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Measurement of the Mid-infrared Fourier Spectroscopic Imaging of Whole Human Face by Portable Apparatus (Size: 50*50mm, Weight: 200g)

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ABSTRACT

In the daily living space, measurement of the biological-substance distributions such as sebum can be realized by the proposed method of imaging-type 2-dimensional Fourier spectroscopy. This method has the strong robustness for mechanical vibrations. So, the spectrometer (size: 50*50mm, weight: 200g) can be produced without anti-vibration mechanism. Moreover, the phase shifter is a core part of the spectrometer, and it is constructed by the low-price bimorph type actuator which is depending on the vibration control of the piezoceramic in proposed method. It is appropriate as the actuator of the phase shifter from the evaluation results of the actuator straightness and position accuracy in the mid-infrared region. As we know, the Fourier spectroscopy has a high light utilization efficiency. Therefore, the low price microbolometer can be used as the imaging sensor. So, the low-price (10,000 U.S. dollars), compact and high portability spectrometer can be produced. Furthermore, the much higher position accuracy in the short wavelength region is requested as we know, the phase shift correction method has been proposed. In this paper, high performance evaluations of the portable spectroscopy apparatus have been discussed by using the CO_2 laser spectroscopy results in the mid-infrared region. Then, the phase shift correction method was explained. At the end, we demonstrated the feasibility of the mid-infrared imaging of whole human faces without active illuminations.

Keywords: Fourier spectroscopy, Spectroscopic imaging, Portable spectroscopy apparatus, Middle infrared light, Biological-substance, Common-path interferometer

1. INTRODUCTION

In the daily living space, measurement of the biological-substance distributions such as sebum can be realized by the proposed method of imaging-type 2-dimensional Fourier spectroscopy [1]. The proposed method is a near-common-path phase-shift interferometer, has the strong robustness for mechanical vibrations. So, the spectrometer can be produced as very simple optical configuration without anti-vibration mechanism. Therefore, the spectrometer's size can be controlled under the 50*50mm and the weight is only about 200 grams. Moreover, the phase shifter is a core part of the spectrometer, and it is constructed by the low-price bimorph type long stroke actuator which is depending on the vibration control of the piezoceramic in proposed method. It is appropriate as the actuator of the phase shifter from the evaluation results of the actuator straightness and position accuracy. As we know, the Fourier spectroscopy has high light utilization efficiency. Additionally, in proposed method we do not use optical part to limit the field angle, which is different about the conventional FT-IR. So, the light utilization efficiency is higher than FT-IR. Therefore, the low price microbolometer can be used in the optics as the imaging sensor. From the above reasons, the low-price, compact and high portability spectrometer can be produced using the proposed method. Furthermore, take advantage of the 2-dimensional spectral imaging which can be obtained by the proposed method. As another mid-infrared Fourier spectroscopy's characteristics, the measurement targets are not need be illuminated. Because of the radiation heat which emitted from the measurement targets can be used as the source light. So, the wide-field view and omnidirectional spectroscopic images can be obtained, if a hyperboloidal mirror is installed as the objective lens [2].

In this report, the principle of the proposed method was explained in the second chapter. In the third chapter, the high performance evaluations of the portable spectroscopy apparatus have been discussed by using the CO2 laser spectroscopy results in the mid-infrared region. In the fourth chapter, the phase shift correction method was explained.

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At the end, we demonstrated the feasibility of the mid-infrared imaging of whole human faces without active illuminations.

2. IMAGING-TYPE 2-DIMENSIONAL FOURIER SPECTROSCOPY

Figure 1 shows the schematic optical diagram of the imaging-type 2-dimensional Fourier spectroscopy. That is a near-common-path phase-shift interferometer. We have installed the phase shifter which is called variable phase filter at the optical Fourier transform plane. The variable phase-shifter consists of two kinds of mirror. One is the movable mirror which is actuated by bimorph type piezoceramic. The other one is the fixed mirror. The arbitrary phase difference can be given to the half of the light flux by the variable phase filter.

