A HANDHELD MINIATURE ULTRAVIOLET LED FLUORESCENCE DETECTION SPECTROMETER **

Zongjie Bi [1], Yanchao Zhang [1], Shanshan Zhang [2], Ling Wang [1], Erdan Gu[3], Zhaoshuo Tian[1*]

[1] *Harbin Institute of Technology at Weihai, Weihai, 264209 China; e-mail:bizongjie@qq.com*
[2] *The Shandong Institute of Shipbuilding Technology, Weihai, 264209 China; e-mail:469514384@qq.com*
[3] *University of Strathclyde, 16 Richmond Street, Glasgow, G1 1XQ, United Kingdom, email: erdan.gu@strath.ac.uk*

This paper presents a handheld micro-fluorescence spectrometer with an integrated ultraviolet light-emitting diode. A small transmission grating was used as a dispersive element to disperse light. The spectrum was detected by a CCD array. The instrument can be connected to a PC or a smartphone through a USB cable for data processing and spectrum display. The spectrometer is 30×30×100 mm^3 only. The spectrometer with a wavelength range from 380 to 750 nm had a spectral resolution of 3 nm. The fluorescence spectra from edible oil, chlorophyll, and paper were measured by the spectrometer we designed. This spectrometer has the advantages of compact structure, small size, light weight, fast detection speed, convenient use, and low cost.

Keywords: *ultraviolet sources, light-emitting diodes, spectroscopy, fluorescence.*

ПОРТАТИВНЫЙ МИНИАТЮРНЫЙ СВЕТОДИОДНЫЙ СПЕКТРОМЕТР ДЛЯ ОБНАРУЖЕНИЯ УФ ФЛУОРЕСЦЕНЦИИ

Z. Bi [1], Y. Zhang [1], S. Zhang [2], L. Wang [1], E. Gu[3], Z. Tian[1*]

УДК 535.372

[1] *Харбинский технологический институт, Вэйхай, 264209 Китай; e-mail:bizongjie@qq.com*
[2] *Институт технологий судостроения Шаньдун, Вэйхай, 264209 Китай; e-mail:469514384@qq.com*
[3] *Университет Стратклайда, Глазго, G1 1XQ, Великобритания, e-mail: erdan.gu@strath.ac.uk*

(Поступила 7 мая 2018)

Представлен портативный микрофлуоресцентный спектрометр со встроенным УФ светодиодом. В качестве дисперсионного элемента для рассеивания световых волн используется небольшая пропускающая решетка. Спектр детектируется с помощью ПЗС-матрицы. Для обработки данных и отображения спектра прибор может быть подключен к персональному компьютеру или смартфону через USB-кабель. Размеры спектрометра 30×30×100 мм, рабочий диапазон 380–750 нм, спектральное разрешение 3 нм. С помощью спроектированного спектрометра измерены спектры флуоресценции пищевого масла, хлорофилла и бумаги.

Ключевые слова: *ультрафиолетовые источники, светодиод, спектроскопия, флуоресценция.*

Introduction. Owing to their high precision, large measuring range, and fast speed, fluorescence spectrometers are widely used in the food, petroleum, chemical, medicine, and environmental protection areas [1–3]. They are also an essential remote sensing equipment [4], which can be used in space and hydrological exploration, etc. In recent years, people have paid more attention to food safety and environmental protection. Thus, there is an urgent need for developing a small and integrated spectrometer to accomplish real-time measurement and quality monitoring [5]. However, traditional fluorescence spectrometers are usually

** Full text is published in JAS V. 86, No. 3 (http://springer.com/10812) and in electronic version of ZhPS V. 86, No. 3 (http://www.elibrary.ru/title_about.asp?id=7318; sales@elibrary.ru).

large in volume and complex in operation, so they are mainly used in laboratory [6]. Currently, one of the important directions of research is to miniaturize the spectrometer and reduce its cost so that ordinary families can purchase and use it for daily detection and monitoring.

This paper presents a handheld micro-fluorescence spectrometer with a high-efficiency and low-cost UV LED as an excitation source. Compared with the conventional spectrometer, this handheld fluorescence spectrometer has such advantages as light weight, small size, quick response, flexible operation, and low cost. This miniaturized spectrometer can be widely used in the fields of food safety detection [7], gem identification [8], water quality monitoring [9, 10], biochemical analysis [11], medical inspection, industrial monitoring, etc.

