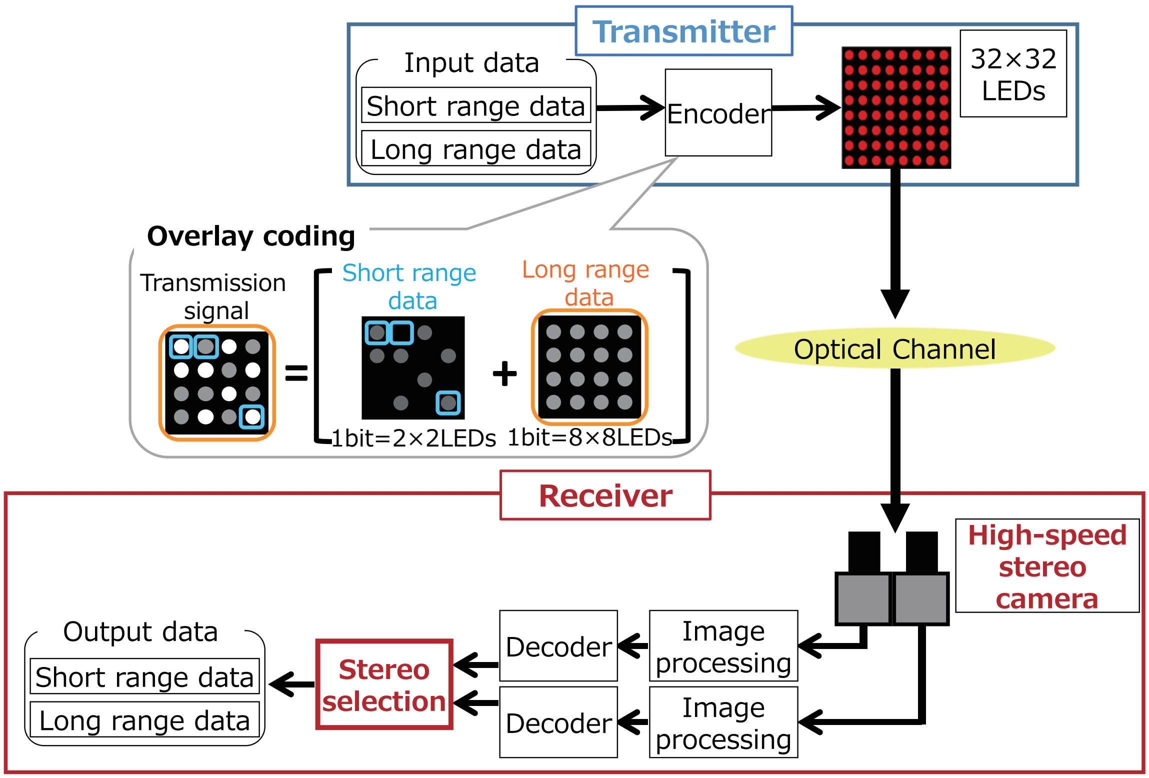


Fig. 1. Block diagram of an ISC system using a high-speed stereo camera.

performance.

According to the results of preliminary experiments (mentioned in Section III), we observed that errors occurred at different LED positions on the right and left cameras. In other words, even if an error occurs in one of the cameras, there is the possibility that the other camera will receive correct data. Therefore, errors can be improved by complementing the images on the left and right sides. To achieve this, we insert a known lighting pattern into the header of a transmission packet as a training sequence. Then, the receiver selects more reliable decoded data from the right and left cameras according to the error distribution obtained by the training sequence. We propose such a reception technique by using stereo cameras to achieve stereo selective reception and enhance the communication performance.

The paper is organized as follows: In Section II, we describe the system model of our target ISC using a high-speed stereo camera. Then, we discuss preliminary experiments involving the high-speed stereo camera receiver (Section III), and based on the preliminary results, we propose a stereo selective reception system to improve the communication performance (Section IV). To verify the effectiveness of the stereo selective reception, Section V provides the results of the conducted experiment. Finally, the conclusions are presented in Section VI.

