Proximity-Driven Light Intensity Modulation for Enhanced Bidirectional Optical Camera Communication

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***Abstract*—Wireless communication has provided numerous advantages across various sectors and in human lives in recent years. It is considered convenient, flexible, and easy to set up. Recently, optical wireless communication (OWC) has emerged as an alternative to radio frequency (RF)-based communication. Optical camera communication (OCC), a sub-topic of OWC, has garnered research interest due to its potential benefits, including high . However, intensity in OCC needs to be regulated, as it can cause disruptions in communication when performed at various distances. In this paper, we propose a method to regulate light intensity based on proximity in a bidirectional communication scenario. Proximity is measured through the transmitter area size in the 2D representation. The experiment demonstrates that the proximity approach can be used as a parameter to regulate light intensity at various distances. Furthermore, the experiment is conducted without modifying any camera parameters, making it adaptable for average brightness environmental conditions.**

***Index Terms*—optical camera communication, light intensity, proximity, object detection**

I. Introduction

Wireless communication has become ubiquitous in all aspects of human life, finding applications across various industries and daily activities. In contrast to wired communication, wireless systems offer convenience and flexibility during setup. In recent years, radio frequency (RF) has been the most common medium for wireless communication. Despite the widespread use of RF as a medium in wireless communication, there are concerns about its potential harm to human health due to the utilization of electromagnetic waves [1]. Additionally, the increasing usage of wireless communication technology may lead to the depletion of RF waves [2].

In recent years, optical wireless communication (OWC) has emerged as a notable research trend. OWC utilizes optical light as a medium for signal transmission, presenting itself as a potential alternative to RF-based communication with several advantages. Optical light in OWC spans a bandwidth of 200 THz in the 700-1500 nm range [3], [4], and it offers increased robustness and resistance to jamming and interference, thereby enhancing the security of communication [5].

Optical camera communication (OCC), a sub-topic of OWC, employs light sources, including light-emitting diodes (LEDs), as transmitters and cameras as receivers [6]. OCC is characterized by lower cost, reduced power consumption, and flexibility in usage and installation. Various types of receivers, including single LEDs or matrices of different sizes (e.g., 4x4, 8x8, and 16x16), can be employed in an OCC system. The advancement of complementary metal-oxide-semiconductor (CMOS) technology enables cameras to capture high-resolution and high-speed images [7].

The incorporation of cameras in OCC presents a unique advantage by allowing receivers to capture transmitters within their field-of-view (FOV), facilitating data receiptment from different angles. This is made possible due to the wide FOV of the camera. Additionally, certain cameras possess the capability to capture objects in far-reaching distances, enabling a transmitter to communicate simultaneously with multiple receivers.

The utilization of LEDs in OCC, where light is dispersed in multiple directions, offers the advantage of enabling data reception from various angles. This characteristic aligns with the principles of Visible Light Communication (VLC), where a single LED serves as the transmitter [8]. Leveraging LEDs with a broad light scattering pattern can prove beneficial in OCC, facilitating data acquisition from diverse orientations.

Nevertheless, it is essential to note that employing an LED array at extended distances presents challenges. The increased distance necessitates higher LED brightness for effective camera readability. Conversely, at shorter distances, intense LED illumination may introduce difficulties in data reading, as the heightened light intensity contributes to unwanted noise. Striking a balance becomes crucial to mitigate the challenges posed by both long and short distances in OCC applications. This underscores the importance of optimizing LED configurations to adapt to varying communication distances and lighting conditions, ensuring reliable and efficient data transmission.

To regulate LED intensity across varying distances, our approach leverages the analysis of object size within the 2D representation captured by the camera. Recognizing the inherent challenges in precise distance measurement from a 2D image, we acknowledge the effectiveness of approximating distance based on object size. This is rooted in the principle that as an object gets closer, its area size in the 2D image expands accordingly [9].

To operationalize this concept, we employ the YOLO (You Only Look Once) object detection technique [10]. YOLO provides a robust mechanism for accurately measuring the area size of the transmitter, as its bounding box closely aligns with the transmitter's shape. Through this methodology, we can effectively estimate the proximity of the transmitter by gauging the object size in the 2D representation.

