Optik 155 (2018) 267–272

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

A compact line-detection spectrometer with a Powell lens

Fuhong Cai [a], Rongnian Tang [a,*], Shaowei Wang [b], Sailing He [c,*]

[a] Department of Electrical Engineering, Mechanical and Electrical Engineering College, Hainan University, Haikou 570228, China
[b] Department of Chemical and Biomolecular Engineering, National University of Singapore, 117585, Singapore
[c] State Key Laboratory of Modern Optical Instrumentations, Centre for Optical and Electromagnetic Research, Zhejiang University, Hangzhou, Zhejiang, 310058, China

ARTICLE INFO

Article history:
Received 1 September 2017
Accepted 2 November 2017

Keywords:
Line-detection
Powell lens
Portable
Spectral information

ABSTRACT

Optical spectra are functions of the emitted or reflected light from the object under observation. The investigation of spectral data can facilitate quantitative analysis and material identification. In this paper, we report a portable line-detection spectrometer for non-invasive sensing of samples of interest. The spectrometer relies on a Powell lens to perform a rapid line detection. Through a manual scanning across a sample of interest, a series of spectra could be acquired. After an unmixing procedure is performed on the detected spectra, the reflected (or emission) spectrum of the sample could be obtained. In this work, the feasibility of the line-detection spectrometer was demonstrated by scanning across a LED screen and fruit samples. These spectral results were applied to determine the composition of the scanned objects, such as the colors of a LED screen and the chlorophyll and carotenoid content in bananas. This method is compatible with many kinds of spectrometer, e.g. Raman spectrometer for high spectral resolution sensing, infrared spectrometer for identification of adulteration. Therefore, this portable device can be a versatile tool to carry out a range of in-site studies in the future.

1. Introduction

Spectral detection is rapidly gaining importance for intact biological specimen sensing, agriculture remote sensing, and environmental monitoring [1–5]. Spectral detection is a very effective method to the study on composition of a sample of interest. There are many advantages of analyzing spectral data, such as non-invasiveness, high sensitivity and minimal sample preparation. For example, fluorescent spectra have been shown to be useful to study the metabolic processes of nanoparticles in a mouse [1]. Raman spectra can be utilized for rapid detection of pesticide residues in fruits and vegetables [5].

Recently, there have been rapid developments of a technology using a single-pixel detection system to capture image [6,7]. Taking a time-resolved spectrometer as a single-pixel detector, Pian et al. developed a hyperspectral time-resolved spectral imaging system [7]. The single-pixel imaging technology relied on structured light to perform signal acquisition, as well as a compressive sensing algorithm to reconstruct an image.

However, fewer have studied the modification of the detection region of the single-pixel detector. Usually, a single-pixel detector can collect light from a circular region, whose area is dependent on the spherical lens set in front of the detector. When a Powell lens is utilized in a single-pixel detection system, the detected region can become a rectangular region. The

* Corresponding authors.
E-mail addresses: rongnian.tang@gmail.com (R. Tang), sailing@kth.se (S. He).

https://doi.org/10.1016/j.ijleo.2017.11.022
0030-4026/

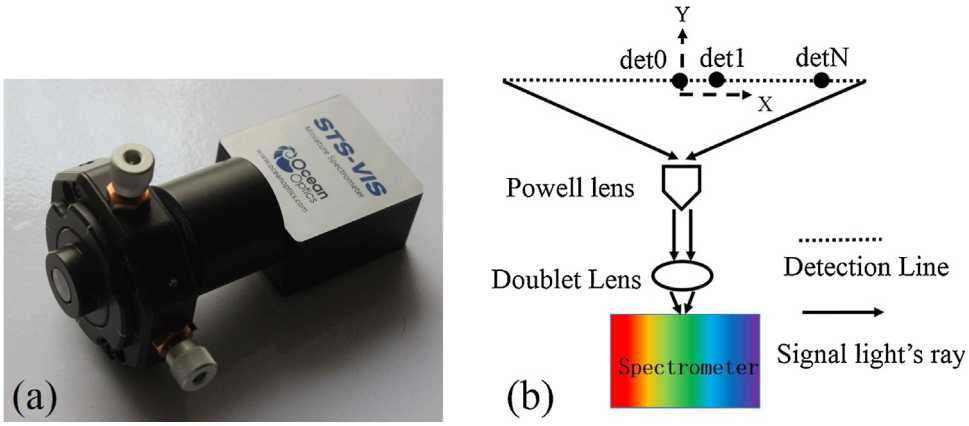

Fig. 1. (a) A photo of the line-detection spectrometer. (b) Schematic illustration of the optical components in the detection system. The Powell lens converts the light emitted from a 'linear region' into collimated light, which is then focused onto the slit of the spectrometer by a doublet lens. In addition, the Z axis is perpendicular to the X axis and the Y axis.