II. System Model

Figure 1 shows the block diagram of our system model.

At the transmitter, the conventional method is applied [13], [14] by dividing the input data into long range data and short range data according to the priority. Then, an overlay coding is applied [14], i.e., the long range data is assigned to 8 $\times$ 8 LEDs for 1 bit and the short range data to 2 $\times$ 2 LEDs for 1 bit. Then, the encoded data is transmitted by pulse width modulation (PWM).

The transmitted signals are captured by the high-speed stereo camera, and the received signals are independently extracted for each camera via image processing [13], [15]. Both decoded data from the stereo camera are compared and either of them is selected. We explain the selection method later in Section IV

TABLE I. SPECIFICATIONS FOR THE PRELIMINARY EXPERIMENT.

Transmitter	
Lighting frequency of LEDs	500 Hz
bit/LEDs	Long range: 8 × 8
	Short range: 2 × 2
Number of transmission bit	Long range: 1920
	Short range: 30720
Receiver	
Camera model	IDP-Express R2000-F made by Photoron × 2
Sensor type	CMOS
Frame rate	1000 fps
Shutter speed	1/1000 second
Resolution	512 × 512 pixel
Focal length	35 mm
Output image	8-bit gray scale
Inter-camera distance	25 cm
Communication distance	30 m

TABLE II. RESULT OF PRELIMINARY EXPERIMENT.

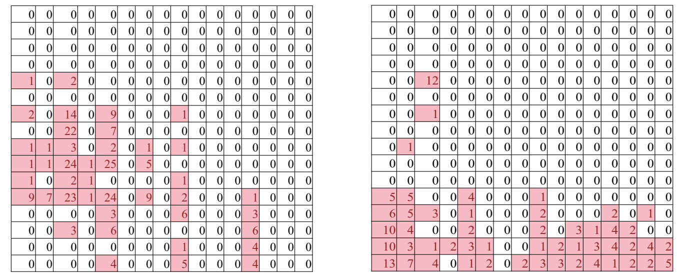
	Number of error bit	
	Long range	Short range
Left camera	1	250
Right camera	0	167
Common errors	0	10

III. PRELIMINARY EXPERIMENT

We conducted a preliminary experiment and considered the result obtained by the high-speed stereo camera. We recorded images of a 32 × 32 LED array transmitter using the high-speed stereo camera under static conditions. Then, the errors in the transmitted signal were detected from the captured images for each camera. The specifications of the preliminary experiment are shown in Table I.

The results of the preliminary experiments are shown in Table II. We also derived error distributions for the short range data in both cameras, as shown in Fig. 2. According to the results, although both cameras recorded the same target LED array, the number of errors was different. Furthermore, common errors in both cameras were only 10 bit for the short range data and no common errors were observed for the long range data. This result implies that even if an error occurs in one camera, the other camera may receive correct data.

Therefore, if the decoded data from the right and left cameras are different, the communication performance may be improved by selecting the more reliable camera. In the next section, we propose how to achieve this.



(a) Left camera (b) Right camera

Fig. 2. Error distributions of short range data in both camera. The Number in each cell indicates the number of errors in the corresponding LED position.

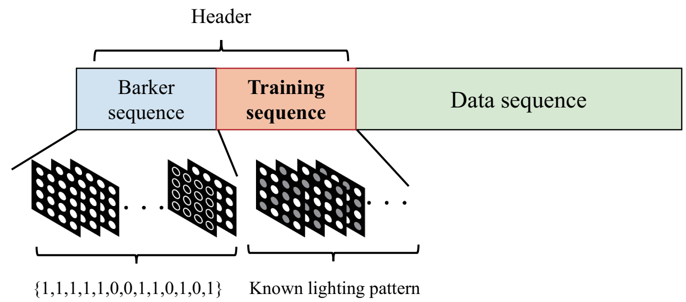


Fig. 3. Packet format for stereo selective reception.

