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Feasibility Demonstration of Wide-Field Fourier-Spectroscopic-Imaging in Infrared Region

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Abstract

We are aiming at the realization of living-environment sensor and non-invasive blood-sugar sensor by the proposed imaging type 2-D Fourier spectroscopy. This method is based on the phase-shift interference between the object beams. As a result, even if the object beams are spatially incoherent, we can observe the phase-shift interference phenomena. In the near infrared region, we can obtain the high-contrast blood vessel image of mouse’s ear in the deeper part by InGaAs camera. Furthermore, in the mid-infrared region, we have successfully measured the radiation spectroscopic-imaging with wild field of view by the infrared module, such as the house plants.

Keywords: Fourier spectroscopic imaging, Infrared radiation, Spectroscopic tomography, Non-invasive blood sugar sensor, Unconstructed-environment measurement;

1. Introduction

We are trying to apply the proposed imaging-type 2-dimensional Fourier spectroscopy [1]-[4] into the natural environment measurement such as the earth observation satellite. As shown in figure 1, the object can't be illuminated by the light source and the field of view is very wide. To solve these issues, we are developing the wide-field-of-view spectroscopic-imaging that can measure the radiation heat. We have successfully obtained the mid-infrared Fourier spectroscopic image that is radiated from object itself. Because the imaging-type 2-dimensional Fourier spectroscopy is the phase-shift interferometer between objective beams without reference beam, the objective rays that are radiated from the single bright-points interferes in each on the imaging plane. Thus, we can realize the 2-dimensional spectroscopy of the spatially incoherent light beams. To apply the proposed method into the mid-infrared region, we should solve the two issues. One is the development of the long-stroke (\geq 10\text{mm}) and

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high-accurate (≤10nm) phase-shifter. And to secure the accuracy of spectroscopic character, we should calibrate the phase-shift value in accordance with the angle of filed [5].

In this report, we introduce SIDM (Smooth Impact Drive Mechanism) with linear encoder to realize the long-stroke high-accurate phase-shifter. We describe the experimental results of the spectroscopic imaging in the infrared region.

2. 2-dimensional Fourier spectroscopy in the mid-infrared region with spatially incoherent lights that is emitted from target object itself

2.1 Optical system for the imaging-type Fourier spectroscopy in the mid-infrared region

We measured the 2 dimensional spectral characteristics in the mid-infrared region that is the spatially incoherent lights emitted from object itself. As shown in figure 2, we construct the imaging-type Fourier spectroscopy that is based on the infinity optical system. We introduce the black body as light source and the wire net as a sample. The radiated mid-infrared lights are collimated by the objective lens. The collimated rays are reflected by the variable phase filter that is installed at the angle of 45 degrees on the Fourier transform plane. The variable phase filter is a kind of phase shifter. And the reflected beams form the image on the camera (Maker: NEC Avio Infrared Technologies Co., Ltd., Type: C100V, Pixel size: 23.5μm×23.5μm) through the imaging lens.

2.2 Variable phase filter for the mid-infrared spectroscopy

The proposed imaging-type 2-dimensional Fourier spectroscopy uses the variable phase filter that can give the arbitrary phase shift between the half flux of the objective beams. The variable phase filter has the movable mirror and the fixed mirror. To apply the variable phase filter into the mid-infrared region, the movable mirror should be actuated in long stroke (≥10mm) and with high accuracy (≤10nm). To satisfy these conditions, we introduce the commercially available stage (Maker: Nano Control Co., Ltd., Type: TS104-G, Product name: Nano Step Slider) which is actuated by SIDM and secure the accuracy of parallel displacement with the linear encoder.
2.3 Experimental results of mid-infrared spectroscopic imaging

The experimental results of mid-infrared spectroscopic imaging are shown in figure 3. Fig.3 (a) shows the observation image of the wire net that is made of the stainless steel. The changes of interference intensities at different positions which are pointed by red circles on observation image are shown in Fig.3 (b). Phase differences are given to the half flux of objective rays by variable phase filter. We confirmed the changes of imaging intensities with interference phenomenon on whole area of the observation image in the mid-infrared region. Fig.3 (c) shows the Fourier spectral characteristics that are transformed from the interferograms in Fig.3 (b). We confirmed the smooth spectral characteristics based on Planck’s law. We demonstrated feasibility of 2-D spectroscopic imaging with spatially incoherent light in the mid-infrared region by proposed spectroscopic imaging method.

