International Journal of Computational Intelligence Systems and Applications. Volume 5, Issue 1, (2017) 42-50
http://www.cayley-nielson.com/ijcisa/

Portable Crop Disease Photoelectric Warning Device Based on Microfluidic Chip

Wang Pan[1], Yang Ning[1,2]*, Chen Lunxu[1], Wang Qing[1], Zhang Rongbiao[1]

[1] School of Electrical and Information Engineering, Jiangsu University, Zhenjiang 212013, China;

[2] Institute of Agricultural Engineering, Jiangsu University, Zhenjiang 212013, China

* Corresponding author

E-mail: *wangpan5926@163.com*

Abstract:

Nowadays, as for the fugal disease of the crops could spread over rapidly and does great harm, meanwhile the early warning technology at this point has not yet appeared, we designed a crop disease early warning platform based on microfluidic chip and photoelectric detection mechanism. First, the system constructs a microfluidic chip by using enrichment principle, and realize the function of collecting spores in the air through a microfluidic chip. After that, the microfluidic chip cooperates with the photoelectric detection unit to analyze and scrutinize the spores in the air. Finally, the mathematical model of the voltage transmission and the concentration of the spores is established by the principle of light transmission. Experimental results reveal that: the concentration of spores and light intensity shows a linear relationship by collecting the data of the transmission voltage in microfluidic region. The coefficient of correlation is 0.9905, which has the characters of high reliability and linearity, and provides a theoretical basis for crop disease early warning technology.

Keywords: Microfluidic chip, Photoelectric detection, Disease early warning**.**

1 Introduction

According to statistics, in China, grain reduction caused by fungal disease could be high as 40% to 50% every year[1]. Once a plant is infected with fungal disease, all the surrounding crops would be severely infected and it is very difficult to treat the disease[2-3], which had bring a serious blow to the high yield of agriculture. Conventional crop disease warning method is the laboratory detection method, but it would cost a lot of energy and resource, also, the detection results can be easily influenced by the external environment conditions. For example, sugar beet powdery mildew outbreak in Heilongjiang in 2010 resulted in 65.1% grain reduction[4]. Until now, the pre-warning technology has not been reported yet and the disease disposal has great hysteresis. Therefore, the demand for intelligent crop disease detection technology is very urgent.

Tan feng et al.[5] had found the difference of spectral information between normal plants and diseased plants using infrared spectroscopy, which could provide a technical support for monitoring of rice blast by near infrared spectroscopy. However, the quantitative analysis error of this method is quite large, and the analysis of atlas is mainly domained by experience, which makes it not conducive to universal. Lin Xiaoyan et al.[6] use computer image recognition technology to realize the automatic detection of poplar spores. Firstly, acquire images are obtained by using microscope, then after a series of image processing techniques, such as denoising, smoothing, corrosion expansion, threshold segmentation, those images

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May, 2017

could be binarization processed, then by extracting and refining the age, the automatic counting of spores could be realized. However, the electronic microscope is not very convenient to operate in the field, so the detection result cannot be real-time display. Tian Youwen et al.[7] used the computer image processing technology and support vector machine classification method to identify the fungi in maize leaves. After the feature extraction, the support vector machine (SVM) pattern recognition method was used to identify maize fungal disease, which is a new research direction of maize fungal disease. However, this method still needs to be handled manually and cannot be fully automation. Li Xiaolong, et al.[8] used the traditional spore trap to capture the fungal spores of the plant, and obtained the image of the sample by using photomicrography, then count the spores by the scaling the image based on the the most recent collar interpolation theory, which also called segmentation processing, with Matlab. However, the analysis speed of Matlab processing is too slow and the user interface is too simple to meet the requirements of processing speed and dispaly. In 2009, Sasaki et al.[9] studied the automatic diagnosis of cucumber anthracnose, and in this study, the influence of the light reflection characters and optical filter on the disease recognition has been systematically investigated. Then, based on the Genetic algorithm, the identify parameters have been determined in aspect of light reflection characters and shape characters to identify the disease. However, the detection accuracy of this study is not very high because the information of color and texture have not been fully used. Malthus et al.[10] studied the reflectance spectra of soybean infected by Botrytis fabae Sardina, and found that the first order reflectivity was higher than the original reflectance, which could be used to monitor the occurrence of pests and diseases. However, the spectroscopy detection device is bulky and can't achieve the portableization of the detection device.

