High-throughput visible image transmission design based on the X-CT root 3D reconstruction system

Xin Guan[1], Jinpeng Wang[1,*], Yang Zhou[1], Teng Zhang[1], Kemo Jin[2,*], and Nianyu Zou[1]

[1] Information Science and Engineering College,
Dalian Polytechnic University, Dalian 116034, China
wangjp@dlpu.edu.cn

[2] Key Laboratory of Plant-Soil Interactions, Ministry of Education, China Agricultural University, Beijing 100193, China
kemo.jin@cau.edu.cn

Abstract. X-ray computed tomography (X-CT) technology can help us observe plants' root structure in a three-dimensional, non-destructive manner under underground soil conditions. Between the CT imaging terminal and the post-image 3D reconstruction processing terminal, there is a massive amount of image data for transmission, and the process requires a lot of transmission time, which is challenging to meet the characteristics of large-scale and high-throughput research. Today's medical transmission bus Technology does not meet the low cost and high convenience of future plant phenotype research. For large-scale population genetic analysis after the three-dimensional phenotype of plant roots, such as quantitative trait locus mapping (QTL) research, it is necessary to have high the technology of flux image data transmission is added based on the three-dimensional analysis of the root system. In this paper, under the conditions of underground soil, a high-throughput visual light image transmission system for X-CT plant root CT scanning imager is proposed. It uses the characteristics of fast data transmission speed and large throughput of visible light, and image transmission can be useful. Reduce the time of image data transmission between the upper imaging terminal and the lower image processing terminal and reduce the later 3D reconstruction research time cost.

Keywords: X-CT, visible light communication, image transmission.

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1 Introduction

To further keep pace with global environmental change and world population growth, crop yields need to increase dramatically. Based on modern agricultural technology, real-time monitoring, and improvement of plant root structure changes are expected to improve water and nutrient absorption and utilization efficiency. In this regard, some researchers have proposed the second green revolution and put more plant phenotypic research into improving plants go to the underground root structure [1]. Due to the invisibility and spatial complexity of plant roots under the condition of underground soil, it is a challenge to observe and process high-throughput in-situ soil root images. With the development of the medical imaging field, it is possible to non-invasively study the three-dimensional phenotypic structure of the root system in the soil. X-CT technology and MRI technology gradually used to study the hidden parts of plants [2]. For X-CT technology, it has great potential in the three-dimensional analysis of plant root phenotype. Compared with MRI, the equipment cost of a non-medical CT scanner will be lower [3]. The medical CT image is a two-dimensional image sequence of the target obtained through the imaging terminal, and a three-dimensional model obtained through the calculation of the lower computer and depicted with a specific software [4]. In recent years, by continuously adapting and optimizing the imaging terminal, medical CT has reduced the scanning time compared with the past. Using higher voltage and current in a specific X-CT scanner, the contrast between plant roots and soil has increased, making Later, better results obtained in root-soil segmentation [5]. For CT image segmentation or reconstruction at the processing end [6], it is necessary to collect a large amount of data from the host computer and complete, precise algorithm calculations.

At the beginning of the 21st century, with the rapid development of computer information technology, wireless networks are gradually used in the modern society. Communication-based on wireless visible light technology can bring higher frequency band bandwidth to the system, but for low-frequency systems, the signal attenuation is not obvious [7]. As the devices in the integrated photodetector manufacturing industry become cheaper, the high-speed, low-cost, short-distance, and highly flexible white LED visible light communication system has aroused scholars' in-depth research. Since 2013, China has included visible light communication technology in the 863 project plan, which has promoted the progress of visible-light wireless communication technology, so that white light LEDs are now widely used in lighting, display, signal emission, and other fields. Visible light communication systems have high application prospects in high-speed communication, smart transportation, indoor positioning, and other fields [8]. Thanks to the high bandwidth and fast transmission rate of white light LED visible light communication, the system can realize some communication application scenarios that meet high throughput.

During this period, the image data transmission needs to consider the conditions of accuracy and high throughput. In recent years, scholars have optimized wireless communication algorithms, continuously optimized the signal-to-noise ratio, and expanded the application field of wireless communication [9-11]. For the data exchange between a specific plant root CT scanner and the lower processing end, the commonly used medical PCI-E bus communication protocol cannot satisfy the low cost and portability characteristics of future plant phenotype detection.

