Experimental Demonstration of LED-based Vehicle to Vehicle Communication under Atmospheric Turbulence

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***Abstract*—Visible light communication (VLC) has been extensively studied for vehicle-to-vehicle (V2V) communication due to its inherent benefits. The effect of atmospheric turbulence, particularly in rainy condition, on the V2V communication using VLC is examined. The experiments for the V2V communication system was implemented with a modified fixed decision threshold (MFDT) scheme in the presence of rain drops. In the proposed study, a red light emitting diode (LED) representing the taillight of a vehicle is employed for transmitting signal and a photodiode is used to recover the transmitted the data using MFDT. It is demonstrated that the proposed V2V communication using VLC under the rainy condition is accurate and reliable with the help of MFDT.**

***Keywords*—Visible Light Communciation, Decision Threshold, Atmospheric Turbulence, Vehicle-to-Vehicle Communication**

I. INTRODUCTION

Recent advancement in visible light communication (VLC) has attracted much interest for short range and free space communication, due to its various benefits, such as unregulated frequency spectrum, security and harmlessness to humans [1]. VLC operates by employing light emitting diode (LED) that is utilized for various applications, such as indoor lighting, vehicle lamps, street lamps, traffic lights, etc. [2]. Recently, extensive studies have been reported in the VLC literature for vehicle lamp based applications. The authors proposed road surface detection techniques based on LEDs [3], protection against rear-end collision [4] and vehicle-to-vehicle (V2V) communications [5].

The V2V communication attracts much attention and becomes an active research topic for vehicle safety. Driving in clear weather conditions with sufficient visibility does not usually pose any danger; however, with poor or no visibility due to bad weathers, it becomes dangerous. Therefore, safety precaution measures should be harnessed in vehicles. As an efficient V2V communication, dedicated short range communications (DSRC) based on radio frequency (RF) technology was proposed [6]. RF based DSRC entails a complex structure with special requirements. Thus, this technique is not yet widely implemented in the market [6]. A laser diode (LD) can also be considered as an alternative to the LED based V2V communication, since laser beam is coherent and provides more power efficiency over a long distance compared to LED. However, LD has a narrow field of view (FOV) which makes it restricted to a vehicle positioned in a straight line, thereby rendering it impractical for the V2V communication. Moreover, LD poses risks to human eyes and skin [7]. LD is also relatively expensive compared to LED and cannot provide illumination [8].

Takai et al. considered a LED based V2V [9]. The work focuses on utilizing a camera to capture the data from LEDs at both daytime and night-time in clear weather. This camera based method has an advantage over a photodiode based method by providing a wider area of detection since it uses a wider sensor. However, the camera based method has several drawbacks, such as high cost, high power consumption and low processing speed. On the contrary, the photodiode based method offers low cost, low power consumption and higher processing speed compared to the camera method [5]. It is customary that the photodiode method uses intensity modulation and direct detection (IM/DD) technique for communication. That is, the brightness of LED is varied at the transmitter and this variation in brightness level is measured at the photodiode of the receiving end, where the photodiode converts the received light intensity into corresponding voltage. The IM/DD method is frequently used in VLC because of simple structure and easiness for implementation.

Unfortunately, the practical implementation of the V2V communication on the road using the intensity based detection method fails to produce reliable data detection due to the presence of atmospheric turbulence such as sun light, fog and rain [10]. To address this issue, the authors have proposed various techniques. Filtering technique and special receiver structure to reduce the effect of sunlight could be employed [5, 10]. However, none of these techniques have yet addressed the resistance and adverse effect from rain. Therefore, an LED based V2V in the rain needs to be reported in the literature.

In this study, the effect of rain on the VLC channel is experimented and an efficient detection technique with a modified fixed decision threshold (MFDT) is applied for outdoor VLC applications. The results show that the proposed V2V communication using MFDT under the rainy condition is accurate and reliable.

In Section II, the VLC experiment with noise due to rain is described. Then, both the experimental results and analysis of the proposed system is explained in Section III. Conclusion is drawn in Section IV.