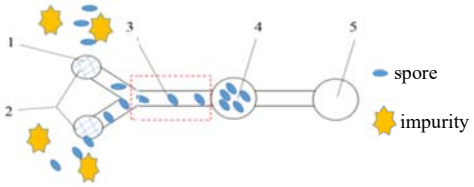
Since the 20th century, microfluidic technology has developed rapidly, which integrates with the analysis, reaction, detection and other steps and has been used widely in biochemical analysis[11-13], immunoassay[14-15], environmental monitoring[16-17] and many other areas[18]. The development of Microfluidic technology has been widely recognized around the world. Its existence makes a leap in the quality testing industry and become the focus of recent detection technology.

Therefore, in this paper, the microfluidic technology was combined with the photoelectric detection technology to propose a portable, low-cost and predictable crop disease detection method based on microfluidic photoelectric detection.

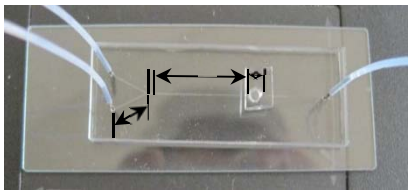
2 System Design

2.1 The design and fabrication of microfluidic chip

The principle of microfluidic chip for capturing spores in the air is shown in Fig.1. Where number 1 is sample inlet and it was used to absorb the air with disease spores, which diameter is 1000 μm. Number 2 is filter, which is used to filter large dust from the air and improve the detection accuracy of the system. Number 3 is microchannel and it is used to convey the air flow, and which channel width is 500 μm. Number 4 is enrichment detection area, which diameter is 2000 μm, it can slow down the velocity of the air flow and enrich the disease spores. Number 5 is electric pumping area, it is connected to a micro pump, which could create a negative pressure in the microchannel and provide the power for spores' collection.



(a) Microfluidic chip structure



(b) Microfluidic chip physical graph

1.Sample inlet; 2. Filter; 3Microchannel; 4. Enrichment detection area; 5. Electric pumping area

Fig.1. Microfluidic chip

The microfluidic chips used in this study are made by using some technologies like hot embossing lithography, injection molding, stamping and so on. As shown in the Fig.1(b), due to the polydimethylsiloxane (PDMS) and glass material which were respectively used as the cover plate and base plate, the light transmission rates of the microfluidic chip could be up to 96%, which shows a good light transmittance ability and guarantee a high detection sensitivity of the photoelectric detection device. Fig1 is the physical map of the microfluidic chip.

2.2 The design of photoelectric detection system

Fig.2 is the schematic diagram of photoelectric detection module. Light emitting diode was used as the light source which can irradiate on the chip. Silicon photodiode was used as light receiving device to accept the optical light signal which penetrate over the chip and convert it into electrical signal by a photodiode, then the digital signal would be magnified and filtered by the detection electric circuit. After that, the processed digital signal would be finally passed into a micro processer through an A/D conversion module.