In this paper, under the research conditions of underground soil, a high-throughput method of visible light image transmission for the root system 3D reconstruction system of X-CT technology is proposed, which provides a kind of upper and lower computer for specific high-throughput root CT scanners in the future. The design of visible light image data transmission utilizes the characteristics of fast data transmission speed and large throughput of visible light for image transmission, which can effectively reduce the time of image data transmission between the imaging terminal and the lower computer, and reduce the research time cost of the overall system.

2 Research content

With the rapid development of plant phenotypes, CT detection techniques for roots in specific soil environments have emerged. X-CT technology uses the data to calculate the linear attenuation coefficient of X-rays and plant roots to form a visual image, create cross-sections, stack them, and reconstruct the soil's plant root structure non-destructively. It has the advantages of high spatial resolution and fast scanning speed. The disadvantage is that the imaging end and the processing end have to communicate and exchange many CT image data after scanning. At present, the single technical solution to solve this aspect gradually revealed. In medicine, there is a PCI-E bus communication protocol for the transmission of massive CT data for clinical diagnosis, which can solve the problem of three-dimensional reconstruction of extensive data and high precision in the CT system. Simultaneously, there is still a need for a specific transmission method for underground plant root CT scanners, which aims to realize a low-cost, high-throughput, and low-loss image transmission system at the imaging and the reconstruction processing end. The position of the visible light image transmission system designed in this paper is shown in Figure 1, which undertakes the high-throughput image transmission work between the upper imaging end and the lower reconstruction end.

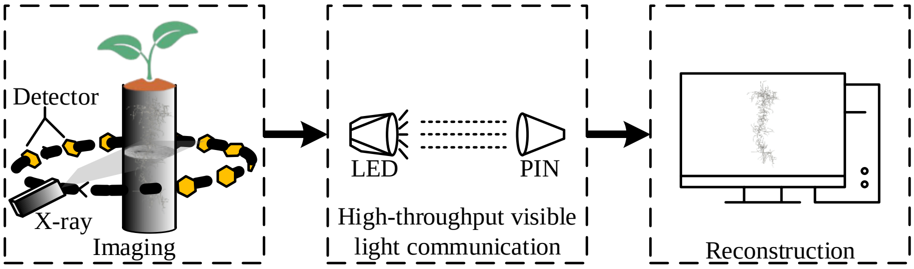


Fig. 1. Location map of the visible light image transmission system

3 Overall design structure

This system based on the white light LED to carry out the visual light communication design between the upper imaging end and the lower reconstruction end of the image information. The CT imaging terminal’s image information communicated through the serial port and the signal modulated to the LED white light source. The visible light is transmitted through the optical channel and received by the photodiode. The signal is demodulated and sent to the serial port of the lower computer to recover and display. High-throughput visible light image transmission and communication between the scanner’s imaging end and the lower reconstruction end. The overall system structure divided into two parts, the transmitting end of the upper CT imaging and the lower reconstruction. The block diagram is shown in Figure 2.

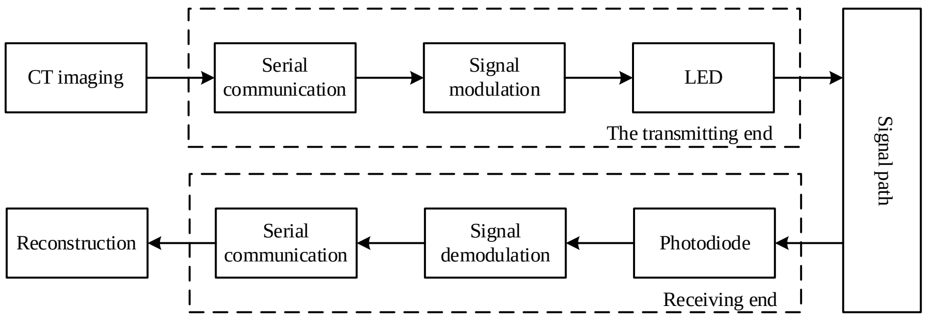


Fig. 2. Schematic diagram of the visible light image transmission system

4 System principle analysis

4.1 The choice of white LED

In the high-throughput visible light image transmission circuit, device selection, and the overall design of the circuit in the future will directly or indirectly affect the performance indicators of communication. This communication system mainly involves the selection of LED and photoelectric detection circuits.