![Interferogram and Spectral Characteristics](image)

2.4 2-D spectroscopic imaging of plant in the middle infrared region

Next, we describe the experimental results of the wild-field 2-D spectroscopic imaging by the proposed spectroscopic imaging method. This experimental optical system is an infinity optical system. Because the emitted lights from far-field are parallel rays, the optical system can be constructed only by imaging lens without object lens.

The wild-field-view infrared image is shown in figure 4. The house plant is shown in Fig.4 (a). In this experiment, we used the Infrared camera module (Maker: NEC Avio Infrared Technologies Co., Ltd., Type: C100V, Pixel size: 23.5μm×23.5μm). The interferogram and the spectral characteristics which were obtained from the different positions on the branch of plant are shown in Fig.4 (c) and (d). This spectral characteristics is compared with the spectral characteristics of black body that was shown in the Fig.3(c). We can confirm the absorption spectrum in the Fig.4 (d). As the result, we can verify the applicability of the imaging-type 2-D spectroscopy to the spatially-incoherent light. In the future work, spectrum accuracy will be quantitatively evaluated.
3. The spectroscopic tomography of the biological tissues

3.1 The spectroscopic tomography of biological tissues in the visible region

We obtained the spectroscopic tomography of a mouse’s ear by the proposed spectroscopic imaging method. The observed tomography by scanning the measurement plane in the depth direction mechanically is shown in figure 5. We observed the mouse’s hair on the skin surface. In addition, the blood vessel’s image can be observed by scanning the measurement plane into the internal skin. Then, the image of blood vessel was blurred by scanning the
measurement plane into the deeper skin. Because this experimental equipment is an infinity optical system, the object lights from focal plane are collimated by object lens. We install the variable phase filter on the Fourier transform plane of the optics system. The variable phase filter can give the arbitrary phase difference to half flux of object lights. Thus, we can obtain the 2-D spectral characteristics. Because this spectroscopic imaging method can limit the depth into the focal plane, we can acquire the 3-D spectroscopic tomography by scanning the focal plane mechanically in the depth direction.

Spectral characteristics which were obtained from the blood vessel area near the skin surface in the visible region are shown in figure 6. The blood vessel area is indicated by dotted line. The spectral characteristics which are obtained from the blood vessel area and the biological tissue area are shown in Fig.6 (a) and (b). We can confirm that the waveform (Fig.6 (a)) has the peak value around 700nm in the blood vessel area. And the waveform (Fig.6 (b)) has the peak value around 650nm in the other areas. The spectral images in each bandpass 400nm~500nm, 500nm~600nm and 600nm~700nm are calculated from spectrums at all pixels, as shown in Fig.6 (c). We observed the blood vessel area as the dark image, because the blue light (400nm~500nm) was absorbed by blood. Because the red light transmitted the blood component, we observed the same area as the light image in 600nm~700nm.

3.2 2-D spectroscopic imaging of biological tissue in the near infrared region

We developed the proposed method into the near infrared region. Because the biological tissue has high transmittance in this region, the spectral absorption index can be measured. The blood vessel image of mouse’s ear was obtained in near infrared region by proposed spectroscopic imaging method. We used InGaAs camera (Maker: Hamamatsu Photonics K.K., Ltd., Type: C10633-13) which has high sensitivity around 900nm~1700nm in the near infrared region. We confirmed the higher contrast observation image that was shown in the left hand side image of figure 7. The blood vessel area is indicated by dotted line. Furthermore, we have successfully obtained the different spectral characteristics at the blood vessel area and the other areas. Those are shown in the right hand side graph of figure 7. In the future work, we will quantitatively evaluate the spectrum accuracy.
Figure 7 2-D spectroscopic imaging of biological tissue in the near infrared Region

4. Conclusion

We successfully obtained the 2-dimensional Fourier spectroscopy of the mid-infrared light that is radiated from the target object itself. The proposed method can be applied for the spatially incoherent lights, because the objective beams emitted from single bright-points interfere in each other. To apply the proposed method into the mid-infrared region, we develop the long-stroke ($\geq 10$mm) and high-accurate ($\leq 10$nm) phase-shifter using SIDM. And we demonstrate the feasibility of mid-infrared Fourier spectroscopic imaging. In the future work, we will quantitatively evaluate the spectrum accuracy using the samples whose spectral characteristics are well known.

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