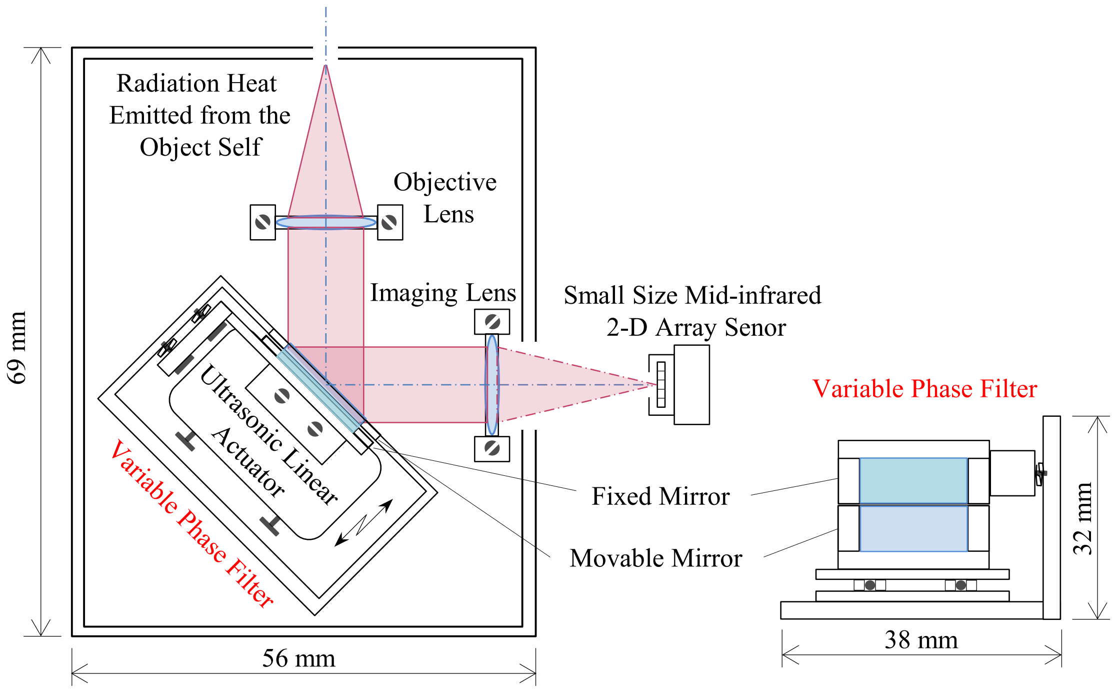


Figure 1. The schematic optical diagram of the imaging-type 2-dimensional Fourier spectroscopy

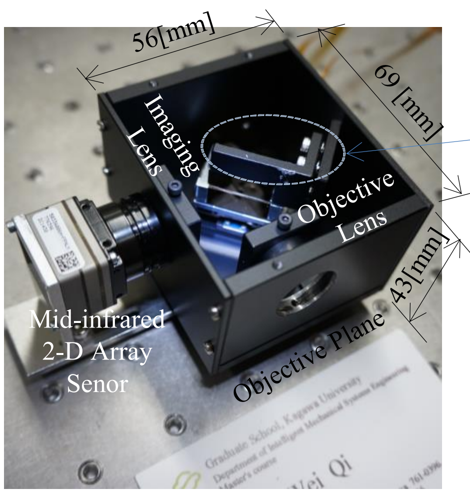
The radiation heat which emitted from the measurement targets is collimated by the objective lens; the collimated rays are reflected by the variable phase filter which is installed on the optical Fourier plane at 45 degrees. Then the reflected rays are imaged on the mid-infrared 2 dimensional array sensor which is installed on the image plane by imaging lens. The interference-intensity-changes which are interferogram can be obtained at every pixels by the mid-infrared 2 dimensional array sensor.

