A Novel Approach Combining Optical Camera Communication and RADAR in Distance Estimation for Dynamic Communication

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***Abstract*—Optical wireless communication (OWC) has emerged as a cost-effective, interference-resistant technology with access to a wide spectrum. As part of OWC, Optical Camera Communication (OCC) has garnered significant attention, operating by transmitting optical signals through Light Emitting Diodes (LEDs) and receiving them with a camera. However, existing approaches do not consider modulation adjustments in dynamic communication scenarios, which can impact data rates and Bit Error Rate (BER) in OCC. Therefore, a method for estimating the distance between the transmitter and receiver in dynamic environments is introduced. This system enables the transmitter to select the appropriate modulation type for data transmission. During testing, the proposed method successfully operated in dynamic conditions, achieving a distance estimation error of 2%. It offered a performance of 7.2 Kbps for OOK modulation, 26.8 kbps for RGB modulation, a Mean Average Precision (mAP) of 0.995, and a processing speed of 2.351 ms.**

***Index Terms*—optical camera communication, modulation, YOLOv5, Radar**

I. Introduction

Nowadays, RF technology has been a primary focus of research and has witnessed substantial growth across sectors like transportation, construction, and medicine. For example, in transportation, RF acts as a communication medium that integrates systems to provide traffic insights on highways [1]. Furthermore, RF plays a vital role in various wireless applications, including cellular networks, Bluetooth, and IoT, forming the basis of modern wireless communication. Despite its widespread use, RF has drawbacks, including limited spectrum availability, susceptibility to interference, and the requirement for licensing in implementation.

Hence, optical wireless communication (OWC) emerges as an alternative technology to address RF technology's challenges. OWC provides resistance to interference, and access to a broad spectrum, and operates without the need for licensing. Optical camera communication (OCC), a subsystem of OWC, employs light-emitting diodes (LEDs) to transmit light and cameras for reception [2]. OCC's main advantage, compared to other subsystems, is its capability to modulate data into invisible frequency-modulated light [3], without causing harm to the human eye. Technical standards for OCC are standardized under IEEE 802.15.7a [4].

Recently, OCC has become a crucial innovation for communication systems in applications like traffic monitoring [5] and healthcare monitoring [6]. However, despite numerous OCC system implementations, it still encounters challenges. One of the main obstacles in OCC development is the use of receiving media that restricts the refresh rate at a lower layer, potentially impeding high data rates.

Furthermore, using OCC for long-distance communication also presents several issues. When employed over longer distances, OCC tends to experience a decrease in stability and focus during communication. This can result in an increase in the Bit Error Rate (BER) and a decrease in the achievable data rate of communication.

To address these challenges, the low frame rate can be overcome by using a high-frame-rate camera. Furthermore, to achieve high data rates in long-distance communication, this paper will utilize an LED array integrated with radar to reduce the BER in OCC. Radar will provide information about the distance between the receiver and transmitter, enabling the transmitter to select an appropriate modulation scheme for data transmission. Additionally, to enhance focus in communication, this technology will leverage You Only Look Once version 5 (YOLOv5) [7] for more accurate LED location detection.

The paper is organized as follows: Part II explains methods to enhance OCC performance through distance estimation and focus. Part III presents results and experimental analysis, while Part IV concludes the paper.

II. Description of Proposed Method

A. System Architecture

Fig. 1 illustrates On-Off Keying (OOK) and RGB modulation for MIMO data transmission in OCC, utilizing distance information obtained from Radar components between the transmitter and receiver. The next step involves enhancing focus through the implementation of YOLOv5 for more precise LED detection, to reduce the BER and significantly enhance data rates in the OCC communication system.

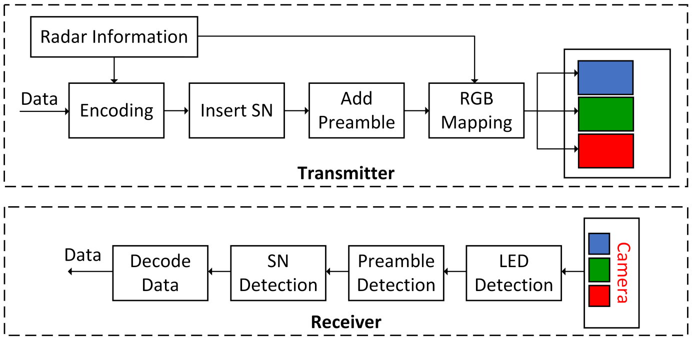

Fig. 1. OOK RGB Architecture for Dynamic Communication

B. Distance Estimation Method

When the transmitter is active, the radar not only detects the receiver (camera) but also human bodies and objects in its vicinity. This results in the reception of unnecessary information during the OCC communication process, particularly when users are within the radar's line of sight. Additionally, if multiple objects are detected simultaneously by the radar, the computational requirements for the detection process increase significantly, leading to greater power consumption and longer processing times. This needs to be avoided to create efficient and computationally lightweight object detection.