White LED is the core component of the emitter of the entire system. According to the manufacturing method of white LED, it can be divided into two types. One is a single light-emitting chip, and the other is a multi-light-emitting chip based on three primary colours. They emit white light on different principles. Communication performance is also different. The current research shows that the outer surface of a single chip emitting blue LED coated with a yellow phosphor, and the white light emitted by the complementary white light has better luminous efficiency and modulation rate, so the choice of LED will directly affect this high-flux addable light The communication quality of the image transmission system. Figure 3 is a schematic diagram of a single-chip white LED.

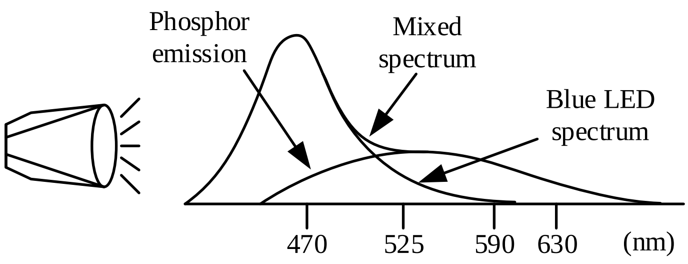


Fig. 3. Schematic diagram of a white LED

4.2 Selection of photodetection diode

In the visible light communication system designed here, the photodetector and circuit's construction directly or indirectly affects the entire communication system's performance. The photodetector diode's function is to convert and restore the optical signal received from the transmitter into an electrical signal. The core component of the receiving end is the photodetection diode. Facing the high-throughput visual light image transmission system based on CT root system, this type of photodetection diode circuit is required:

(1) The response speed is fast, the frequency bandwidth is comprehensive, and it can adapt to the environment of high-throughput transmission of CT images.

(2) The photoelectric conversion circuit is simple, and the photoelectric conversion efficiency is high. It can convert the optical signal emitted by the transmitter to the greatest extent. The photoelectric conversion efficiency determined by the current responsiveness R_I, where I_s is the output current and P is the incident light power.

$$R_I = I_S / P \quad (1)$$

(3) The photoelectric detection circuit has good linearity, and the electrical signal is less interfered with by the internal noise of the circuit.

(4) The photodetector diode's frequency response range should match the white LED's luminous effect at the emitter.

Nowadays, photodetection diodes have been applied to equipment in many fields, including CT scanners. The typical and commonly used silicon photodetection diode has high photoelectric conversion efficiency, a simple design of the front-end amplifying circuit, and a responsivity range of 0.3~0.45A/W. It has high quantum efficiency in the visible light field and is satisfied with this design. In terms of practical application, because of its low price, it is also widely used. Figure 4 shows the response curve of a typical silicon photodiode.

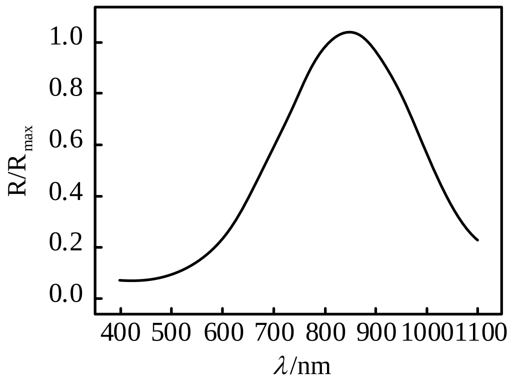


Fig. 4. Silicon photodiode response curve

5 Circuit design

5.1 Transmitter circuit design

The visible-light image transmission transmitter's design based on the X-CT technology root system 3D reconstruction system roughly consists of three parts: USB serial communication module, signal amplifier circuit module, and white light LED drive circuit module. Among them, the white light LED drive circuit is the core part of the transmitting end, and its working principle is to convert the modulated direct current signal into the light signal emitted by the white light LED and amplify the modulated electrical signal. In the visible light communication image transmission system, white light LED is used as the light-emitting signal source. Because of its high-frequency response characteristics, the signal peak value and power consumption heating under long-term DC bias should be considered when designing the white light LED drive circuit. Controllable factors.