The variable phase-shifter gives an arbitrary phase difference at a half flux of climated objective rays. As an initial condition, the phases of every ray emitted from single bright points are equal and form the bright interference image. If half wavelength phase-difference is given to the half flux of objective beams, two fluxes are interfered each other on imaging plane and weaken each other as interference phenomenon. In this case, the intensity of formed points becomes to be low. And then, if single wavelength difference is added to the half flux of objective beams, two half fluxes are strengthen and form bright-points with high intensity. If we use monochromatic light as a light source, the simple cosine waveform of interference-intensity changes is observed in accordance with the amount of phase-shift value. For spectroscopy, we use the polychromatic light as a light source. For long wavelength components, cyclic changes of interference intensity become to be low frequency. Intensities of short wavelength components changes with high frequency. Sum of these multiple-cyclic interference-intensity-changes form the interferogram at every pixels simultaneously. As mentioned previously, because the interferogram consists of multi-frequency waveform, we can acquire the relative intensities at each frequency analysis by mathematical Fourier transform algorithm. As we know, the conventional Fourier spectroscopy, we can convert into spectroscopic characteristics which are the relative intensities at each wavelength by inverted value of frequency.

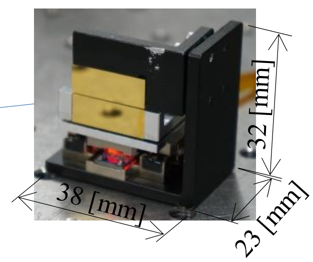
3. THE PORTABLE MID-INFRARED FOURIER SPECTROSCOPY APPARATUS

3.1 The specifications of the portable mid-infrared Fourier spectroscopy apparatus

The portable mid-infrared Fourier spectroscopy apparatus is shown in figure 2. The germanium lenses which have high transmission in the mid-infrared region are used in the optics. The microbolometer (Maker: FILR, Type: Quark 336) was used as the 2 dimensional imaging sensor. The variable phase shifter was actuated by the low-price bimorph type long stroke actuator (Maker: Technohands CO., Ltd, Type: TULA XDT50-045, Stroke: 4.5mm). The proposed optics is a near-common-path phase-shift interferometer with the strong robustness against mechanical vibrations. So, the proposed optics can be constructed as simple optical configuration without anti-vibration mechanism. From the above reasons, the low-price, compact and high portability spectroscopy apparatus can be achieved by using the proposed method. Moreover, the spectroscopic imaging can be realized not only under a prepared environment such as laboratory, but also under the unstructured environment such as outdoor.



Variable Phase Filter



Specifications	
Outside Dimension	69[mm]*56[mm]*43[mm]
Wavelength Region	8[µm]~14[µm]
Phase Shift	5.6[mm]
Wavelength Resolution	18[nm]

Figure 2. The portable mid-infrared Fourier spectrometer and specifications

3.2 Performance evaluations of the portable mid-infrared spectroscopy apparatus

The performance of the portable mid-infrared spectroscopy apparatus is evaluated by obtaining the line spectrum of CO_2 laser (Maker: Access Laser, Wavelength: 10.6 [µm], Half bandwidth: 0.5 [µm]). The mid-infrared light emitted from the light source CO_2 laser transmitted the pinhole which was installed on the measurement plane. The phase difference was given to the half of flux by the variable phase filter. The interferogram was gotten by the mid-infrared 2-dimensional array sensor on the imaging plane. That is shown in figure 3. Then, the spectroscopy characteristics can be obtained using the mathematical Fourier transform algorithm. As the figure 3 shows, the line spectrum of CO_2 laser can be confirmed at the wavelength 10.6 µm with the half bandwidth 0.5µm. That is same as the specifications of the light source CO_2 laser. So, the proposed the portable mid-infrared spectroscopy apparatus can obtain the mid-infrared Fourier spectroscopic imaging. That was demonstrated by obtaining the line spectrum of a CO_2 laser.