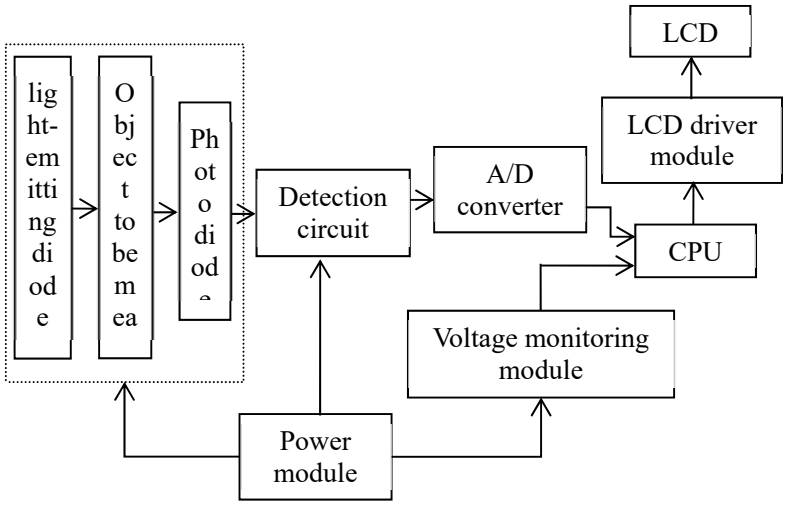


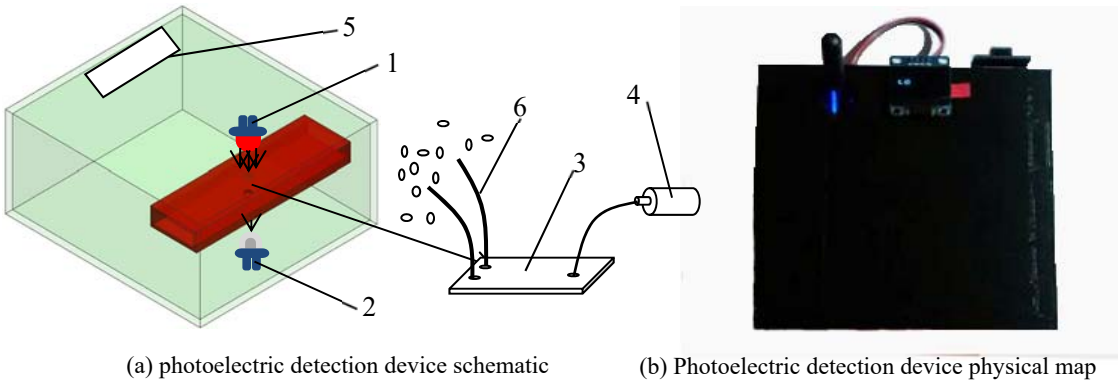
Fig.2. Photoelectric detection system

Furthermore, the A/D conversion module, LCD driver module and voltage monitoring module would be respectively set inside of the single chip microcomputer. The voltage signal would be converted into digital quantity signal by the A/D conversion module, the amount of spores would be displayed by the LCD module and the real-time voltage supply could be monitored by the voltage monitoring module. If

the power supply voltage is too low, the detection accuracy of the device would be effect accordingly. So we use this module to monitor the power supply voltage. When the power supply voltage is too low, a symbol of low voltage will be displayed on the LCD and the voltage supply of the device will power off. The power module provides the power for the entire system, including the chip power supply, ensure the normal operation of the system.

2.3 Construction of the experimental platform (Construction of the photoelectric check system)

Fig.3 is a schematic diagram of the photoelectric detection device. In the dark light condition, the experimental device includes a red light emitting diode, silicon photodiode, microfluidic chip, micro pump, liquid crystal display. Then place the microfluidic chip in the detection area and set red LED closed to the upper surface microfluidic chip, furthermore set the photosensitive diode close to the lower surface of microfluidic chip to receive the light intensity signal. In addition, connect the micro pump to the pumping area to provide microfluidic chip the power to absorb spores in the air flow. Then those signal would be convert into electrical signal by a photodiode and displayed on the LCD. Fig3 (a) as the photoelectric detection device schematic and figure 3 (b) is the physical map of photoelectric detection device.



(a) photoelectric detection device schematic (b) Photoelectric detection device physical map

1. Red light emitting diode; 2 Silicon photodiode; 3 Microfluidic chip; 4 Micro pump; 5 Liquid crystal display; 6 Soft tube

Fig.3. Photoelectric detection device

3. Principles of Aerodynamics

When the disease spores are dragged into the microfluidic channel, they would be affected by the vertical upward force Ft and forward drag force Fr[19]. Because of those two different direction force, the motion state of disease spores would change and those disease spores would be out of the channel surface and drift with the air flow, and inertial lifting force Ft could be written as Eq(1):

$$F_t = 1.615 \times \mu d_p^2 \left(\frac{\rho}{\mu} \times \frac{du}{dy}\bigg|_{y=\frac{d_p}{2}} \right)^{1/2} v_p \tag{1}$$

Where the μ(N·s/m) is the viscosity of the air, dp(m) is the particle size of the micro particles, ρ is the density of the air, vp (m/s) is the velocity of the air flow at the center of the micro particles, u(m/s) is the velocity of the air flow whose motion direction is parallel to the solid surface. As for drag force of the micro particles Fr, according to the Stokes law[20] could be written as Eq(2):

$$F_r = 1.7009 \times 3\pi\mu d_p v_p \tag{2}$$

Where μ is the dynamic viscosity of the air; d_p(m) is the particle size of the micro particles; and v_p (m/s) is the velocity of the air flow at the center of the micro particles.