This estimation then becomes instrumental in dynamically controlling the LED intensity. As the object size fluctuates with changing distances, the LED intensity is automatically adjusted. This adaptive approach ensures that the LED brightness is optimized for reliable communication, overcoming challenges posed by both extended and shortened distances in our optical communication system. So, in this paper, we suggest a method for managing LED brightness in a two-way OCC. By gauging the size of the object, we can regulate the LED intensity. We achieve this by sending a signal to the LED, instructing it to adjust its brightness based on the measured object size. This approach allows us to dynamically control the LED intensity, ensuring effective communication in both directions.

The remainder of the paper is organized as follows. Section II describes the proposed method. Section III presents the analysis of the experiment and discussions. Section IV draws the conclusion and our future research based on the results.

II. Description of Proposed Method

A. System Architecture

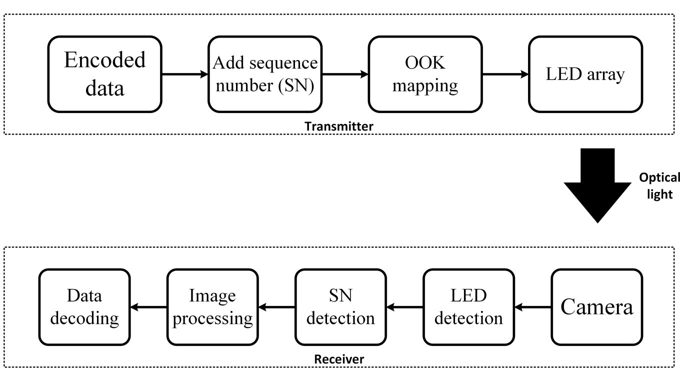

Fig. 1. System architecture.

The outlined methodology is illustrated in Fig. 1. Within this system, the transmitter employs on-off-keying (OOK) to encode the data onto the LED array [11]. This modulation process distinguishes between bits "1" and "0," corresponding to the activation and deactivation of the LEDs, respectively. As previously noted, numerous OCC systems utilize diverse transmitters, ranging from a single LED to an array of LEDs. The utilization of an LED array offers the advantage of achieving a heightened data rate. This is attributed to each LED in the array accommodating one bit representation, consequently resulting in an elevated data transfer speed.

Sequence numbering (SN) is utilized in the transmitter as an identifier between LED transmitters. The addition of SN also serves to enhance the performance of the system by facilitating the detection of any missing packets, particularly in oversampling scenarios. The length of the SN can be adjusted according to the system's requirements, accommodating changing channel conditions which is known to affect wireless communication system.

The decoding process on the receiver involves multiple stages to extract the modulated data. Initially, the LED transmitter, identified through the YOLOv8 model, establishes a Region of Interest (RoI), enabling focused 2D image processing solely on the transmitter. Our work maintains unaltered camera parameters, necessitating the application of various image processing techniques. The camera parameters remain unaltered to facilitate effective object detection, ensuring the visibility of the LED array during the experiment.

The first step involves employing an absolute scaler, which converts pixels to absolute values and transforms them into unsigned 8-bit integers. Following this, a Gaussian blur [12] is applied to mitigate noise and eliminate extraneous details, especially those arising from scattered light produced by the LEDs. Subsequently, grayscale transformation is implemented, converting the image into a grayscale representation.

The ensuing step employs a thresholding method to convert the image into binary values (0 and 1). This process yields various clear shapes, and contours are drawn around these shapes. From the contours, rectangular shapes are generated by outlining rectangles around them. These rectangular shapes represent bits generated by the transmitter and only certain size rectangles that are considered for the decoding. All these steps are executed within the receiver using the Python OpenCV library. This comprehensive decoding approach ensures the accurate extraction of modulated data from the transmitted signals.

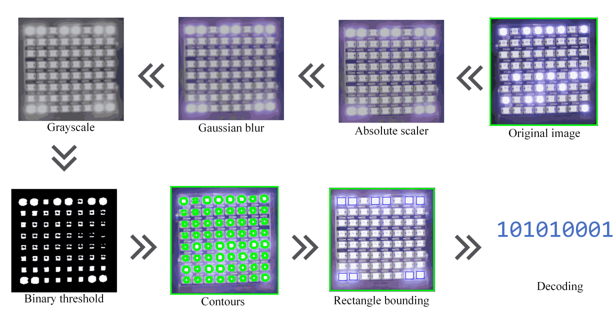

Fig. 2. Image processing in receiver side.

