Optics Communications 428 (2018) 1–6

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

The design and implementation of a low-cost multispectral endoscopy through galvo scanning of a fiber bundle

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ARTICLE INFO

Keywords:
Spectral imaging
Endoscope
Galvo mirror
Image relay
Imaging

ABSTRACT

In this work, we report the design and implementation of a compact, cost-effective multispectral imaging endoscope. First, a spectral image scanning system is built, by combining a micro-imaging system with a spectrometer and a galvo mirror. Then a fiber bundle is utilized to transmit the optical image of a sample to the spectral image scanning system. Through galvo scanning, a 3D spectral image cube emitted from the sample can be acquired. Thus, a spectral image scanning endoscope is achieved, by combining such a scanning spectral imaging system with the fiber bundle. This obtained spectral image scanning endoscope is low-cost and easy to fabricate. The spectral imaging endoscope can be applied to perform macro-imaging for biological samples and micro-imaging for resolution test target. From those tests, the spectral resolution of our imaging system is about 5 nm and the spatial resolution is about 26 μm. These results suggest that our system has the potential for clinical and point-of-care applications.

1. Introduction

In bio-photonics area, deep tissue imaging is still a scientific challenge due to the strong scattering property of bio-tissues in the visible and near infrared region [1–3]. In order to have a better visualization of the tissues and organs inside the human body, minimally-invasive imaging systems were developed in some biomedical scenarios. For example, in clinical diagnostics, endoscope systems have been widely applied to perform *in vivo* or *ex vivo* imaging for tissues and organs. Combinations of endoscopy and advanced imaging techniques have attracted great interests in the past few years. For example, nonlinear optical endoscopy was developed for three-dimensional (3D) optical imaging [4]; and optical coherence tomography (OCT) based endoscopy has been utilized in elastic scattering imaging [5–7]. In addition, fluorescent endoscope can provide the real-time cellular imaging [8,9] due to the high contrast of fluorescent imaging [10,11]. By observing these spatial images from the endoscope system, medical workers can make an initial diagnosis. In practice, pathological examinations are usually required before a final diagnosis can be made.

However, some lesions are too difficult to perform biopsy [12]. To overcome this problem, researchers applied some fiber probes to perform diffuse reflectance spectroscopy on lesion tissues [13–17]. The detected spectral signals, which contained the light–tissue interaction information, have been successfully used to differentiate tumors from normal tissues. By combining spectral and spatial information, researchers have developed spectral imaging endoscopes [18–21]. In Ref. [18], Kester et al. applied an image mapping technique to carry out real time spectral imaging for human tissues. In Ref. [19], Zhang et al. combined Fourier transform spectroscopy with an endoscopy to develop Fourier transform endospectroscopy, which might be used to study the tissues under the illumination of mid-infrared light [22].

Both Refs. [18] and [19] utilized image relay system to transmit the images obtained from a fiber bundle to a spectral image mapping/scanning system. However, these spectral image mapping/scanning systems required relatively expensive optical elements. In our work, we report the design and implementation of a compact, low-cost multispectral imaging endoscope with a portable spectral image scanning system. It can be used in point-of-care applications. In addition, our system is built from some off-the-shelf components, and the cost can be in a relatively low level. In the present system, we used a small-size imaging lens to simulate a graded-index (GRIN) lens or micro lens in an endoscope. We can use this setup to verify the feasibility of the

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https://doi.org/10.1016/j.optcom.2018.07.044
Received 14 May 2018; Received in revised form 8 July 2018; Accepted 14 July 2018
Available online 17 July 2018

