Research on Receiving Visible Light Signal with Mobile Phone

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Abstract. In this paper, based on ambient light sensor and camera sensor, two different receiving methods of visible light signal are experimentally studied. For ambient light sensor, its response time and light intensity are analyzed. The results show that it is available to transmit data with 0.2 kbps data rate over 2 m. For camera sensor, the relationship and difference between original data and corresponding image are studied for the first time. Besides, a series of methods are used to process the original data instead of the image, including data adjustment, histogram equalization and polynomial fitting. Using camera sensor, 2 kbps data rate over 0.3 m transmission with real-time processing of data in mobile phone is achieved even if the stripes are not clear enough, which is faster and more robust. The research is beneficial for practical application of visible light communication (VLC).

Keywords: Visible light communication (VLC) · Light sensor · Camera sensor · Signal receiving

1 Introduction

Traditional wireless communication has encountered bottleneck because the spectrum resources are exhausted gradually. The visible light has unregulated spectrum to exploit, which has gained increasing attention [1]. And the development of light emitting diode (LED) technology provides a basis for using the visible light to transmit information [2]. Visible light communication (VLC) is different from the traditional wireless communication and optical fiber communication, it's a kind of new communication technology. It uses LED as transmitter and utilizes the continuous changes in state (on-off) of the light to transmit information. VLC combines lighting with communication together, and it is considered as part of 5G system. However, there are still lots of problems to be solved for practical application, and the signal receiving technology is the key point.

In recent years, smart phone becomes increasing popular and it contains many sensors which can detect the visible light. From the report of Internet

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Data Center (IDC), the shipments of smart phones in the whole year of 2015 reach 1.4329 billion [10]. Therefore it is significant of utilizing the exiting mobile phone resources in VLC system. The rolling shutter effect of camera sensor can be used for receiving the visible light signal [3–9]. However, the problem of blooming effect will affect the decoding of signal seriously. The literatures [3,4] capture the image from a reflected surface to mitigate blooming effect, which wastes lots of energy. The literatures [6–9] process the gray image and solve the blooming problem with the method of digital image processing to a certain extent.

In this paper, we study two different receiving methods of visible light signal using ambient light sensor and camera sensor in mobile phone. The experiments are conducted indoor with sunlight and lamplight, the transmitter is a LED whose output power is 9.8 W, and the receiver is a Samsung Galaxy Nexus mobile phone. For ambient light sensor, its response time and light intensity are analyzed. The minimal response time is about 5 ms and the illumination can still be easily distinguished when the distance is 2 m. The results show that it is available to transmit data with 0.2 kbps data rate over 2 m. This method is simple and it utilizes the existing device in mobile phone instead of additional hardware, which can reduce the cost and be used in low rate demand condition. For camera sensor, the relationship between the original data and corresponding image is studied. In particular, the way of data-represented gray level in mobile phone is different from that in common situation, therefore it is necessary to adjust the data before further processing. The principle of data adjustment is adding 256 to the negative value and remaining the positive value. Moreover, the data matrix of original data is compared to the data matrix of corresponding image in MATLAB, the result shows that the original data is different from the image. The literatures [6–9] process the image to decode the signal, which may loss some information. To solve this problem, processing the original data instead of the image is proposed, which can be more accurate. After adjusting the data, histogram equalization is used to increase the difference between light and dark stripes, and polynomial fitting is used to make decision on the data. We process as much data as possible to avoid random error. After data processing mentioned above, the information sent by LED can be recovered successfully even if the light and dark stripes are not clear enough. Using camera sensor, 2 kbps data rate over 0.3 m transmission with real-time processing of data in the mobile phone is achieved, which is faster and more robust.

2 Principle

2.1 Ambient Light Sensor

The visible light is part of the electromagnetic wave, and its wavelength is from 380 nm to 780 nm. For the receiver, the illumination is often used to represent the strength of the received light signal, and it's measurement unit is lx.

The ambient light sensor is assembled in mobile phone, and it's a hardware device which can detect the visible light signal. The light sensor is a photodiode, and it can get the value of illumination when the intensity of ambient illumination changes. The light sensor records the data in the perspective of one dimensional. For this reason, it can be used to receive and decode the visible light signal. The illumination of ambient light changes all the time due to the ambient light noise, however, the noise can be ignored when compared to the signal.