Therefore, in order to reduce the spike escape rate of the disease spores, it is necessary to reduce the drag force F_r by reducing the air flow velocity at the center of the micro particles.

4 Experimental

4.1 Test Samples

The test sample, strawberry grey mold spores, was provided by Jiangsu Agriculture and Forestry College. During the experimental process, the aerosol particles of strawberry were prepared by aerosol generator and uniformly released in a 1L container. As the amount of spores in the container is abundant enough, so, the concentration of spores in the container during the experiment could be considered as a constant value. The experiment was carried out using the photoelectric system device for 10 min collection of fungal spores, and then the chip was placed under a microscope to calculate the average spore concentration of 3 × 103 / mm2, which could be further considered as the standard unit sample concentration. Besides, the number of spores in the microfluidic enrichment zone could be controlled by the controlling time of air pump.

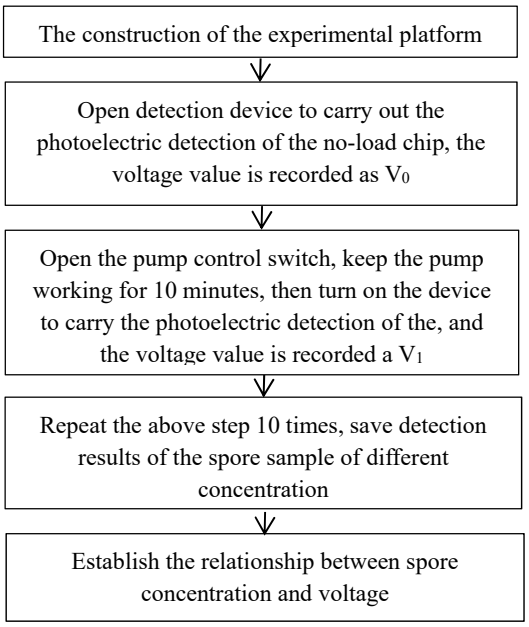


Fig.4 Flow chart of the experimental steps

4.2 Experimental steps

1) The inlet of the chip is connected to the container where the aerosol spores are located through a hose, the outlet of the chip is connected to the air pump through the hose and the spores are collected by the photoelectric detection device (shown in Figure 3b).

2) Turned on the power supply of the photoelectric detection device to carry out the transmission test of the no-load chip which would be used to collect the spores in the further test, then the transmission voltage value is recorded as V0.

3) Open the pump control switch and keep it working for 10 minutes to provide the power of fungal spores getting into the enrichment region of the chip. Turn on the photoelectric detection device to carry out the transmission detection of enrichment area, the detected voltage value is recorded as V1.

4) Repeat the step3 ten times to detect the spores sample of different concentration, the record the experimental data. According to the detection result, the mathematic relationship between transmission voltage and concentration of spores can be established, according to which the concentration of spores under test could be obtained.

5 Optics Selection

In the photoelectric detection system of crop fungal disease based on microfluidic chip, the main system parameters include the selection of light source and photodetector.

5.1 Selection of light source and selection of parameters

The effect of different color light sources on the experimental results is very significant. Different colors of light corresponding to different wavelengths, according to the different light source sensitivity of the light-emitting device selection. The four colors of blue (450nm), green (500nm), yellow (550nm) and red (650nm) were selected as light source devices, and the samples collected by the above experiment were used. According to the experimental results of the light source device selection. Different spores' concentration in different light source corresponding to the transmission voltage value shown in Fig.5, light source and detection sensitivity of the relationship shown in Table 1.