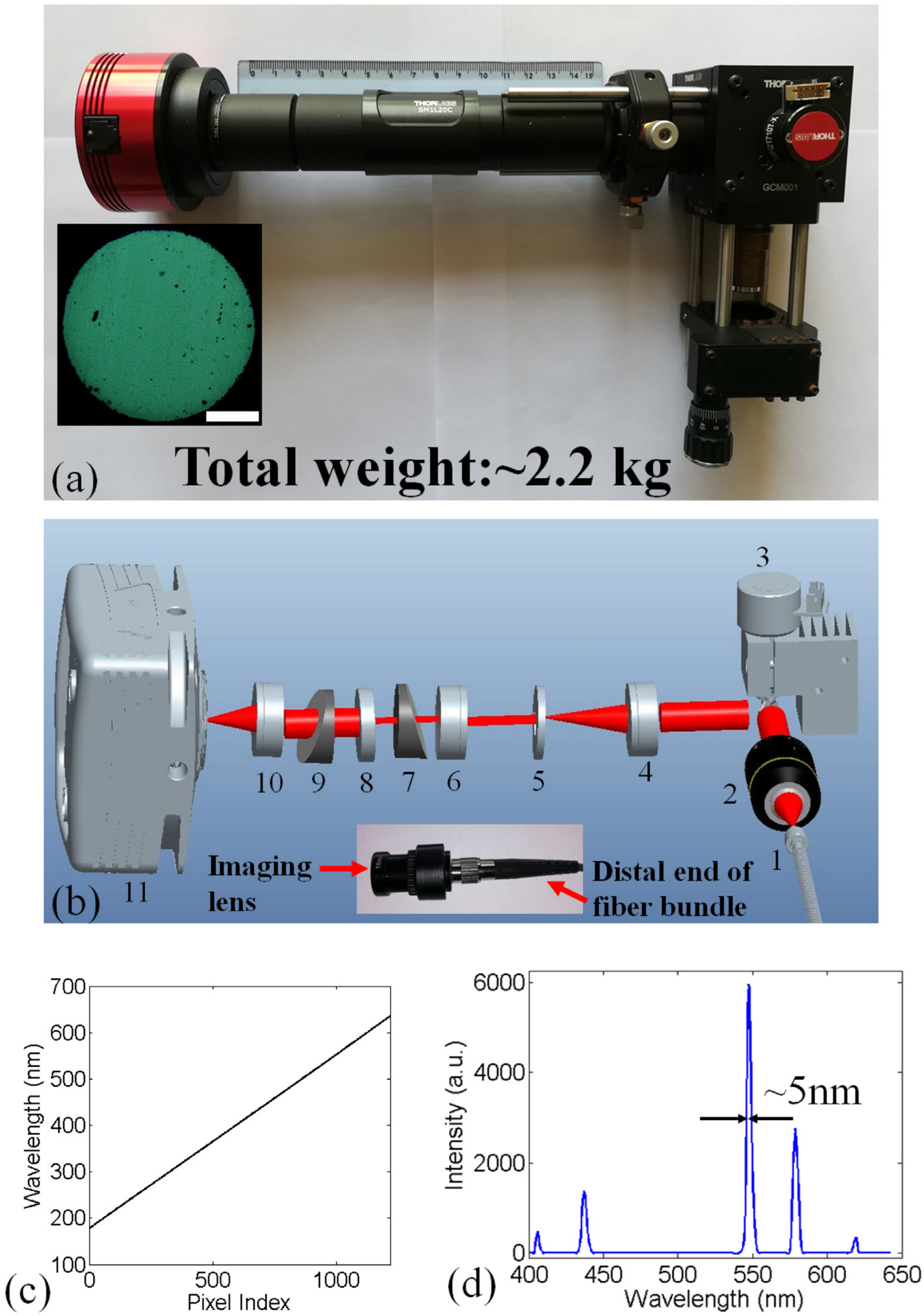

Fig. 1. (a) Photo of our fiber bundle based multispectral imaging endoscope. The unit for the ruler is millimeter. Inset: Photo of fiber bundle's end face; Scale bar: 500 μm. (b) Schematic illustration of our system: 1. fiber bundle, 2. objective, 3. galvo mirror, 4. doublet lens, 5. slit, 6. doublet lens, 7. prism, 8. grating, 9. prism, 10. doublet lens and 11. CMOS. Inset: Photo of the distal end of fiber bundle. (c) Relationship between the pixel index of CMOS camera and the calibrated wavelength. (d) Spectrum of a mercury lamp measured by our system.

system. Based on our system, we will refit a medical endoscope for *in-vivo* spectral imaging in the future. The details of the system construction will also be presented in our work.

2. Methods and materials

In our work, we utilized a fiber bundle to transmit images of experimental samples. Usually, a micro-imaging system is sufficient to capture the spatial image from the proximal end of the fiber bundle. However, a micro-imaging system cannot acquire the spectral information. Hence, we replaced the camera of a micro-imaging system with a home-made imaging spectrometer to detect the spatial and spectral information simultaneously. As described in other works, only the spectral information from a line region can be obtained by an imaging spectrometer [23]. To derive 3D spectral image cube (two-dimensional spatial images at various wavelengths), a galvo mirror was installed between the micro-imaging system and the imaging spectrometer.

Fig. 1(a) and (b) show the photo and schematic illustration of our system, respectively. All of the optical–mechanical components were