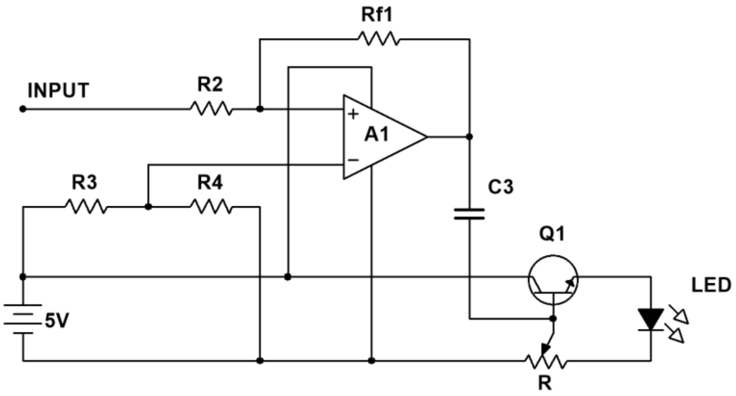


Fig. 5. Schematic diagram of a white LED drive circuit

The transmitting end of this design adopts on-off keying (OOK) signal modulation technology. After the central control chip's digital signal modulated and output, the purpose is to modulate the image binary signal flow at the LED drive circuit's front end to the white light LED to emit high frequency Flashing light signal. OOK modulation is a practical optical communication modulation technology. It controls the transmission frequency according to the amplitude of the signal. When the signal amplitude is high, the carrier frequency is transmitted, which is "on", represented by the digital signal "1"; otherwise, the carrier frequency not transmitted. Frequency, which is off, is represented by a digital signal "0". Figure 6 is the OOK modulation principle diagram. The carrier used to transmit digital information, and the carrier signal used to control the on-off changes.

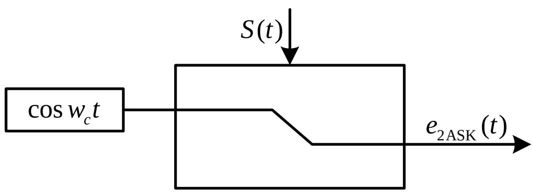


Fig. 6. OOK modulation schematic diagram

The overall system principle diagram of the transmitting end shown in Figure 7. Among them, C1, C2, C3 are filter capacitors. The amplification factor of amplifier A1 is shown in Formula 2.

$$A1 = \frac{R_{f1}}{R_2} \tag{2}$$

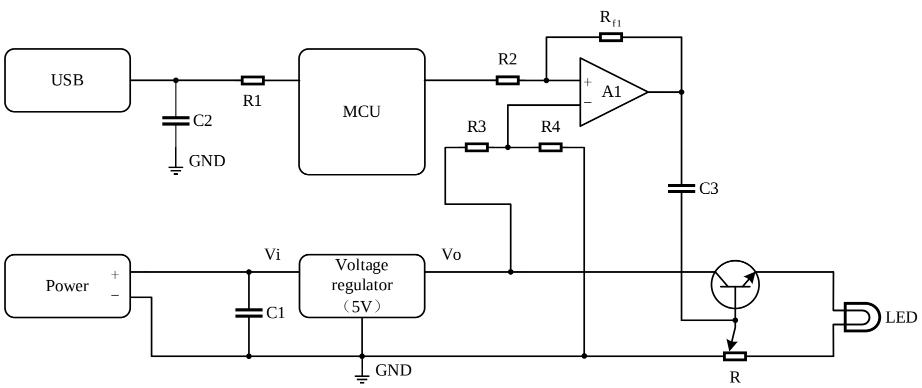


Fig. 7. Schematic diagram of the transmitter circuit

5.2 Receiver circuit design

For the receiving end, it is mainly responsible for receiving optical signals, converting the optical signals into electrical signals through silicon photoelectric detection circuits, and finally returning them to image data streams through operational amplifiers and digital-to-analogue conversion circuits. The receiving end design roughly divided into two modules: the silicon photoelectric detection and receiving amplifier circuits. When the optical signal transmitted in the space channel, it will be interfered with and attenuated by background noise, and the dark current in the photodetection diode must be considered. Therefore, when designing the photoelectric detection circuit, it is necessary to consider the amplification of the electrical signal's amplification and the filtering of the dark current and other noises. Figure 8 is a schematic diagram of a silicon photoelectric detection circuit.