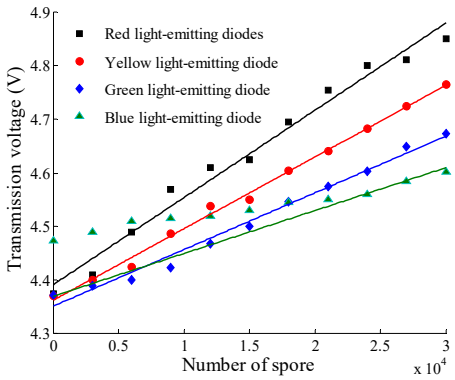


Fig.5. Light source optimization

Table 1 different light source correspond to different sensitivity

Light source	Sensitivity
Red light-emitting diodes	1.63×10^{-5}
Yellow light-emitting diodes	1.34×10^{-5}
Green light-emitting diodes	1.057×10^{-5}
Blue light-emitting diodes	8.01×10^{-6}

From the table 1, we can see that the sensitivity between the transmission voltage and the spore concentration is different under the condition of different color light source. When the light source is selected as the red light emitting diode, the linear relationship between the measurement and the system is uniform and the linear relationship is more effective reaction of fungal spores, and the detection sensitivity is highest. Therefore, the photoelectric detection device selects the red light emitting diode as the system detection light source.

5.2 Selection of photodetector

As the core of the photoelectric detection system, the photodetector must have a series of characteristics such as anti-electromagnetic interference, high precision and good sensitivity. Select the photodetector from the following aspects to consider, Firstly, the selected photodetector is spectrally matched to light-emitting diodes and optical systems. The system uses infrared light to compare with the photodiode. Secondly, the characteristics of photoelectric conversion in the radiation energy match the selected light-emitting diode. Then, the parameters of the selected device are the same as those of the optical signal of the selected photodiode, the modulation method, the waveform, and the electrical characteristics of the input circuit. Finally, as the overall environment changes, the time in the work can be in a stable state. Combined with the above conditions, silicon photodiode was selected as a photodetector.

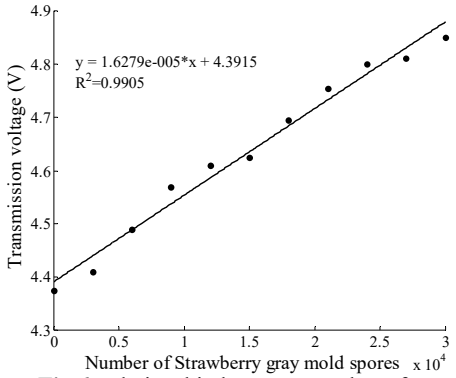


Fig.6. relationship between number of spore and transmittion voltage

6 System analysis and verification

In this study, the strawberry grey mold spores are selected as the test samples to verify the detection ability of the crop disease pre-warning photoelectric detection device based on the microfluidic chip by fixing the specific detection target. In the verification experiments, the red-LED was selected as the light source of the detection device and the silicon photodiode was selected as the light detector to receive the light which pass through the detection area of the microfluidic chip and output the light intensity signal, then the analog light intensity signal would be transit into a digital voltage signal, also called the transmission voltage, by the data and A/D signals processing module. The experimental results could be seen in Fig.6, the x-axis represents the concentration of the spores and the y-axis represents the value of transmission voltage. After the linear fitting of the experimental result, a linear relationship between the concentration of spores and transmission voltage is shown in Fig.6. The linear model could be established

as y = 1.6279e-5×x +4.3915, and the linear correlation coefficient is 0.9905, so the concentration of the crop disease spores could be determined once the transmission voltage of the microfluidic chip is obtained.

7 Conclusion

A microfluidic chip based on microfluidic photoelectric detection device was proposed, which designed the sample inlet, filter, microchannel, enrichment detection area and electric pumping area. In the choice of light source devices and photodetectors, the optoelectronic system uses red light as the light source, silicon photodiode photodetector to reduce system detection error. The combination of microfluidic chip and photoelectric technology provides a new development direction for miniaturization, automation and portability of crop fungal disease detection devices. This new method can avoid the complex manual operation and promote the development of pre-diagnosis and early warning technology of disease.

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