2.2 Camera Sensor

The camera sensor is an array of photodiodes, and it is the most important hardware device to detect light signal in mobile phone. We utilize the rolling shutter effect of camera sensor to detect the visible light signal. The detail of rolling shutter effect is in [3–5]. Figure 1 shows the procedure of taking photo with camera, both the data and the image can be got in our program. The relationship and difference between data and image are studied in detail later.

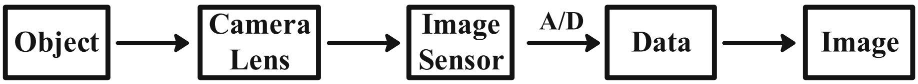

Fig. 1. Procedure of taking photo with camera: the data is YUV format and the image is JPEG format.

3 Experiment, Results, and Discussion

Figures 2 and 3 show our system block diagram and experiment setup respectively. In transmitter (Tx), we use FPGA to generate a certain binary sequence for cycle and drive the LED array light through the LED driver. In receiver (Rx), the light sensor or camera sensor detect the visible light signal, then we process the data and display the results in mobile phone. Because the android system is open source, we do the experiment with a Samsung Galaxy Nexus mobile phone, whose version of android is 4.0.

3.1 Ambient Light Sensor

When the ambient illumination intensity changes, our program can save the intensity of illumination and the time it happens. The sensitivity of ambient light sensor in android has four levels, as shown in Table 1.

We choose the fastest level and conduct the experiment under different conditions. The experiment conditions are shown in Table 2. The data with different rates is analyzed and the result shows that the minimal time interval is about 5 ms, which means the highest sensitivity of light sensor can detect the signal

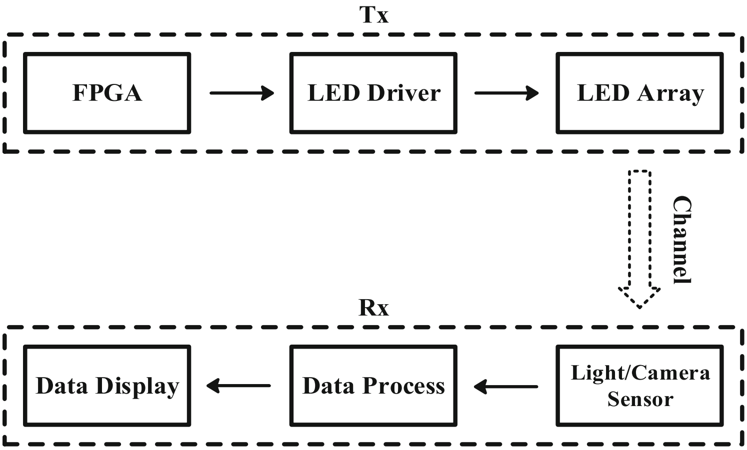

Fig. 2. System block diagram: the upper part shows the Tx (which includes a FPGA, an LED driver and an LED array) and the lower part shows the Rx (mobile phone).

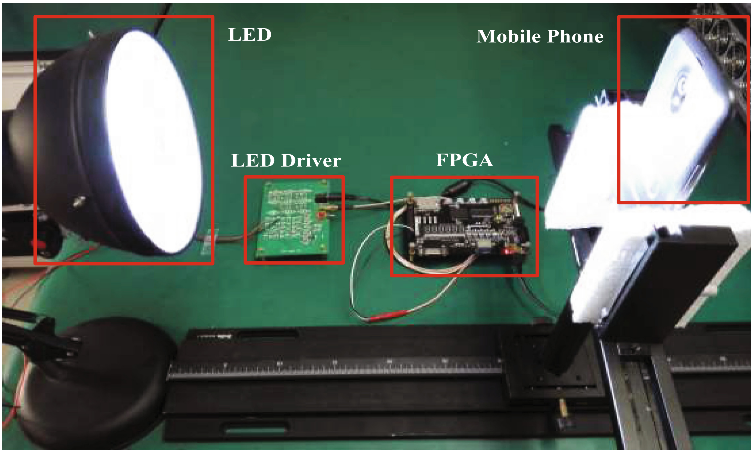

Fig. 3. Experiment setup

Table 1. Sensitivity of ambient light sensor

Sensitivity level	Time delay (μs)
Sensor delay fastest	0
Sensor delay game	20,000
Sensor delay UI	60,000
Sensor delay normal	200,000