length-width ratio of the rectangular region is about 86.7 (see Section 2), hence the detection region can be considered as linear. In this work, we propose a cost-effective, portable line-detection spectrometer (LD spectrometer) with a Powell lens. By using the LD spectrometer, we cannot acquire the spatial information as an imaging spectrometer does. But we can perform rapid line-detection for intersected sample. Also, this method is compatible with many kinds of spectrometer, and an ultra-high spectra-resolution sensing can be carried out by selecting a proper spectrometer.

In this paper, this LD spectrometer utilizes a Powell lens to collimate light emitted from a linear region and a doublet lens to focus the collimated light on a slit. This optical setup leads to loss of spatial optical information along the linear region. However, the focused light contains all spectral information coming from the linear region. As the focused light passes through a slit, a diffraction module and detection module in the spectrometer, we can obtain one spectrum on the data acquisition system. Usually, a detected sample is composed of multiple different components. Hence, the spectrum is the mix of reflected (or fluorescent) light from all of those elements. In certain situations, we want to determine the composition of the sample of interest. Nevertheless, one spectrum is not yet sufficient to perform a spectral unmixing procedure [8] to study the composition of sample of interest. Since the proposed system is compact and portable, we can hold the LD spectrometer to scan the sample. During the scanning process, a series of spectra can be acquired. Based on the spectral data, we able to estimate the composition of the detected sample by spectral unmixing algorithm.

2. The line-detection spectrometer setup

In this section, the essential components of a LD spectrometer are described in detail. A photo of the LD spectrometer is shown in Fig. 1(a). All components have been assembled together. Firstly, a compact diffraction grating spectrometer (STS-VIS, Ocean Optics) was used as the diffraction and detection module. The spectral resolution is 6.0 nm. The integration time for STS-VIS is set as 200 ms in our work. Then an optical tube was utilized to hold a doublet lens. One end of the optical tube was connected to the SMA-port of STS-VIS via a 1/4-36 threaded hole. The other end of the optical tube was connected to a translation mount (CXY1, Thorlabs), which was used to hold the Powell lens [9]. Generally, a collimated laser beam could be fanned out to a straight laser line in one dimension using the Powell lens [10,11]. Based on the reversible nature of light, the Powell lens could also convert the light emitted from a 'linear region' into collimated light. This collimated light was then focused into the slit of spectrometer by a doublet lens. The schematic diagram is shown in Fig. 1(b). The light signal emitted from a linear region was collected by the Powell lens, passing through the doublet lens and then detected by the STS-VIS spectrometer.

The difference between the LD spectrometer and an imaging spectrometer is explained below. An imaging spectrometer acquires spectrum of every point on a linear region. Hence, an imaging spectrometer can collect spectral and imaging information simultaneously. However, with the LD spectrometer, the light signals from all points on a linear region are collected and focused onto one slit of the spectrometer simultaneously, and the spectrometer then acquires spectral data representing an integral of the spectral signals from all points. In this way, rapid line detection can be achieved. However, this optical setup leads to the loss of imaging information. Even without imaging information, the LD spectrometer can still be used to estimate of the compositions. This feature will be demonstrated in Section 3. In the following article, for convenience, a single measurement result of the LD spectrometer is defined as a line integral spectrum, and the detected linear region is defined as a detection line.

To test the system performance, the following experiments were carried out. As shown in Fig. 1(b), a dashed line coinciding with the X axis on a diffuse screen was defined as a 'linear region'. The diffuse screen is placed at y = 30 cm away from the Powell lens. By adjusting the position of the Powell lens using CXY1, the detection line of the LD spectrometer was aligned