Deep Learning based RS-OFDM scheme considering mobility environment for Optical Camera Communication system

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***Abstract*—** Rolling-Shutter Orthogonal Frequency-Division Multiplexing was presented in IEEE 802.15.7a Task Group, which proposed new standard for Optical Camera Communication (OCC). OFDM is a digital communication modulation method used in high rate wireless communication to reduce the channel distortion occurred by multi-path effect. Based on this advantage, OFDM has been extensively employed in optical wireless communication for many applications such as the IoT, V2V, V2X, and Smart Factory. However, the movement effect is a significant impact for OWC systems since it results in an optical channel variance in processing time, which decreases performance of OCC system. In the movement environment, to detect the starting frame, conventional shows disadvantages, then we have to find new algorithm to increase OCC performance. In this study, the deep learning algorithm was employed instead of Van De Beek algorithm, which reveals disadvantages compared this approach. In a 2 m/s velocity environment, our technique enables the OCC system to communicate over long range (up to 18 m) with low error.

Keywords—RS-OFDM, Deep Learning, IEEE 802.15.7a.

I. Introduction

As the request for high-speed data transmission grows, novel technologies were researched to advance performance of communication system. Wireless communication shows a lot of benefits compared wired communication since it is easier to deploy for wide spread data deprived of cables. the development of wireless communication has been crucial to the expansion of mobile networks. Consuming a wider frequency range is important to growth data rate, however, radio frequency (RF) systems are little by little effete assets. Many researchers have been working on the sub THz spectrum in order to develop the sixth generation of mobile communications (6G), that promises capacity to provide high speed (10–100 Gbps) and low latency [1]. However, we have to emphasize: a human health may suffer as a result of the increased frequency.

Visible Light Communication (VLC), Light Fidelity (LiFi), and Optical Camera Communication (OCC) emerge as three potential alternatives to RF system. The following can be used to summarize the benefits of VLC, LiFi, and OCC over communication system based-RF waveform: If non-flicker methods were available, light waveform would not be damaging to human health. If the carrier frequency up to 200 Hz was employed, optical communication system can deploy without damaging people's eyes, according to reference [2-3]. The bandwidth of radio waves is more than a thousand times higher than that of visible light. Moreover, VLC/LiFi/OCC systems are less expensive to implement than radio frequency systems due to the visible light infrastructure used in smart homes, hospitals, and automobiles.

Orthogonal frequency-division multiplexing (OFDM) is a digital communication modulation method. It uses multi-carrier frequency instead of single carrier frequency as conventional modulation scheme. The bandwidth is split hooked on orthogonal sub-carriers in broadband wireless communication systems because it reduces channel distortion occurred by ISI (inter-symbol interference). The bandwidth usage is efficient compared Frequency Division Multiplexing (FDM) method because the sub-carriers in an OFDM method can overlap with other sub-carriers considering Fourier transform algorithms. Besides that, CP is included to account for the channel distortion in the RS-OFDM frame [4].

Camera on-off keying scheme technology, that supports a high speed, was presented at document [5]. IEEE 802.15.7-2018 too specifies COOK system in 2018. However, the C-OOK system has a number of shortcomings, for example a high error and a short range. It is not good for the next generation OCC system. Rolling Shutter OFDM scheme was proposed in 2019 [6], however, it did not support for mobility effect and long distance. MIMO C-OOK scheme is suggested using the matched filter for high-rate OCC presented in [7-9], however the mobility effect was ignored.

MIMO methodology, which can decide simultaneous connections with several LEDs and single camera, can be employed successfully with OCC system [10-11]. It is advantage of OCC compared VLC/LiFi, which are difficult to apply MIMO technique. OCC system may apply the popular region of interest (RoI) approach to locate a number of light sources. Currently, Deep Learning was applied widely in OCC system [12]. The authors of documents [13-15] suggested the orthogonal frequency-division multiplexing (OFDM) system with the rolling shutter parameter (RS-OFDM) for high-speed Optical Camera Communication system. However, Deep Learning just applied for tracking and detection. In this study, we suggested the new algorithm for detection of starting frame of OFDM system using Deep Learning, which cannot detect by conventional algorithm in movement environment.

The remain of this study was separated into three sections. Section II presents the construction of Rolling Shutter-OFDM method utilizing Deep Learning for starting frame point detection. In Section III, the implemented results and system analysis are presents. Section 4 presents the conclusion of this paper.

II. System Architecture

In this section, we suggested to use Deep Learning for starting frame of OFDM system, which cannot detect by conventional algorithm (Van De Beek) in movement environment. Figure 1 shows details of RS-OFDM system using Artificial Intelligent.