IV. STEREO SELECTIVE RECEPTION

To select more reliable decoded data, we insert known lighting patterns into the header of the conventional packet format [21] as a training sequence. The proposed packet format is shown in Fig. 3.

The high-speed stereo camera receiver first determine whether candidate regions are VLC transmitter or not by barker sequence as well as the conventional work. Then, by reading the training sequence, the error distributions, $p_l(i, j)$ and $p_r(i, j)$ (i, j indicating the LED positions), are generated for each camera, as shown in Fig. 2. Finally, the decoded data is selected according to the flow chart shown in Fig. 4 with generated error distributions.

The decoded data from both cameras, $d_l(i, j)$ and $d_r(i, j)$, are compared and if they are equal, both data can be used as output data $d(i, j)$. Otherwise ($d_l(i, j) \neq d_r(i, j)$), the receiver compares the corresponding positions of the error distributions, $p_l(i, j)$ and $p_r(i, j)$ and one of the decoded data with the lower error rate at the corresponding position is selected as the output.

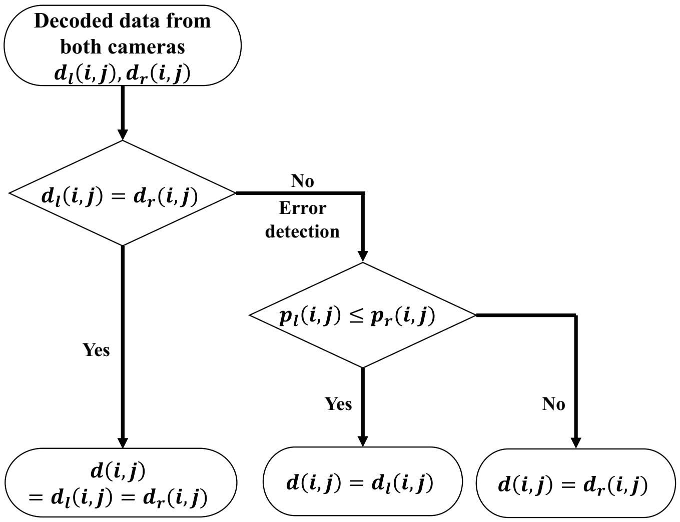


Fig. 4. Flow chart of the stereo selective reception.

TABLE III. SPECIFICATIONS OF THE EXPERIMENT.

Transmitter	
Lighting frequency of LEDs	500 Hz
bit/LEDs	Long range: 8 × 8
	Short range: 2 × 2
Number of transmission bit for training sequence	Long range: 1920
	Short range: 30720
Number of transmission bit for data sequence	Long range: 9600
	Short range: 153600
Communication distance	30 - 60 m

In this manner, an improvement in the communication performance can be expected by selecting one with more reliable decoded data based on the error distributions.

Note that although we adopted an overlay coding in this work, the stereo selective reception is available for other coding schemes, such as layered space-time coding (STC) [22], [23].

V. Experiment

This section provides an additional experimental result to verify the effectiveness of the stereo selective reception. Similarly to the preliminary experiment in Section III, we recoded a 32 × 32 LED array transmitter using a high-speed stereo camera under static conditions. The array transmitted a signal with the proposed packet format, and the specifications of the transmitter used in this experiment are shown in Table III. Note that the specifications of the receiver are the same as those in Table I. The bit error rates (BER) performance of both the long range data and short range data were evaluated at a communication distance of 30 - 60 m.