Table 2. Experiment condition

Data sent	Binary number
Modulation format	OOK
Frequency (Hz)	0–100
Distance (m)	0–2

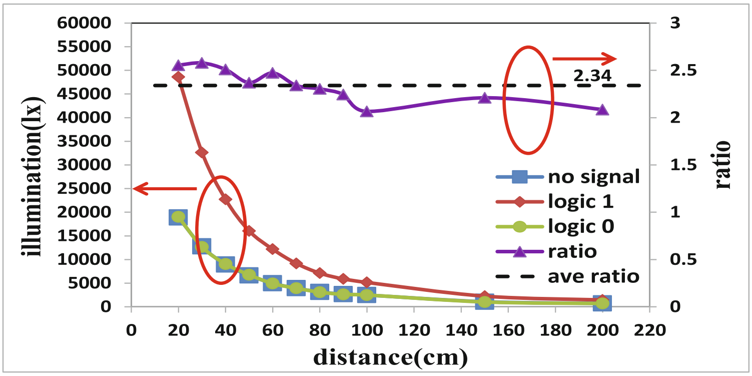

Fig. 4. Illumination with distance: the blue line (continuous) indicates no signal, the red line (continuous) indicates signal logic 1, the green line (continuous) indicates signal logic 0, the purple line (continuous) indicates the ratio of logic 1 and logic 0, the black line (dashed) is the average of the ratio. (Color figure online)

with the rate of 0.2 kbps. Then we choose 100 Hz as an example for further analysis, and the results of illumination (average value) with different distance are shown in Fig. 4.

It particular, the data without signal is the same as the data with signal logic 0 for OOK signal. The blue line coincides with the green line in Fig. 4, which is consistent with the theory. As the distance increases, the illumination decreases accordingly, but the strength of logic 1 signal is always about twice than that of logic 0 signal. Figure 5 shows an example of the illumination data when the distance is 2 m, and the data can be easily distinguished by the threshold. In the example the average of illumination is regarded as the threshold.

3.2 Camera Sensor

Both the data and corresponding image shown in Fig. 1 can be got from our program, then we compare them to find a better source for processing. The relationship between the data and corresponding image is experimented. In our android program some special data is set and corresponding image is generated to verify the relationship between data and image. Figure 6 shows the result of experiment.

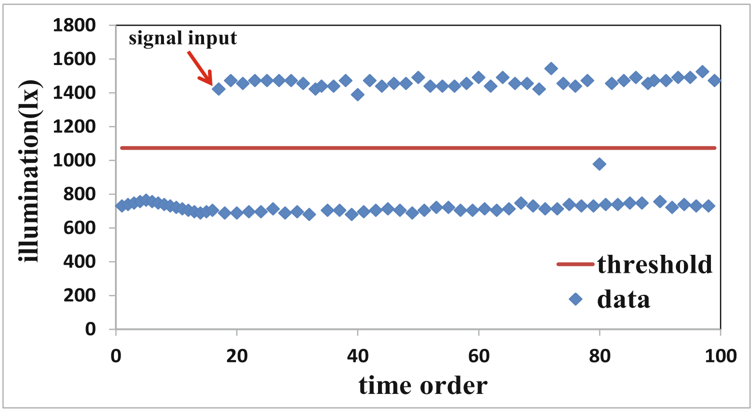

Fig. 5. Illumination of 2 m: the blue spot indicates the illumination and the red line (continuous) indicates the threshold. (Color figure online)