II. VLC Experiment

The V2V communication plays an important role in enhancing vehicle safety when meteorological conditions are bad. Among many weather conditions, we focus on the effect of rain interference. Fig. 1 shows the concept of the LED based V2V. A car in front will send data using a red LED from the taillight to a following car equipped with photodiodes under rain interference.

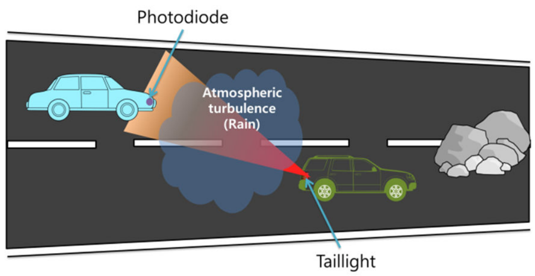

Figure 1. Proposed System

A. *Effect of Noise due to Rain*

In order to evaluate the effect of noise from the rain, a chamber which facilitates rain effect was developed. The experiment was conducted to measure the effect with and without rain in a controlled laboratory chamber environment.

Fig. 2 shows the comparison between the transmitted data and the received data. It can be observed that the transmitted data is received accurately without any errors with the fixed decision threshold employed at a photodiode value of 50. Further experiments were carried out under the effect of rain. Fig. 3 shows the experimental results. Due to the rain, it is observed that the intensity is decreased. In addition, it can be seen that some spurious peaks occur as marked 'A', 'B' and 'C.' This is due to the fact that when light passes through a boundary between two different isotropic media, i.e., air and water drops, its direction will change according to Snell's law [11].

A further investigation was conducted on the occurrence of the peaks. We transmitted 2,000 bits and measured the intensity from the photodiode. After the signal is received, the threshold is determine and the data is thus detected by observing the received signal as a whole. Also we measured the probability of having the marks 'A','B' and 'C.' The probabilities of 'A', 'B' and 'C' were found to be 0.85%, 0.25% and 0.65%, respectively. It is worth noting that the most problematic peak is 'A,' causing detection errors since it occurs relatively frequently and approaches the threshold limit. This is attributed to the use of fixed decision threshold (FDT), even though the transmitted data was '1,' the received intensities were considered low, which means that the data were detected incorrectly.

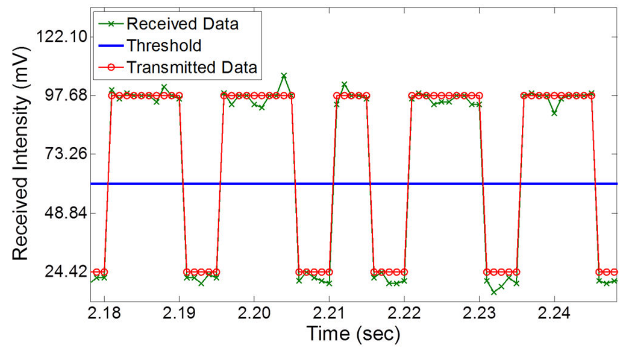

Figure 2. Transmitted and measured data with no rain

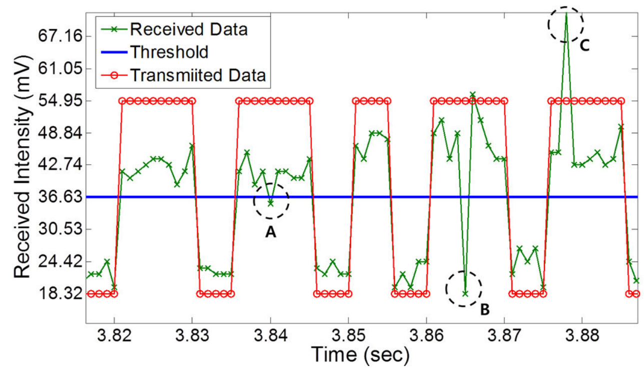

Figure 3. Transmitted and measured data with rain

This problem could be alleviated by increasing the sampling rate. It can be shown, however, that the increase in the sampling rate would require more MCU performance, higher power consumption and higher cost. The proposed MFDT adjusts the threshold limit based on the attenuation caused by the rain, thereby providing the improved BER performance.