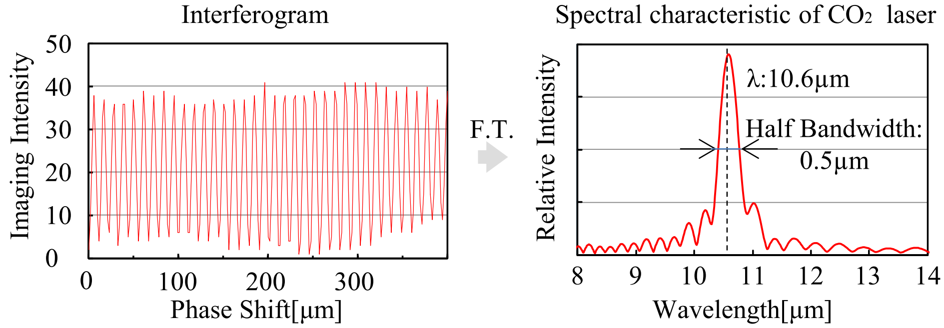


Figure 3. Obtained line spectrum of CO_2 laser by proposed portable mid-infrared Fourier spectroscopy apparatus

4. PHASE SHIFT CORRECTION METHOD BY THE BANDPASS FILTER

4.1 Why the phase shift correction is necessary

Our final goal is the realization of the non-invasive measurement of the biogenic-substance, such as the blood glucose concentration, by using imaging-type 2-dimensional Fourier spectroscopy. Here, high accuracy of the quantitative analysis and precision measurement of components are very crucial. The background such as the light-source fluctuation (vertical axis, about 2%) and the phase shift uncertainty (horizontal axis, about 0.2%) are inevitable issues when obtaining high accuracy. Reference light is necessary to correct errors due to light source fluctuation and phase shift uncertainty [3]. In the chapter 3, the high performance evaluations of the portable mid-infrared spectroscopy apparatus was discussed by using the CO_2 laser spectroscopy result in the mid-infrared region. But in the short wavelength region, such as the visible light region, the much higher position accuracy of the phase shift is requested. In this chapter, the phase shift correction method will be explained by using the He-Ne laser spectroscopy result.

4.2 The spectroscopic characteristic of He-Ne laser which obtained by proposed portable spectroscopy apparatus

The optics was used same as in the 3.2 section. The Plano convex lenses (BK7) were used as the objective lens and the imaging lens. The light source was He-Ne laser. According to the sampling theorem, the sampling was set at 141 mm. The phase shift was 70μm and the wavelength resolution was 5.72nm. The obtained results are shown in the figure 4.

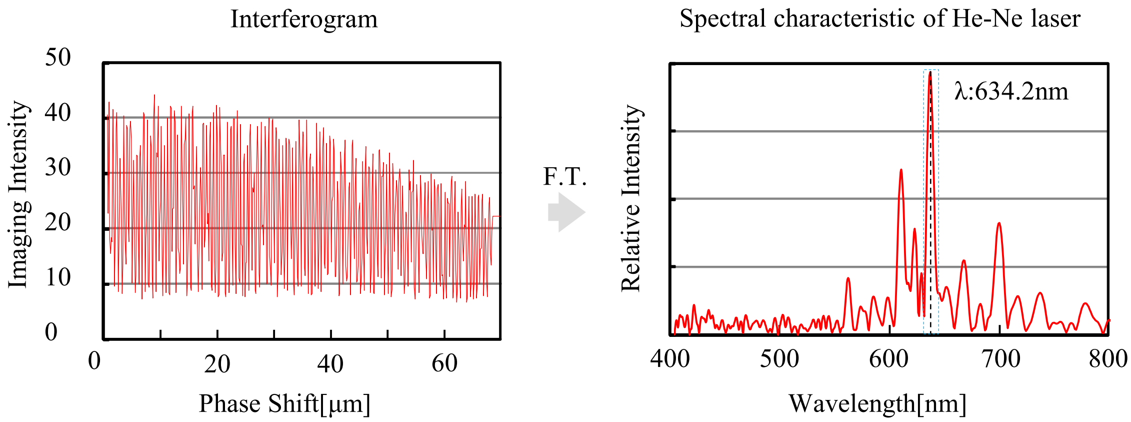


Figure 4. Obtained line spectrum of He-Ne laser by proposed portable Fourier spectroscopy apparatus

The spectroscopic characteristic of the He-Ne laser is shown on the right hand side of the figure 4. A few line spectrums which are around the signal wavelength 634.2 nm are confirmed. These were caused by the position error of the phase shift.