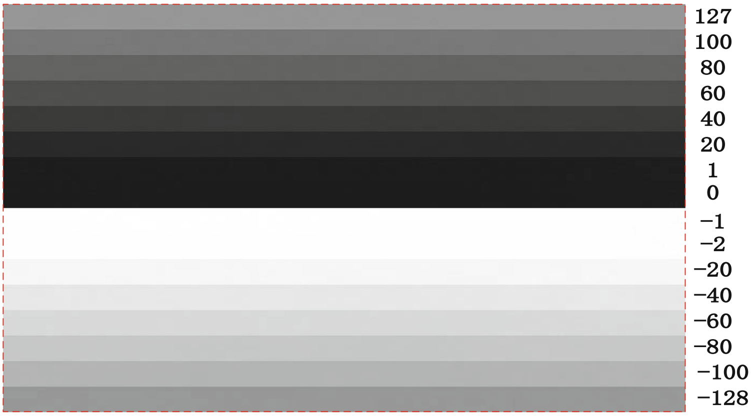

Fig. 6. Relationship between image and data: the gray level of image (left) corresponds to the number (right).

The image is generated according to special data, and the range of byte data is from −128 to 127. Through the experiment we know that in the camera built-in mobile phone the number 0 represents black. When number changes from 0 to 127 the gray level of image changes from black to gray, which is the same as the common method of data representation. In particular, the number −1 represents white. When number changes from −1 to −128 the gray level of image changes from white to gray, which is different from that in common.

Because the way of data-represented gray level in mobile phone is different from that in common situation, it is necessary to adjust the data before further processing. The principle of data adjustment is adding 256 to the negative value and remaining the positive value. After adjusting, the number 0 and 255 represent black and white respectively, and the rest number represent different gray level.

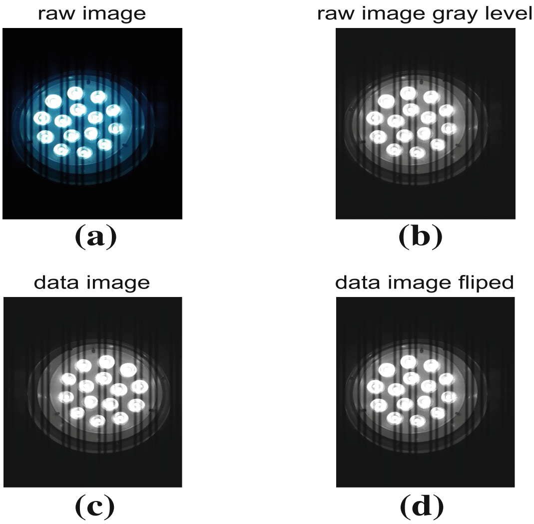

Fig. 7. Data and corresponding image: (a) is the raw image captured by camera, (b) is the gray level of (a), (c) is the image generated in MATLAB with the original data and (d) is the horizonal flipped image of (c).

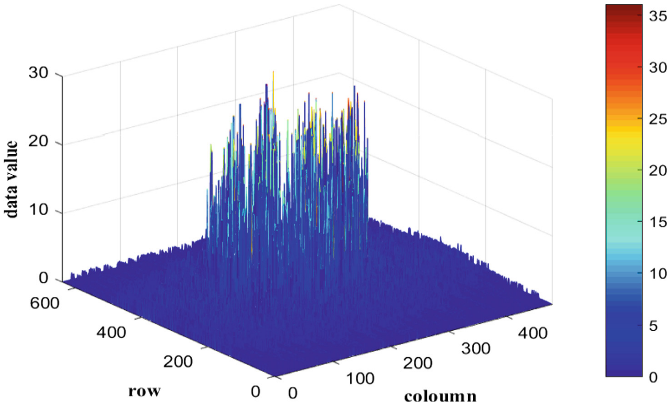

Fig. 8. Difference of data and image: the result of (d)–(b) in Fig. 7

After figuring out the relationship between the data and corresponding image, the data is compared to the image to study the difference between them. We display the data and corresponding image with MATLAB and the result in Fig. 7 shows that the image (b) is the same as the image (d). Then we subtract the data matrix of (b) from the data matrix of (d) and the difference is shown in Fig. 8. It is obvious that most of the data in Fig. 8 is not equal to 0, which means the data is different from the corresponding image. Considering the data is more original than the image, we select the data instead of the image for further processing.

The data captured by camera (in Fig. 9) is not as uniform as the data captured by light sensor (in Fig. 5) due to dimensional factor. The position of LED relative to the mobile phone will affect the value of light and dark stripes. The value of data close to the LED is larger than that far away, which even leads to the value of logic 1 is smaller than that of logic 0. Therefore it is necessary to use polynomial fitting.