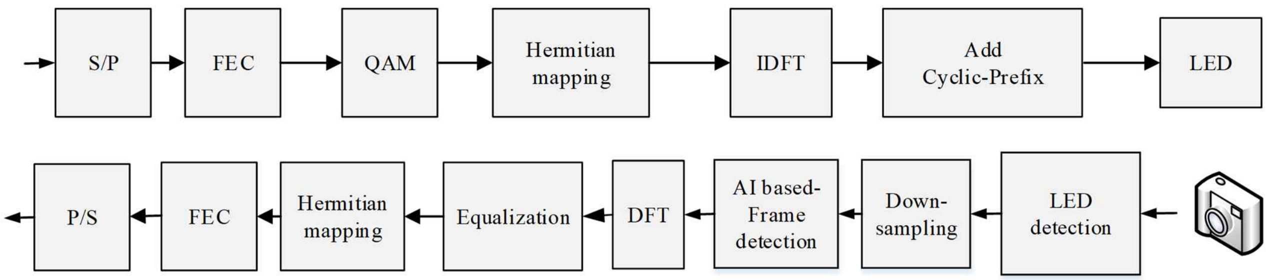

Figure 1. System architecture of RS-OFDM system for starting frame point detection using Deep Learning

2.1. Cyclic-Prefix

With RS-OFDM scheme, Cyclic-Prefix (CP) has also vital for decreasing inter-symbol interference impact. The symbol size and environment channel time delay define the length of CP. Figure 2 shows the concept of Cyclic-Prefix part in the RS-OFDM symbol.

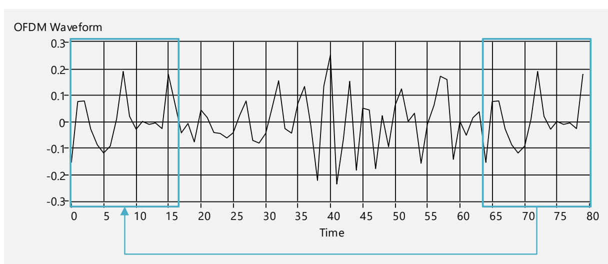

Figure 2. RS-OFDM symbol with cyclic-prefix

2.2. Pilot

The pilots should be added in the OFDM frame to decide the channel estimation in advance spreading. Because the pilot signal not bring the payload, the we should to consider minimize the pilot density and pilot position. The pilot spacing of the OFDM symbol is studied and applied in [16].

2.3. Deep learning for decoder

A time synchronization and frequency synchronization method using CP to determine a maximum probability utility to forecast the time and frequency deviation was proposed by Van De Beek et al. [17]. The start of frame can also be determined by leveraging the characteristics of cyclic-prefix. We suggested using the Van de Beek procedure to quickly identify RS-OFDM frames for OCC systems in document [18]. The traditional algorithm, however, does not enough to provide good performance in RS-OFDM system because of the movement situation channel in OCC system (blur in images, decreasing SNR, etc.). As illustrated in Figure 1, we presented Artificial Intelligent in this paper to identify the starting point of OFDM symbol.

III. EXPERMENTAL RESULTS

In OCC system, the frame rate variation effect makes a lot of burden for receiver side. To decrease the frame rate variation impact, we deploy RS-OFDM modulation scheme in several time with different distances, camera, and shutter speeds. The SN length for the asynchronous process was picked appropriately. The OFDM system was implemented using a FLIR rolling-shutter camera considering camera frame rate between 55 and 65 frames per second (fps). Figure 3 show the scenario of RS-OFDM implementation at 1m distance, while Figure 4 displays the interface of receiver side using LabVIEW programming.

Figure 3. Setup scenario.

