An Experimental Study on Ground-to-UAV Communications

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Abstract

Optical wireless communication (OWC) technologies are gaining significant research interest due to their ability to cater to the demand for high bandwidth and provide simple, low-cost, secure, and flexible solutions for next-generation wireless communications. Recently, unmanned aerial vehicle (UAVs), commonly known as drones, has been the subject of concerted research, and have attracted significant interest in rapid deployment for both military and civil applications. In this paper, we analyze experimentally, the ground-to-UAV optical communication link. An experiment test-bed using a varying pulse width laser and photodiode is constructed to characterize the propagation channel. In particular, we investigate the path loss, bit error rate, and semi-angle at half-power. The results provide insight into the ground-to-UAV propagation channel characteristics.

Keywords: On-off keying, optical wireless communication, pulse width modulation, unmanned aerial vehicle

1. Introduction

The proliferation of wireless communications stands out as one of the most important phenomena in the history of communication engineering. Radio-frequency (RF) enabled wireless communication technologies have been facing the continuously increasing demand for high data transmission capacity [1]. Therefore, researchers have been focusing on sixth-generation (6G) communication technologies that are expected to be deployed in near future. However, the RF band of the electromagnetic spectrum is fundamentally costly since most sub-bands are exclusively licensed. Unlike RF carriers where spectrum usage is restricted, the optical carrier frequency does not require any spectrum licensing [2]. OWC is a technology that uses an optical signal to transfer data from one point to another through an unguided channel. OWC is considered the next frontier for high-speed broadband connection as it offers extremely high data transmission, ease of deployment, low power consumption, reduced size, and lower implementation cost. OWC uses either lasers or light-emitting diodes (LEDs) as transmitters and photodiodes or photon multiplier tubes (PMT) as receivers [3].

Unmanned aerial vehicles (UAVs), commonly known as drones, have seen dramatic development in wireless communication applications. UAVs have been the subject of concerted research recently owing to their flexibility, autonomy, and broad range of application domains. In particular, UAVs can provide cost-effective and reliable wireless communication solutions to a large number of real-world communication problems [3]. In particular, UAV-enabled communications have several distinctive features. They can be a viable solution to a wireless recovery network in case of outrage and terrestrial disruption [4].

To analyze the benefits of UAV deployment for OWC communications, one important aspect is to analyze the propagation channel accurately [5]. Another important factor is to analyze the beam width on the performance. Motivated by this, in this paper, we conducted an experimental campaign and investigate the path loss, bit error rate, and semi-angle at half-power for the ground-to-UAV optical communication link. The received power as a function of the transmission distance is also analyzed. Moreover, we analyze the impact of the pulse width on the link performance.

The rest of the paper is organized as follows. Section 2 presents the experimental campaign. Results and discussions are provided in Section 3. Finally, the conclusions are drawn in Section 4.

2. Experiment system

The transmitter section is depicted in Fig. 1. To regulate the current flowing through the transmitting circuit, we applied a voltage to the current driver DS10 using a 6V battery. The constant current generated by the current driver operates the IR LED M940D2. We utilize the IR LED with a large beam divergence angle and Fresnel lens. In Fig. 2, we illustrate the complete transmission setup with Arduino, connected to a laptop, employed to generate modulated pulses.

Figure 3 depicts the receiver section. The signal received at the receiver is condensed into a Fresnel lens. Only the light of the wavelength between 940nm and 960nm is filtered using the IR filter FBH940-10. The signal is converted into an electrical signal through the photodiode FDS 10X10. It is worth mentioning that the optical signal cannot be processed directly to analyze the performance metrics and hence converted into an electrical signal. It is then amplified with an amplification factor of 100 by utilizing an op-amp using ua741. To perform this amplification a 3V DC power supply is utilized. Arduino and nRF24l01P+PA+LAN modules are used to wirelessly communicate the signal amplified by the op-amp. Arduino and nRF24l01P+PA+LAN modules are connected to the Laptop to analyze the results.

To analyze the performance of a ground-to-UAV link, a series of experiments were conducted. The experiments were

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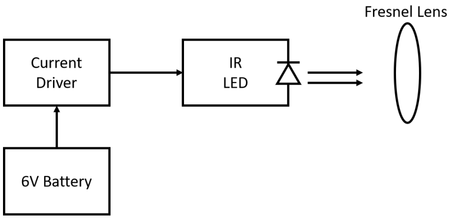

Figure 1. Transmitter side.