Therefore, this issue is addressed by implementing an information separation algorithm that distinguishes between moving objects (non-receivers, such as humans, etc.) and stationary objects (receivers, like cameras). As illustrated in Figure 2, this algorithm enables more efficient data processing from the radar and reduces the computational load.

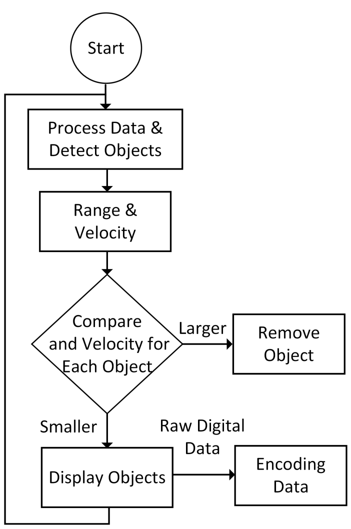

Fig. 2. Noise Removal method flow chart

The initial stage involves transmitting electromagnetic waves in the form of short pulse signals to detect objects around the transmitter. When the pulse signal is successfully reflected and received by the radar, information regarding the distance and velocity of each object around the radar can be obtained. However, the information received by the radar results in pulse signals that are not constant and dynamically change when objects are in motion. Therefore, limits have been established to ensure that only stationary objects (receivers) are detected, and objects detected with distances and velocities exceeding predefined program parameters are considered as interference in object detection using radar. Once the radar successfully detects pulse signals that meet the specified criteria, this data is forwarded to the data encoding system within the OCC system for processing and selecting the appropriate modulation type to meet the communication system's requirements.

C. Transmitter

After obtaining information from radar detection, details regarding the distance between the sender and receiver are incorporated into the payload of the data packet, which comprises a text stream. This payload is then converted into a binary representation, specifically using ”1” and ”0.” Once the data payload has been represented in binary form, a sequence number (SN) is added to each packet to distinguish the sequences within each binary-represented packet.

Furthermore, complete binary packets are equipped with a preamble, which serves as a symbol frame to assist the receiver in data processing. Before mapping the data packets onto the LED array, the information obtained from the distance estimation between the transmitter and receiver is taken into account to determine the appropriate modulation type. This step is crucial as it directly impacts the data rate in communication.

Based on the distance estimation results detected by the radar, the transmitter will utilize two modulation types: OOK and RGB. RGB modulation will be employed when the system detects a receiver at a distance of less than 1.5 meters, while OOK modulation will be used when the receiver is located beyond 1.5 meters.

D. Receiver

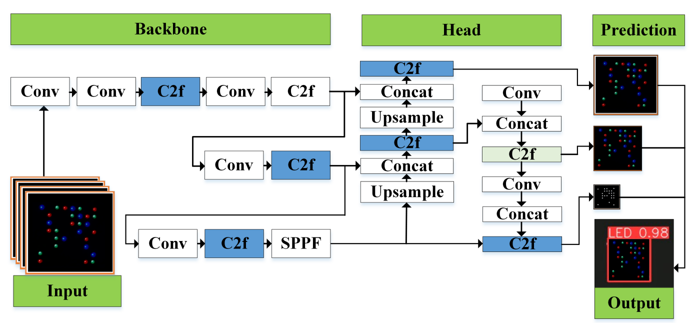

Fig. 3. YOLOv5 Architecture

On the receiver side, data decoding is performed by detecting the LED array using YOLOv5, as illustrated in Fig. 3. LEDs identified by YOLOv5 define the Region of Interest (ROI), enabling focused 2D image processing exclusively on the transmitter. Subsequently, the transmitter performs preamble reading, followed by SN reading and sorting of the received information. Data is then decoded based on the SN carried by each packet, and finally, the data is converted into a human-readable format. Performed by detecting the LED array using YOLOv5. LEDs identified by YOLOv5 define the ROI, enabling focused 2D image processing exclusively on the transmitter. Subsequently, the transmitter performs preamble reading, followed by SN reading and sorting of the received information. Data is then decoded based on the SN carried by each packet, and finally, the data is converted into a human-readable format.