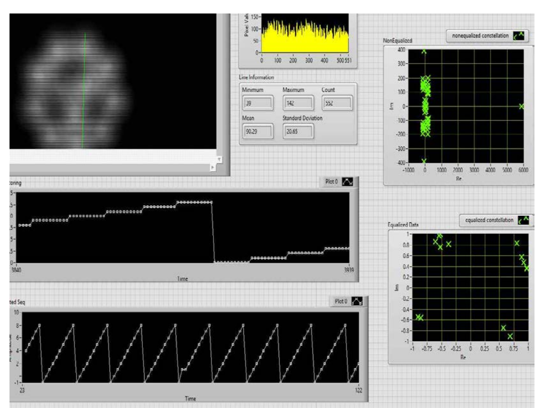

Figure 4. Receiver interface

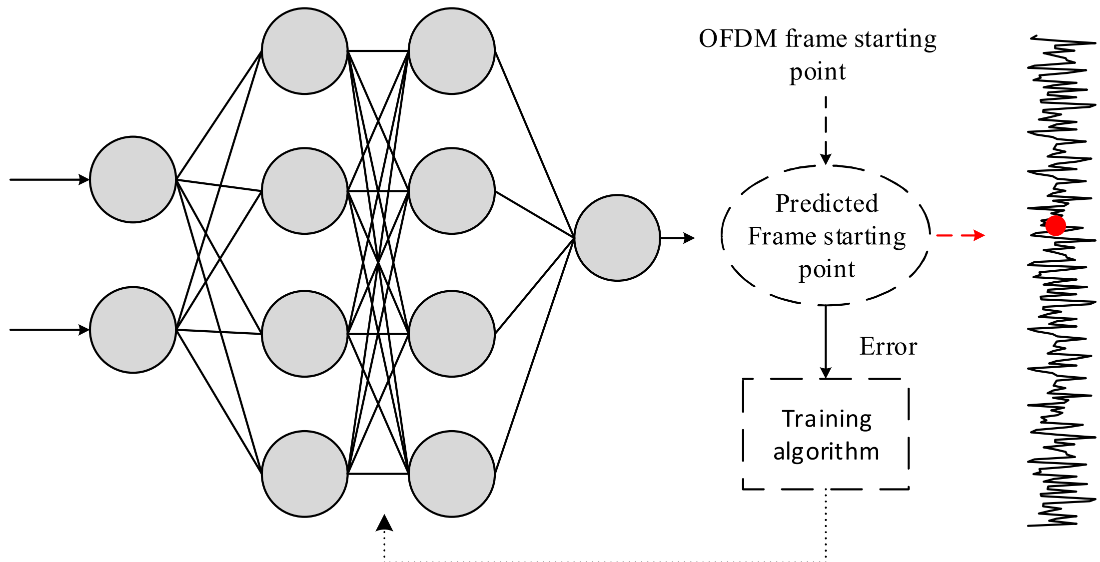

Figure 5. The starting point detection of OFDM frame using Artificial Intelligent

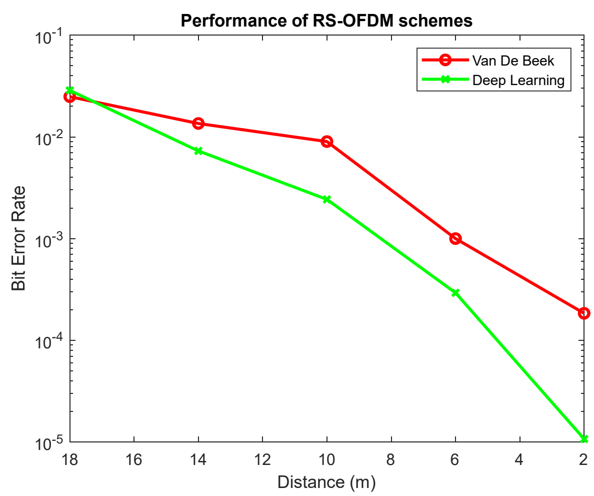

Figure 6. BER performance of RS-OFDM with Van De Beek and Deep Learning methods at velocity of 2m/s.

In Figure 5, we proposed the Deep Learning algorithm for starting point detection. As mentioned above, the time synchronization and frequency synchronization in OFDM method are important to decode data. Then if the starting point detection of OFDM were wrong when decoding, the decoding performance will have a lot of error. Figure 6 show that the BER of 10^{-4} can achieve at 6m distance but just 2m distance with Van De Beek algorithm. However, the exposure time should be control be carefully, which can increase or decrease SNR value of OCC system but it also reduces or increased the communication bandwidth [19-20].

Table 1 shows RS-OFDM parameters, which implemented several times with different clock rates. We can see that, with OFDM symbol length of 128 bits, we can achieve data rate of 1.92 kbps with packet rate of 15 packet per second. However, with OFDM symbol length of 256 bits and packet rate of 25 packet per second, we can achieve data rate of 6.4 kbps. Compared with Figure 6, we can make sure that: we can achieve 6.4 kbps with 6 m distance to get BER of 10^{-4} value considering velocity of 2m/s.

Table 1. RS-OFDM parameters

Transmitter		
Frequency	20 kHz	40 kHz
OFDM symbol	128	256
Channel coding	Hamming (8,4)	RS (15,11)
Packet rate	15	25
Receiver		
Camera	FLIR rolling shutter camera	
Camera frame rate	60 fps	
Throughput		
Uncoded data rate	1.92 kbps	6.4 kbps
Coded data rate	0.96 kbps	4.693 kbps

IV. Conclusion

In this paper, we proposed a deep learning algorithm for rolling shutter OFDM scheme for long distance and mobility environment. In mobility scenario, the deep learning algorithm reveals better than the conventional algorithm (Van De Beek algorithm) to predict the start of frame because the multi-path channel makes channel distortion. The comparison between Van De Beek and Deep Learning methods at velocity of 2m/s verse distance also were presented. Finally, the RS-OFDM parameters also shown to highlight the contributions of this study.

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