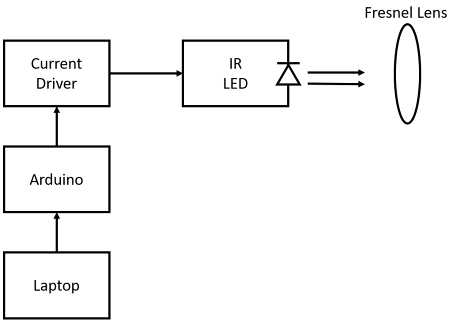

Figure 2. Transmitter side with modulation.

conducted inside the corridor of the building to block the interfering light from the outside. Moreover, to improve the performance further, we employed an IR filter. The experiments were conducted around 10 PM in October 2022.

Due to the hovering of the UAVs, utilization of the laser diode may result in a pointing error. Therefore, we considered an LED for transmission, as it offers a wider beam divergence. However, it is worth mentioning that the output power of the LED is very low. We observed that the LED's power dropped sharply as we increased the distance. However, this limitation can be overcome by employing a Fresnel lens and op-amp composed of ua741.

The equation for obtaining the power shown in the PD spec sheet is shown in Eq.1. The maximum power sent by the LED was measured and the result was found to be 2.25 mW. In Equation (1), P represent power, V is PD's output voltage, R is responsivity, and R_L is the load resister.

$$P = \frac{V}{R \times R_L} \tag{1}$$

We conducted three experiments. In the first experiment, power was measured at intervals of 10 m to analyze the received power as a function of the baseline distance. In the second experiment, the received power was measured by changing the pulse width and distance to check the BER. In the third experiment, we measured an angle that was half the power to

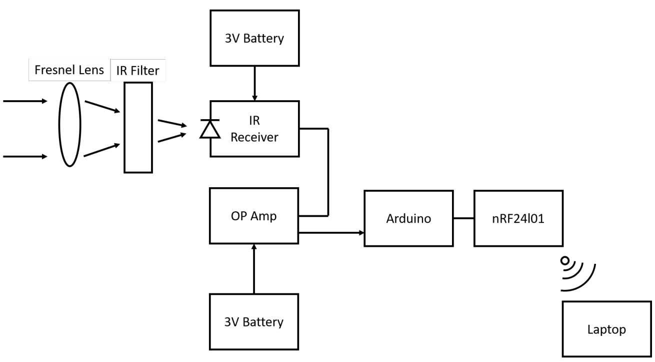

Figure 3. Receiver side.

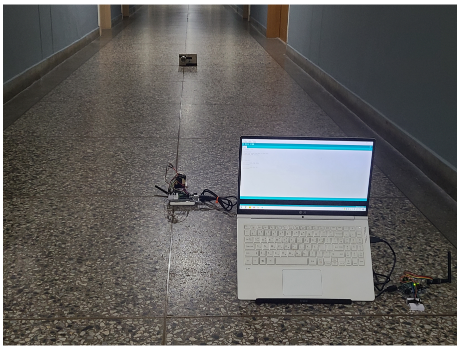

Figure 4. Experiment to measured the received power.

find a reliable angle range.

2.1. Measurement of power by distance

Data were collected at regular intervals at distances of 10 m and 30 m for remote communication. It is worth mentioning that, for a distance below 10 m, it was difficult to distinguish the data, whereas it was difficult to collect precise data when the baseline distance was set to more than 30 m. Therefore, the measurements were conducted for distances of 10 m, 20 m, and 30 m.

IR LED and PD were placed in a line of sight as shown in the figure. The received signal and its corresponding value were measured through nRF24l01 connected to Arduino. It is to be noted that, when the received value was 0 m, the measured signal was divided by the voltage value measured by the multimeter to obtain the proportional coefficient. The output voltage of the photodiode is obtained by this proportional coefficient, and reception power was calculated by utilizing Eq. (1).

At a baseline distance of 0 m, the reception value was 530 and the multimeter value was 2 V. Assuming a linear relationship, the proportional coefficient was calculated as 260. The power received was measured as 2.25 mW.