B. Proximity for brightness intensity control

As previously mentioned, the absence of camera modification in this approach raises concerns about potential light noise interference in communication. The OCC system's inability to function may arise from the camera's challenge in detecting LEDs due to high brightness. This paper proposes a technique

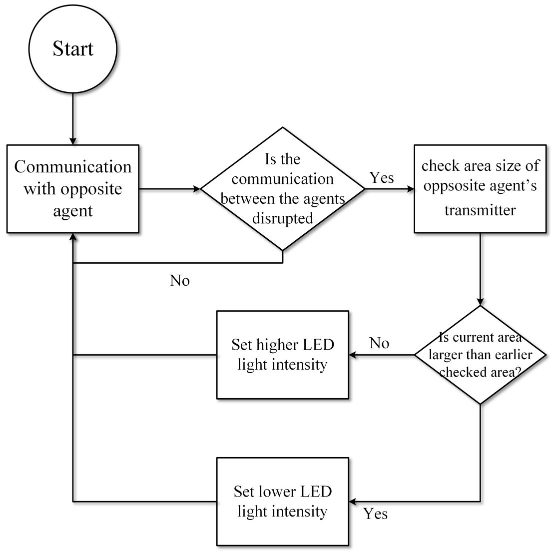

Fig. 3. LED array mapping.

to address this issue by leveraging the proximity of one agent to another in bidirectional communication.

The proposed technique introduces an innovative method for regulating LED intensity, focusing on the utilization of object size in the 2D representation as a crucial parameter for determining distances between receivers and the transmitter. As illustrated in Fig. 3, the initial trigger for this method occurs when communication is disrupted, signaled by agents unable to communicate with each other. When communication is disrupted, each agent must examine the size of the opposing agent and adjust the LED light intensity based on the determined LED array size.

The measurement of object size is facilitated through the YOLOv8 object detection model. This model not only identifies the object's presence in the 2D image but also provides a bounding box for accurately measuring the transmitter's size in the 2D representation.

III. Results and Discussion

A. 2D object size correlation with the object proximity to regulate intensity in OCC

In this section, we detail the experimental validation of our proposed method using two webcam cameras and a single transmitter. Prior to the experiment, a meticulous fine-tuning of the YOLOv8 object detection model was undertaken. YOLOv8 offers various models, including YOLOv8n, YOLOv8s, YOLOv8m, YOLOv8l, and YOLOv8x. For this investigation, we exclusively employed YOLOv8s and fine-tuned it using a dataset comprising 750 images featuring an 8x8 LED array. The training parameters used is mentioned in Table I and the performance of YOLOv8 model is summarized in Table II.

The experiment was conducted within the setup illustrated in Fig. 4 and Fig. 5, where two OCC agents were positioned

TABLE I

YOLOv8s object detection training hyperparameters.

Hyperparameter	**Value**
Learning rate	0.01
Momentum	0.937
Weight decay	0.0005
Batch size	1
Epoch	100

TABLE II

Fine-tuned YOLOv8s object detection performance evaluation.

Metrics	**Score**
mAP@0.50	0.97
Precision	0.96
Recall	0.92

at different distances. The experiment was performed in indoor scenario with average brightness condition. In the first scenario, the agents were placed 0.5 meters apart, and in the second scenario, the distance was reduced to 0.3 meters. Using Arduino, the LED intensity ranged from 0 to 255. At the distance of 0.5 meters, the intensity was set to 50 and would be reduced as the distance between the agents decreased. Specifically, for every 10-centimeter reduction in distance, the intensity would decrease by 10. This reduction pattern also applies when the distance is increased, with the intensity increasing by 10 for every 10-centimeter increment.

Fig. 4. Experiment setup with initial distance between agents is 0.5 meter.

Fig. 5. The distance between agents is reduced 0.3 meter as Agent B approaches Agent A.

TABLE III
HARDWARE USED FOR EXPERIMENT.

Hardware
Intel i7 12th gen
Nvidia RTX 3060Ti
Neopixel 8x8
Foscam W41

TABLE IV
SOFTWARE USED FOR EXPERIMENT.