B. *Experimental Setup*

Fig. 4 shows the experimental setup for the evaluation in rain condition test. The chamber was equipped with water pump, pipe and shower head for generating heavy rain condition. Both the transmitter and the receiver unit were installed to each side of the chamber. By using the chamber, the effect of rain was evaluated without any external light interference.

The transmitter unit is composed of a Micro Controller Unit (MCU) and one red LED (1W). STM32F4-Discovery is used as the MCU for generating the signal. The distance between LED and PD is considered based on a general LED taillight (3W power). However, a 1W red LED is employed in this scale-down experiment.

The receiver unit consists of an MCU and a photodiode. TSL252R photodiode, which is designed specifically for red visible light wavelength (630nm), is used to detect light. The photodiode is connected to the MCU and then the sensor value is calculated by using 12 bits analog digital converter (ADC). After measuring light intensity with MCU and PD, the results are sent to the computer through a serial communication. Therefore, the intensity can be computed by using Eq. (1)

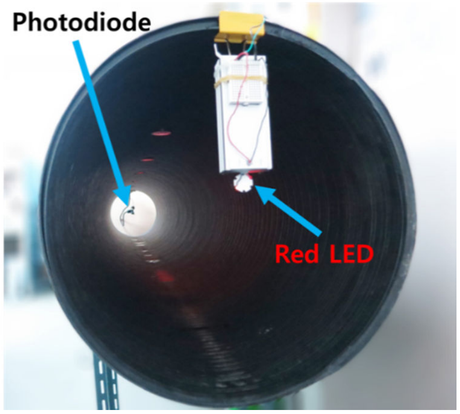

Figure 4. Experimental setup

$$\text{Output (V)} = Photodiode\ Value \times \frac{5\ (\text{V})}{4095} \quad (1)$$

III. Result and Analysis

A total of 20,000 bits were transmitted and then both bit error rate (BER) and signal to noise ratio (SNR) were measured in both weather conditions, i.e. with and without rain. After acquiring the data, the proposed technique with MFDT was applied. Table 1 shows the results. The MFDT based proposed technique is found to be superior.

TABLE I. Experiment Results

	Without rain	With rain (FDT)	With rain (MFDT)
SNR (dB)	11.2582	4.4925	4.4925
BER	0	0.2095	0.0068

As described in Table 1, it was observed that when rain is added to the VLC channel, SNR values were decreased by approximately 60%, compared with the SNR value for no rain condition. Similarly, BER was increased to approximately 0.21 with the FDT employed. It is evident that the proposed V2V with MFDT produces a significant gain in terms of SNR and BER. It should be noted that MFDT is set to an intensity value lower than FDT by approximately 23%. In order to validate the effect of this modified decision threshold, the BER values were obtained across various possible threshold values as shown in Fig. 5. It can be found that when the threshold is reduced by approximately 23% from the standard FDT value (30), i.e. the present MFDT, the system yields the best BER performance.

IV. Conclusions

The V2V communication method using VLC is presented in the rainy condition with MFDT. The results show that the proposed MFDT yields a significant BER performance gain for the V2V system. The present experiment can be further conducted outdoors to verify the proposed MFDT for V2V. Nonetheless, the proposed method exhibits its potential as a means to counter rainy conditions in V2V and thus would be useful in delivering an efficient future V2V system outdoors.

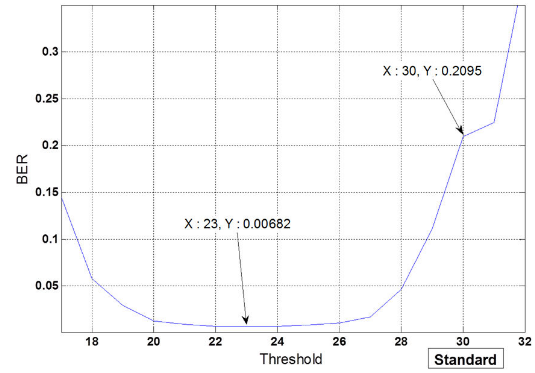

Figure 5. BER graph according to changing theshold

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