As a result of measuring the minimum transmission power, all analog signals at all distances were measured to be zero. The maximum transmission output result was 525, 527 at 20 m, and 255 at 30 m, respectively, and when converted into power, it was 2.25 mW, 2.25 mW, and 1.12 mW. Path loss of the measured power is obtained by

$$L = 10log_{10}\frac{P_r}{P_t}, \tag{2}$$

where L denotes the pathloss, P_r is received power, P_t is transmission power.

2.2. Power measurement according to pulse width

Using Pulse Width Modulation, We checked the degree of signal reception according to the pulse width. The board rate of Arduino was set to 9600, and the IR LED was pulse modulated with Arduino and transmitted at a distance of 10 m, 20 m, and 30 m.

We determined the threshold of the signal based on the intermediate value between the average value of both the HIGH signal and the LOW signal. Also, the power of the transmitted pulse signal was measured at an interval of 0.1 seconds, and BER was measured based on this.

2.3. Adjusting semi-angle at half power

When the signal was transmitted at a distance of 0.5 m between the IR LED and the PD, the angle when the maximum value of the transmission signal reaches half was measured. From the experimental findings, we found that half the maximum value was 1.03 mW at 30.96 degrees.

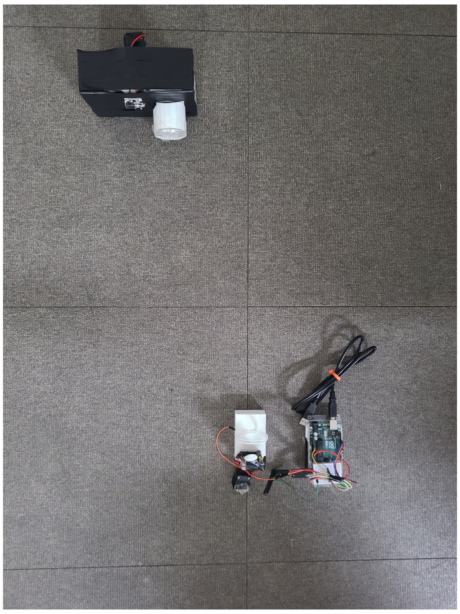

Figure 5. Experimental setup for the measurement of semi-angle.

3. Results and Discussions

Fig. 6 depicts the amplified power relative to the baseline distance for the LOS link configuration. It is to be noted that, the performance is found to be satisfactory up to the distance of 20 m. However, it was found that a value reduces to half when measured at 30 m.

The received power (mW) as a function of the baselined distance (m) is depicted in Fig. 7. For analysis, we consider three different cases with PW set to 0.1, 0.5, and 1. Interestingly, it can be seen that, for PW set to 0.1, the received signal power measured was highest.

The BER relative to the baseline distance is illustrated in Fig. 8. We like to point out that, the smaller the value of PW, the smaller the BER.

According to the theory, the maximum amplification value should be 3V, but in the actual experiment, the measurement range was limited to about 2.1V. Therefore, it is determined that it affects the received power and path loss and BER accordingly at short distances.

The semi-angle was measured at about 30.96 degrees, and after that, the transmission power decreased significantly each time the angle was increased. From the experimental results, an important observation can be inferred that in the ground-to-UAV communication link, the performance can be reliable even if the drone is tilted to about 30 degrees.

When we set the value of pulse width to 1 s, at 10 m, an average high value of about 0.892 mW was measured, and BER was measured to be 0.075. In addition, the path loss is -4.018 dB. At 20 m, an average HIGH value of about 0.189 mW was measured, and BER was measured to be 0.07. Also, the path loss is -10.757 dB at 30 m, an average HIGH value

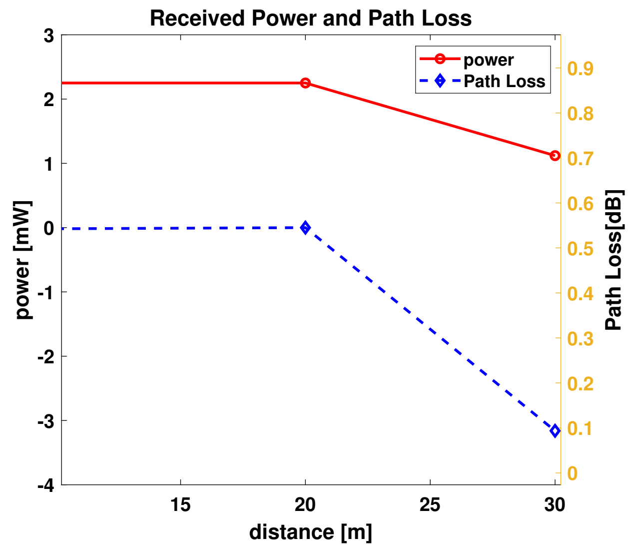

Figure 6. Amplified power and pathloss as a function of the baseline distance.