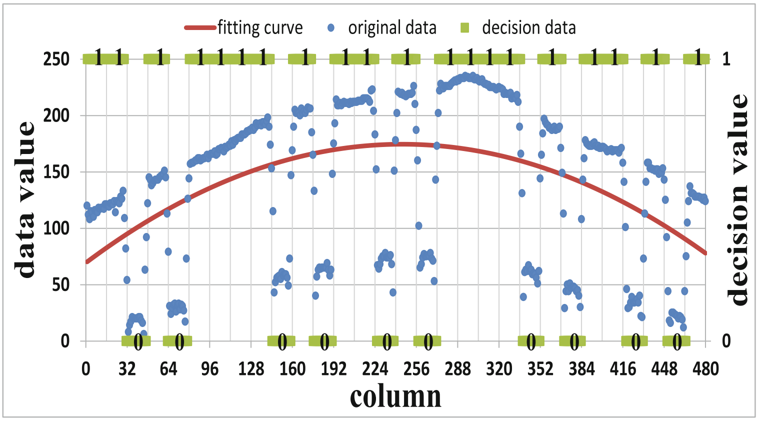

Fig. 9. Polynomial fitting for data decision: the blue spot is the original data, the red curve is the fitting curve, the green spot is the value of decision and the binary number is the data sent by LED. (Color figure online)

Figure 9 shows the approach of data processing, and it is an example for a row of data. We regard the fitting polynomial curve of the original data as the threshold and get the decision data by comparing the original data to fitting curve. Obviously, the data received is same as the data sent.

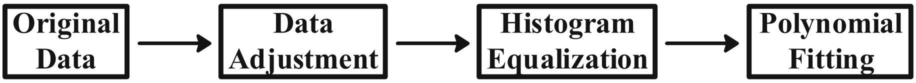

Fig. 10. Procedure of original data processing

Figure 10 shows the procedure of original data processing. We process the data as much as possible to avoid random error. For the data matrix we get, its size is 640 * 480. It is processed as the example does, then 640 rows of decision data can be got totally. All the 640 rows of data are added together according to column. The number is regarded as logic 1 if it is bigger than 320, otherwise regarded as logic 0. We get the final decision value and recover the data sent by LED. All data processing is done in mobile phone with our android program, and Fig. 11 shows different android program interface.

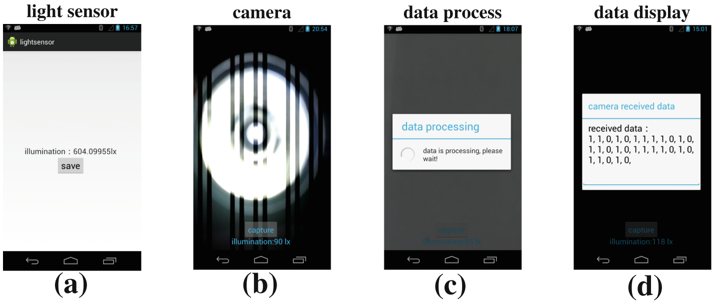

Fig. 11. Android program interface: (a) is for light sensor, (b) is for camera, (c) is for data processing and (d) is for data display.

4 Conclusion

Two different receiving methods of visible light signal based on ambient light sensor and camera sensor in mobile phone are experimentally studied in detail in this paper. The experiments are conducted indoor with sunlight and lamplight, the transmitter is a LED whose output power is 9.8 W, and the receiver is a Samsung Galaxy Nexus mobile phone. For ambient light sensor, its response time and light intensity are analyzed. The results show that it is available to transmit data with 0.2 kbps data rate over 2 m. This scheme can be used in low rate demand condition, such as sending the mark of LED beacons for indoor location system, sending the password to access the wireless network and so on. For the camera sensor, the relationship and difference between data and image are studied, and we propose processing the original data instead of the image to avoid loss of information. After data adjustment, histogram equalization and polynomial fitting, the information sent by LED can be recovered successfully even if the light and dark stripes are not clear enough. Using camera sensor, 2 kbps data rate over 0.3 m transmission with the real-time processing of data in mobile phone is achieved, which is significant for practical application of VLC.

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