III. Result and Discussion

A. Radar Distance Estimation

To assess the accuracy of the OCC system concerning the distance between the receiver and transmitter, tests were conducted over a range of 0.5 to 2 meters, with a 0.5-meter increment at each stage of testing. The performance results of the proposed system are detailed in Table 1. The measurements revealed an error range of 2% to 4.6%. During implementation, challenges arose in detecting the LED array as its size reduced with increasing distance. As a result, the radar struggled to detect the receiving object.

TABLE I
Distance Estimation Result

Actual Distance	Estimation Results(m)	Error(%)
0.5	0.51	2.00%
1	1.02	2.00%
1.5	1.57	4.60%
2	2.06	3.00%

The results of radar estimation implementation with OCC are displayed in Figure 5. The proposed method successfully removes unnecessary dynamic objects during the receiver detection process and only shows stationary objects during the detection process.

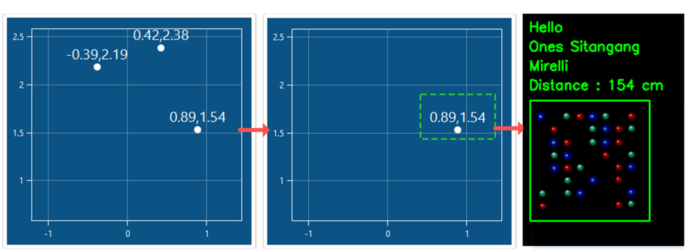

Fig. 4. Dynamic Object Detection

B. Modulation and detection performance

Table 2 presents the achievable data rates by incorporating radar-provided information into the system. In RGB modulation, data rates range from 0 to 26.8 kbps, with values from 10^{-3} to 1. It can be observed that the data rate decreases at a distance of 1.5 meters, as the receiver encounters challenges in color decoding over longer distances. Ideally, the system can maintain effective communication at a distance of 1 meter with high and stable data transmission rates.

In OOK modulation, the data rate ranges from 3.8 to 7.2 kbps, with error rates between 10^{-3} and 10^{-1}. Despite its relatively low data rate, this modulation maintains stability in transmitting information, making it suitable for applications that prioritize communication stability over high data rates.

The training results using YOLOv5 are presented in Table II. Overall, the proposed model exhibits excellent performance, with mAP0.5 of 0.995, mAP0.5:0.95 of 0.999, precision of 0.998, recall of 0.998, and a processing time of 2.351 ms.

TABLE II
Distance Estimation Result

Metrics	Score
mAP@0.50	0.995
mAP@0.50:0.95	0.999
Precision	0.998
Recall	0.998
Speed(ms)	2.351

The results of applying all the proposed methods in this paper, including distance estimation, modulation, and YOLOv5, are depicted in Figure 5. It should be noted that at a distance of 205 cm, objects detected by the camera will become smaller and denser. Therefore, for longer distances, each LED in the LED array may be challenging for the camera to detect, although the positions of the LED array can still be detected by radar and YOLO. However, this challenge can be overcome by using an LED array circuit with modified LED sizes, thus improving the communication range. Most of the proposed approaches have demonstrated their ability to accurately detect and estimate distances, effectively select modulation for data transmission, and have successfully resulted in improved data rates and lower BER within the OCC system

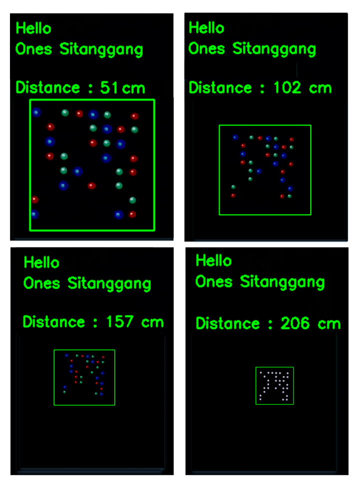

Fig. 5. Object detection using YOLOv8 for OOK and RGB modulation at various distances

IV. CONCLUSION

In this paper, we introduce an OCC scheme based on distance estimation obtained from Radar detection results. The proposed scheme is capable of providing flexibility to the OCC system to adapt the modulation type based on the distance during communication. This approach has also succeeded in enhancing the performance of OCC in dynamic communication scenarios, resulting in an increase in data rates and a reduction in the BER in the communication system. Furthermore, this paper explores the utilization of image-based detection using YOLOv5 to improve detection performance and reduce image acquisition processing time in OCC.

In future research, the focus of the study will be on developing a algorithm that takes into consideration suitable modulation schemes for Vehicle to Vehicle (V2V) and Drone to Drone (D2D) communications in high-noise environments, such as mobility and distance. Channel estimation will also be considered. Consequently, it is expected that the data rate can be significantly improved, and the BER reduced in OCC systems.

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