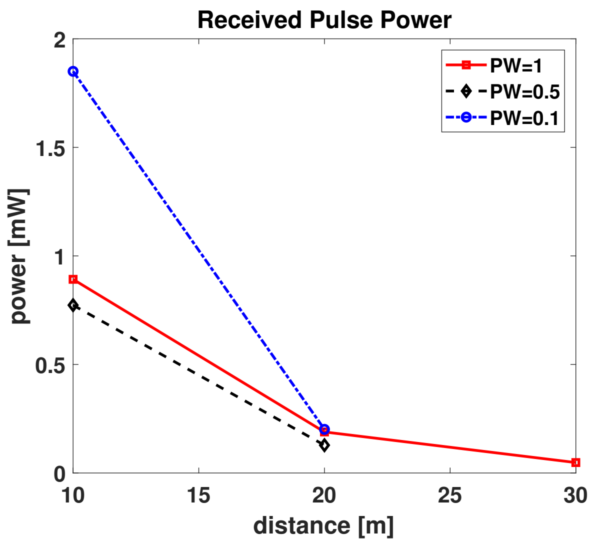

Figure 7. Power relative to the baseline distance for different values of PW.

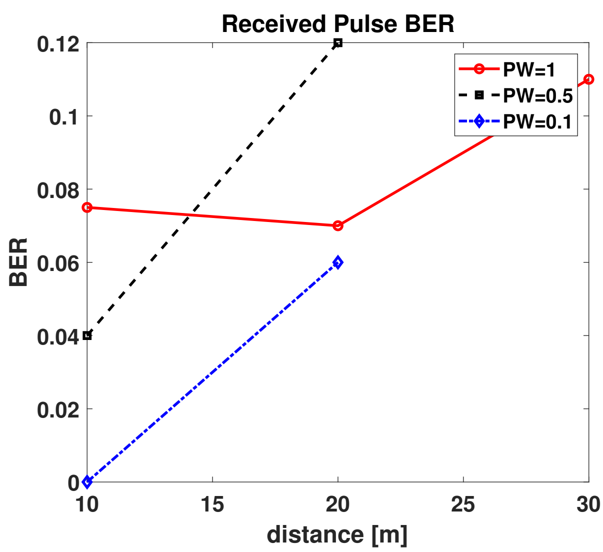

Figure 8. BER relative to the baseline distance.

of about 0.048 mW was measured, and BER was measured to be 0.11. Also, the path loss is -16.709 dB

When we set the value of pulse width to 0.5 s, at 10 m, an average HIGH value of about 0.773 mW was measured, and BER was measured to be 0.040. Also, the path loss is -4.64 dB. At 20 m, an average HIGH value of about 0.128 mW was measured, and BER was measured to be 0.12. Also, the path loss is -12.45 dB. It was impossible to measure at 30 m.

When we set the value of pulse width to 0.1 s, at 10 m, an average HIGH value of about 1.85 mW was measured, and BER was measured to be 0. Also, the path loss is -0.85 dB. At 20 m, an average HIGH value of about 0.201 mW was measured, and BER was measured to be 0.06. Also, the path loss is -10.49 dB. It is to be noted that, at a baseline distance of 30 m, the received power ceased to measure.

4. Conclusions

In this paper, we have reported a recent data collection experiment, in which a variety of link performance measurements were conducted to characterize the ground-to-UAV optical communication link. We have analyzed the link with IR LED employed as a transmitter and a photodiode as the receiver. In particular, we have analyzed the link performance in terms of BER. In addition, we have studied the impact of pulse width on communication performance. The following important observations have been inferred from the experimental outcomes. Importantly, it was found that the higher the PW, the higher will be the BER. The results demonstrate the current advancement in optical UAV communication and provide insight into establishing robust ground-to-UAV communication links.

Acknowledgments

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