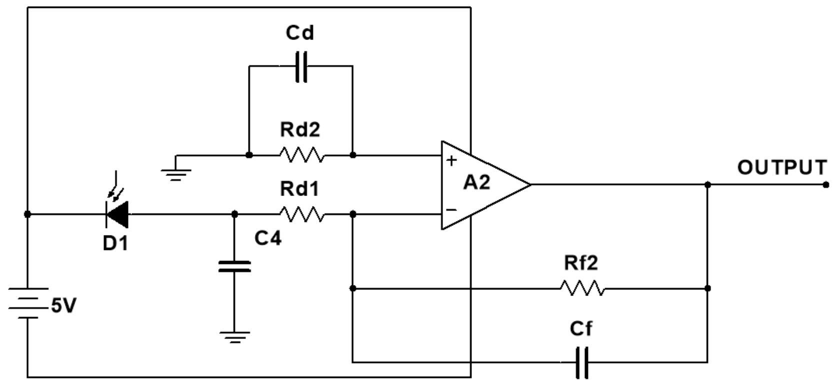


Fig. 8. Schematic diagram of silicon photoelectric detection circuit

R_{f2} is used as the feedback resistor. Because the silicon photodiode's resistance is relatively large, it is easy to oscillate at the feedback resistor and increase noise, so the resistance cannot be selected too large. C_f is used as a feedback capacitor to control the frequency response of the receiving circuit to prevent self-excitation. Generally, this capacitor is several picofarads. The amplification factor of amplifier A2 is shown in Formula 3.

$$A2 = -\frac{R_{f2}}{R_{d1}} \tag{3}$$

The overall system principle diagram of the receiving end shown in Figure 9. Among them, R7 and C5 composed of low-pass filters. Two functions realized in the circuit of this design. One is to amplify the photodetection diode's electrical signal, and the other is to filter. R_{f2} and C_f form a feedback circuit and an operational amplifier form a voltage negative feedback amplifier circuit, making the circuit have the advantages of low noise and frequency bandwidth. The feedback circuit controls the receiving end amplifier circuit's frequency response, and the upper cut-off frequency represented by f. VDD is the working voltage of the chip, in which the resistance value of R7 pull-up resistance is determined by the driving device voltage V_O , current I_O , the sum of leakage current of all the driving gate outputs high current at ordinary times I_{OZ} and the total input current I_{IL} connected to the lower end of the pull-up resistance.

$$f = \frac{1}{2\pi R_{f2} C_f} \tag{4}$$

$$\frac{V_{DD} - V_{O(max)}}{I_{O(max)} - I_{IL}} \leq R7 \leq \frac{V_{DD} - V_{O(min)}}{I_{OZ} + I_{IL}} \tag{5}$$

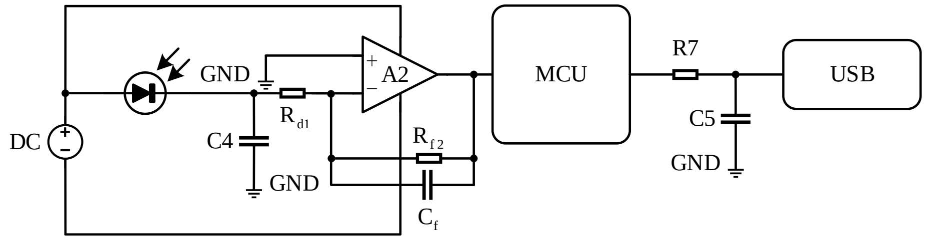


Fig. 9. Schematic diagram of the receiver circuit

6 System transmission test

To simulate the CT imaging terminal's connection at the transmitting end, connect the USB to the upper computer and power on the transmitting end, connect the USB to the lower computer on the receiving end, and power on the receiving end. Under normal lighting conditions in the laboratory, the transmitter and receiver fixed at a certain distance, and the bit error rates at distances of 10cm, 20cm, 30cm, 40cm and 50cm and the high voltage signal at the receiving end counted separately. Figure 10 (a) (b) shown.