Structure and characteristics of the handheld spectrometer. The handheld fluorescence spectrometer is composed of four parts: an UV light-emitting diode (LED) light source, a light dispersive system, a detection system, and a data processing system, as shown in Fig. 1. A 365 nm LED was chosen as the UV light source. The light dispersive system is composed of a slit, a collimating mirror lens, a focusing lens, and a transmission grating. A high sensitivity imaging CCD was used in the detection system. The spectrum data was transmitted through the USB interface to a computer or a mobile phone for processing and display.

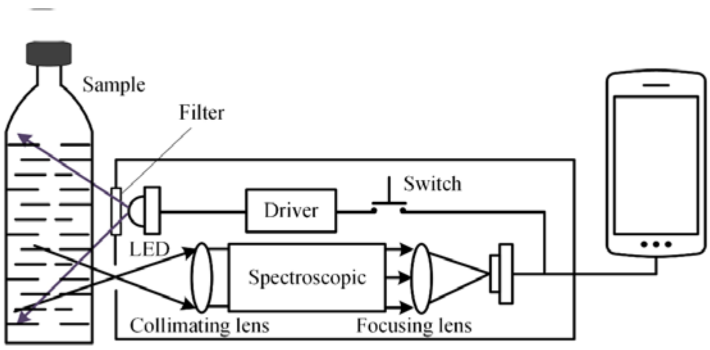

Fig. 1. The structure of the handheld miniature UV fluorescence spectrometer.

A 365 nm band-pass filter is placed in front of the LED to obtain narrowband UV light. The light source, the spectroscopic system, and the detection system are integrated into a rectangular aluminum box of 30×30×100 mm. The light signal is received, converted into an electrical signal by the detector, and then transmitted to a computer or a mobile phone through the USB cable that provides power (5 V, 500 mA) to the spectrometer.

When the UV LED is turned on, the spectrum of the background light and fluorescence of the target induced by the UV light can be measured. When the switch is off, the measured spectrum is only that of the background light. A comparison of the main parameters of our spectrometer and those of the current international miniature spectrometers is shown in Table 1 [12]. Our spectrometer integrates the LED UV light source with a small volume, which is convenient and easy to use. The spectrometer with a wavelength range from 380 to 750 nm had a spectral resolution of 3 nm, calibrated by the Ocean Optics Spectrometer Model.

TABLE 1. Performance Comparison of Commercial Spectrometers with the LED Spectrometer

Specification	Ocean Optics	Hamamatsu with USB Board	Smartphone spectrometer with Hamamatsu Sensor	UV LED fluorescence spectrometer
Bandwidth, nm	360–1100	340–840	340–780	380–750 (350–820)
ADC Bits	16	16	10	8 (Multi pixels accumulation)
Operating System	Windows	Windows	Android	Windows or Android
Spectral Resolution, nm	10	15	15	3
Size, mm	89.1×63.3×34.4	108×70×35	88×37×22	100×30×30
Weight, g	224 (without light source)	198 (with light source and battery)	48 (with light source, battery, Bluetooth connection)	100 (with UV LED light source)

The main features of Spectrometer are the following:

1) An imaging CCD is used as the detector. The light with different wavelengths is spatially spread onto the CCD so that different column pixels measure different light energy. By accumulating the values of the vertical pixels, higher intensity resolution and sensitivity can be achieved.

2) The background noise reduction function is designed in the software. During the fluorescence measurement, the measured spectra include the fluorescence and background light when the LED is on and only the background light when the LED is off. The background noise subtraction function is designed and can be selected in the software so that the accurate fluorescence spectrum of the target can be obtained by subtracting the measured fluorescence spectrum from the background spectrum.

3) This spectrometer can detect transparent packaging liquid samples without pretreatment, such as oil, water, and alcohol.

Spectrum detection experiment. To test the performance of the spectrometer, the fluorescence spectra of edible oil, plants, and paper were measured.