Software
Ubuntu 22.04
PyTorch, ONNX, Arduino

In this study, as mentioned in Table III, the Foscam W41 camera is used as receiver. The camera itself operates at 30 frames per second (fps), is equipped with a CMOS sensor, and features automatic light correction. Additionally, the camera utilizes a glass lens instead of a plastic lens. Using the camera, it was estimated that at a distance of 0.5 meters, the calculated area was around 15,000, while at 0.3 meters, the calculated area was approximately 15,800. Therefore, employing a simple regression equation, the formula to get the intensity of the LEDs was determined to be:

$$f(x) = \frac{1}{90}\lceil 18500 - x \rceil \quad (1)$$

Here, 90 represents the gradient derived from the two values of area size and intensity.

Fig. 6. From the perspective of Agent B, when Agent B distance gets closer, the last intensity of the LEDs are changed to adjust with the distance.

In the experiment, as depicted in Fig. 6, when agent B approached agent A, the camera of agent A faced challenges in detecting the LEDs in agent B's LED array due to excessive brightness. This hindered communication, prompting a need to reduce the LED intensity of agent B. Consequently, agent A adjusted its LED array's light intensity so that agent B could effectively receive the signal. By calculating the area size of Agent's A transmitter, brightness of Agent B's LEDs can be adjusted based on the proximity to Agent A. The similar scheme is also applied to Agent A. Through this approach, the intensity of the LEDs can be controlled based on the proximity. Furthermore, in this scheme, there is no additional devices or sensors utilized, hence lower energy consumed in estimating the distance.

B. 2D image processing for unmodified camera parameters

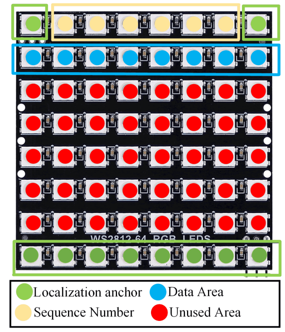

Fig. 7. LED array mapping.

As previously highlighted, this work incorporates image processing steps for the decoding of transmitted data, all while maintaining the original camera parameters. Specifically, only the second row of the 8x8 LED array transmitter is utilized for this purpose. The transmitted data comprises characters, with each character represented by 8 bits. Notably, both the top and bottom rows of the transmitter function as the sequence number (SN) and identifier for the object detection process. In contrast to the previously proposed OCC method, where camera parameters remain unmodified, this approach ensures enhanced visibility of the transmitter, leading to improved observation. Additionally, this method allows the receiver to assess whether the data is obtained from the correct transmitter or not.

Additionally, our investigation includes a robust assessment of the Bit Error Rate (BER). Remarkably, employing the image processing steps described above, even without any modification to the camera parameters, the transmitted data can be reliably obtained with minimal errors within the range of 0.5 to 1 meter distance. This underscores the effectiveness of our approach in ensuring data integrity without compromising the original camera settings. The limitations of this approach include potential distractions in communication under various brightness conditions, particularly under excessive brightness conditions. This is attributed to the absence of camera parameter modifications, making the communication sensitive to changes in brightness conditions.

TABLE V
BER ESTIMATION ON DIFFERENT CHARACTERS TRANSMITTED AT ONCE (DISTANCE 0.5-1 METER).

Characters	BER
1-10 chars	7.70×10^{-2}
11-20 chars	8.30×10^{-2}
21-30 chars	8.40×10^{-2}
31-40 chars	8.70×10^{-2}

IV. CONCLUSION

In this paper, we present an approach to regulate the intensity of LEDs in a bidirectional Optical Camera Communication (OCC) system based on proximity. Our method is designed to address scenarios in which communication is disrupted as the distance between the agents changes. The LED usage in OCC can introduce noise and interference due to its way in emitting light through scattering, making it challenging for the receiver to correctly receive transmitted data. By utilizing proximity, estimated through the size of the transmitter in 2D representations, we establish that the closer the transmitter is to the receiver, the larger its size appears in the image. The measurement of the transmitter size is achieved through a fine-tuned YOLOv8 object detection model. We also conducted experiments on the approach without modifying camera parameters, as object detection requires visual clarity to detect the model.

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