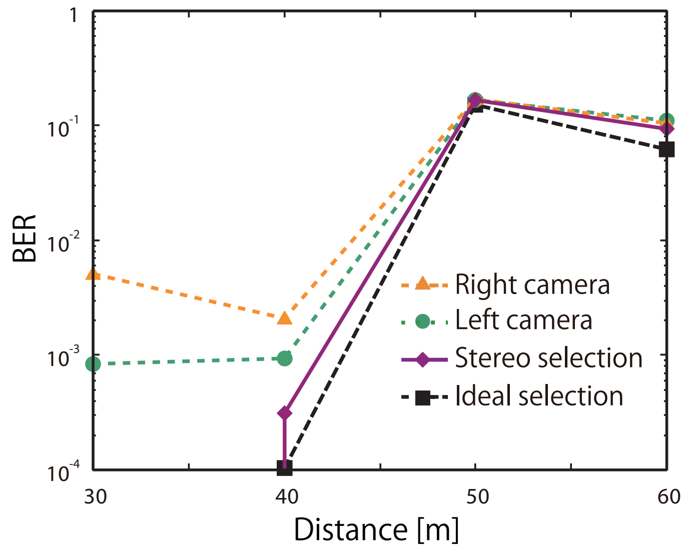


Fig. 5. BER performance of the long range data.

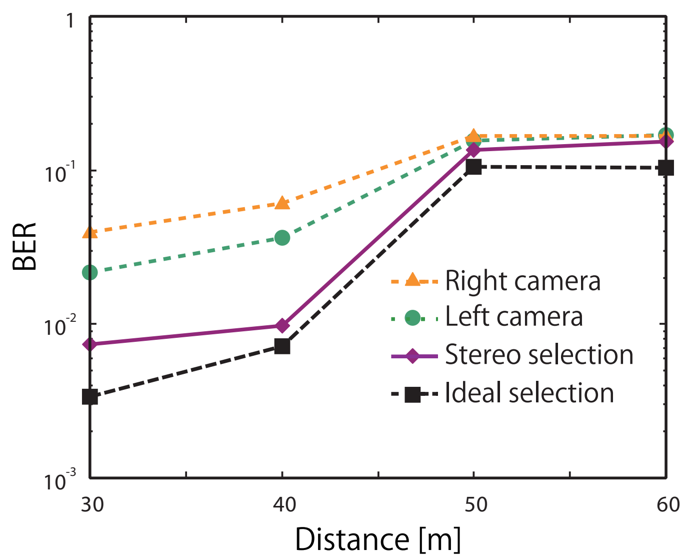


Fig. 6. BER performance of the short range data.

Figures 5 and 6 show the BER performances for the long and short range data, respectively. We compared the proposed stereo selective reception with the results obtained by the conventional method (left and right cameras) as well as the common errors observed in both camera (i.e., the ideal performance for the proposed method). We observed that the proposed stereo selective reception improved the BER performance, which was corrected by about 70% as compared with the conventional method at a communication distance of 30 - 40m. Also, the stereo selective reception showed a BER performance that was close to the ideal selection within this range. An improvement of the BER performance was also observed in the range of 50 - 60 m, although the degree of improvement was lower in this case.

At a short communication distance, the correlation between error distributions in left and right cameras were low and the correlation coefficient was 0.09 at 30 m. Therefore, stereo selection was effective to improve BER performance because left and right cameras can interpolate errors each other. On the other hand, at a long communication distance, the correlation between error distributions in left and right cameras were high and the correlation coefficient was 0.83 at 60 m. Hence, left and right cameras were difficult to interpolate errors each other and improvement of BER performance was lower. If we set wider inter-camera distance, the correlation of error distributions expects to be lower. However, the field of view (FOV) that stereo selection is available will be narrower.

VI. Conclusions

In this paper, we first proposed the use of a high-speed stereo camera for an ITS-ISC receiver. Then, we proposed a selective reception method for decoded data using the differences in the vision of stereo cameras to improve the communication performance. Based on the error distributions generated by inserting known lighting patterns, the one with higher reliability was selected from the decoded data obtained from the left and right cameras. As an experimental result, we observed that the proposed stereo selective reception improved the BER performance compared with the conventional method.

Herein, we evaluated the effectiveness of the proposed method in stationary environments, but we still need to examine it in mobile environments as a future scope of our proposed study.

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