Spectrum detection on edible oil. The florescence spectra of edible oils with different nutritional values could discriminate the quality of the oils. In the experiment, four kinds of oil were detected using our spectrometer. Figures 2a,b are the spectra of the same-brand soybean oils from two manufacturers, and Fig. 2c,d are the spectra of the corn germ oil and olive oil, respectively. The fluorescence intensity and peaks are obviously different.

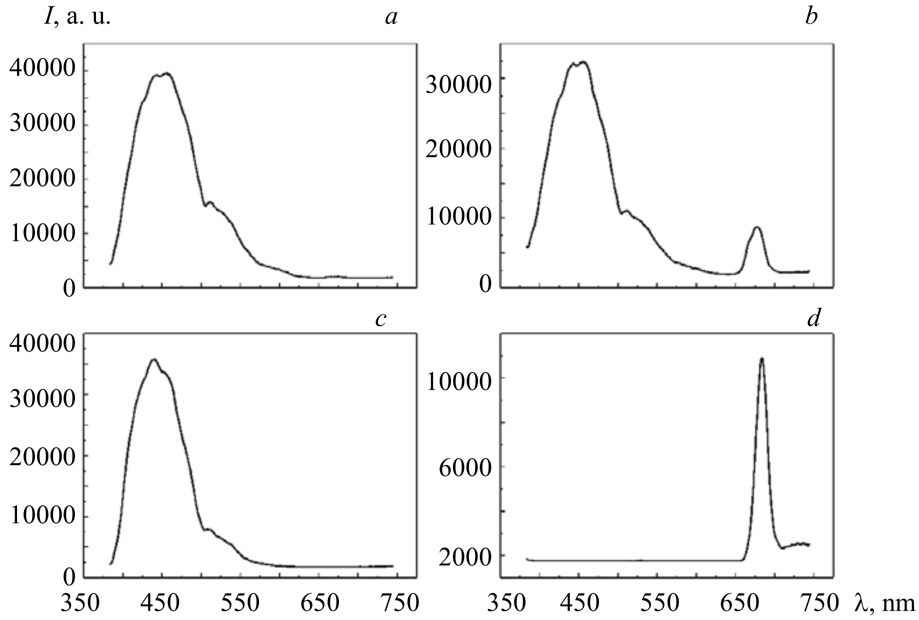

Fig. 2. Spectra of different oils by different manufacturers: (a) Jinlongyu Soybean oil (Qingdao); (b) Jinlongyu Soybean oil (Yantai); (c) corn germ oil; (d) olive oil.

Chlorophyll detection. Chlorophyll plays an important role in the photosynthesis process of plants [13]. The growth and development of plants can be monitored by measuring their chlorophyll content [14]. It is of great significance to guide the management of cultivation and fertilization scientifically.

The fluorescence spectra of the green leaf and the yellow apple were measured with our spectrometer. As shown in Fig. 3, the characteristic peak of the green leaf occurs at 685 nm, which is much stronger than that of the yellow apple.

Paper fluorescence detection. The whiteness and appearance are two important indicators to evaluate the quality of paper products. At present, one way to improve these two indicators is to add a fluorescent whitening agent [4, 15], which is harmful to human health. Therefore, it is necessary to evaluate the content of the fluorescent substances in paper products, especially in food wrapping paper.