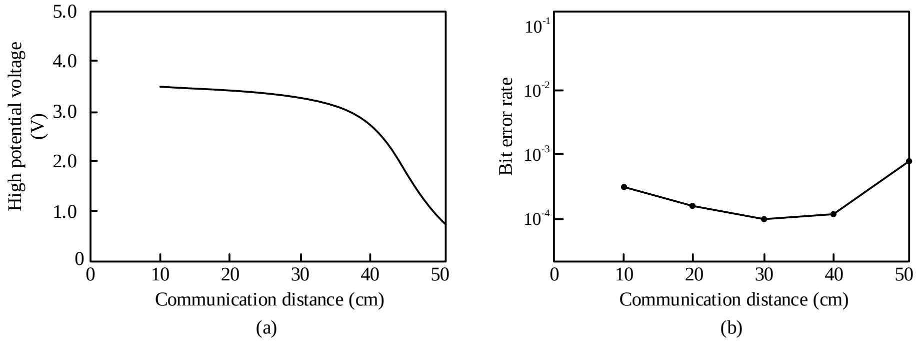
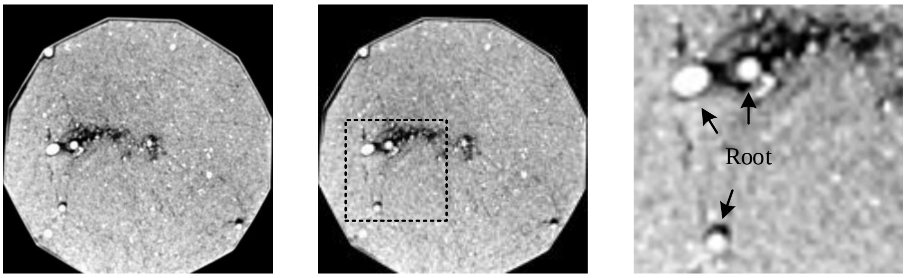


Fig. 10. (a) The relationship between communication distance and high-voltage signal at the receiving end, (b) The relationship between communication distance and bit error rate.

It can be seen from Figure 10 (a) that the high-level output at the receiving end of this system is related to the communication distance. The voltage values of the output signals at the receiving end at different distances sampled, it can be seen from the change curve that when the communication distance is less than 40cm, the output voltage does not change much with the distance. When the communication distance is greater than 40cm, the output voltage drops smoothly. Figure 10 (a) can be inferred that the best communication distance of this system is within 40cm.

It can be seen from Figure 10 (b) that when the communication distance of this system is less than 30cm, the bit error rate decreases with the increase of the communication distance. When the communication distance is greater than 30cm, the bit error rate increases with the communication distance increase. And increase. In summary of Figure 10 (a) after experimental and theoretical analysis, there is an optimal communication distance with a minimum error rate 10^{-4}, and this system is 30cm. Figure 11 shows the transmission diagram of the transmitting end and the receiving diagram of the receiving end under the optimal communication distance of 30cm.



(a) The original image of the sender

(b) The image received by the receiver

(c) The root characteristics

Fig. 11. Image transfer test diagram

7 Conclusion

In the future, high-throughput three-dimensional analysis of roots in soil will gradually become a hot issue in plant phenotyping. High-throughput technologies will be integrated into the platform for three-dimensional root detection to achieve high-throughput. In the follow-up, large-scale 3D reconstruction quantitative research, the high-throughput visual light image transmission system for root CT scanning imager is a brand new image transmission option for future root phenotype detection. Compared with the traditional medical CT machine's image transmission bus solution, this design considers the high-throughput image information transmission, and the total cost will significantly be reduced. Future high-throughput plant root phenotype image data research provides a brand new transmission option, which can be used on specific root CT scanners.

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