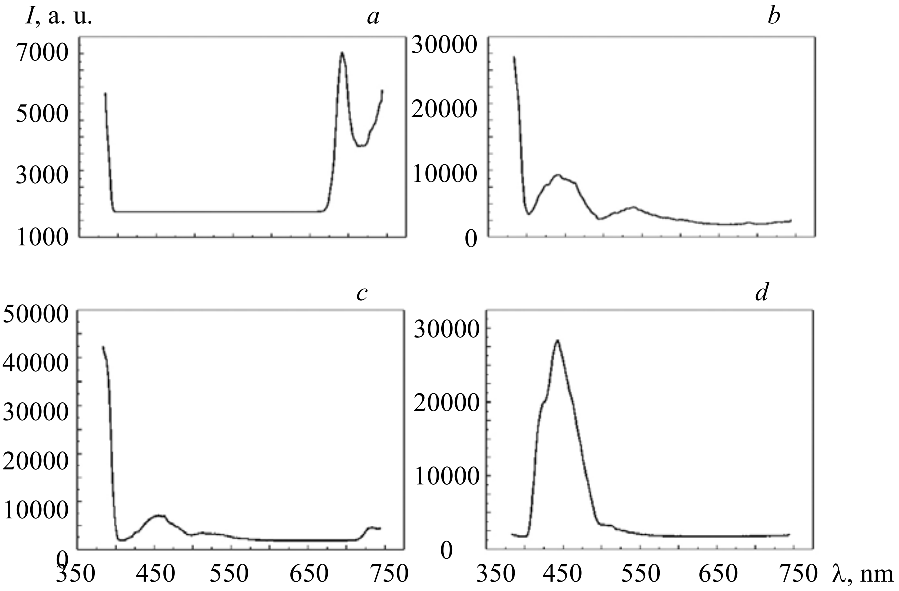

Fig. 3. Comparison of fluorescence spectra of green leaves (a), yellow apples (b), tissue paper (c), and printing paper (d).

Conclusion. This paper presents a micro UV fluorescence spectrometer integrating a UV LED, a small optical system, and a detection system. This spectrometer can be connected to a PC or a mobile phone via a USB cable for spectrum image processing and display. Compared with the current popular microspectrometers on the market, it has the advantages of better spectral resolution, faster detection, and a lower price. In our experiments, by using a UV LED to irradiate the targets, the fluorescence spectra of edible oils, plant chlorophyll, and paper were measured. Because of its small volume and low price, it can be extended to domestic use and other fields.

REFERENCES

1. X. X. Fang, H. Y. Li, P. Fang, J. Z. Pan, Q. Fang, *Talanta*, **150**, 135–141 (2016).
2. H. Wang, Y. Qi, T. J. Mountziaris, C. D. Salthouse, *Rev. Sci. Instrum.*, **85**, No. 5, 055003 (2014).
3. E. B. Ishay, G. Hazan, G. Rahamim, D. Amir, E. Haas, *Rev. Sci. Instrum.*, **83**, No. 8, 084301 (2012).
4. F. B. Yang, J. Z. Pan, T. Zhang, Q. Fang, *Talanta*, **78**, No. 3, 1155–1158 (2009).
5. H. Li, H. Wang, D. Huang, L. Liang, Y. Gu, C. Liang, S. Xu, W. Xu, *Rev. Sci. Instrum.*, **85**, No. 5, 056109 (2014).
6. J. LIU, Z.-m. QIN, Y. ZUO, S.-p. LIU, *Paper Paper Making*, **3**, 030 (2011).
7. A. C. Ranulfi, M. C. B. Cardinali, T. M. K. Kubota, J. Freitas-Astú, E. J. Ferreira, B. S. Bellete, M. F. G. F. da Silva, P. R. V. Boas, A. B. Magalhaes, D. M.B.P. Milori, *Biosyst. Eng.*, **144**, 133–144 (2016).
8. D. Bersani, P. P. Lottici, *Anal. Bioanal. Chem.*, **397**, No. 7, 2631–2646 (2010).
9. J. R. Etheridge, F. Birgand, M. R. Burchell, B. T. Smith, *J. Environ. Quality*, **42**, No. 6, 1896–1901 (2013).
10. S. Landgraf, *J. Biochem. Biophys. Methods*, **61**, No. 1-2, 125–134 (2004).
11. Z. Rena, S. Huang, G. Liua, Z. Huanga, L. Zenga, *Proc. SPIE*, **8192**, 81920A-1 (2011).
12. L. Sun, Y. Zhang, Z. Tian, X. Ren, S. Fu, *Appl. Opt. Photonics Chin.*, 96740X-6 (2015).
13. S. Lenk, P. Gádoros, L. Kocsányi, A. Barócsi, *Eur. J. Phys.*, **37**, No. 6, 0604003 (2016).
14. A. J. Das, A. Wahi, I. Kothari, R. Raskar, *Sci. Rep.*, **6**, 32504 (2016).
15. H. Huang, Y. Li, J. Liu, J. Tong, X. Su, *Food Chem.*, **185**, 233–238 (2015).