4.3 Extract the He-Ne laser signal component and the phase shift error component from obtained spectroscopic characteristic

The line spectrum of wavelength 634.2nm with 13nm width was extracted as the signal component from the obtained spectroscopic characteristic. That is shown on the left hand side of the figure 5. The others spectrums are noise component which from the position error of the phase shift. These are shown on the right hand side of the figure 5.

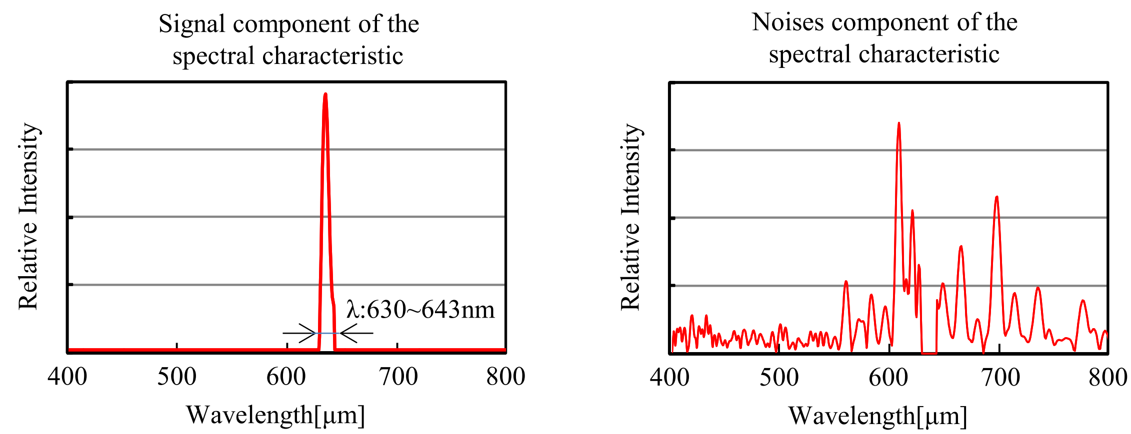


Figure 5. Extract signal component and the noises component from the obtained spectral characteristic

Then, the signal component and the noise component were analyzed by mathematical inverse Fourier transform. The results are shown in the figure 6.

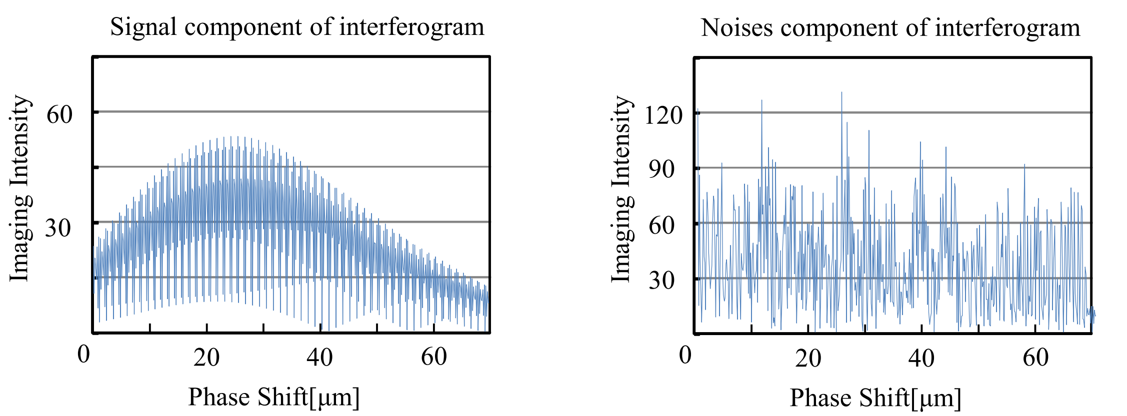


Figure 6. The signal component of interferogram and noises component of interferogram

The periodic curves which obtained from the signal components of the spectroscopic characteristics by inverse Fourier transform. These can be confirmed on the left hand side of the figure 6. The noise components are shown on the right hand side of the figure 6. In the future, the signal components and noise components will be used for phase shift correction.

5. RADIATION LIGHTS EMITTED FROM HUMAN BODIE'S HEAT ITSELF

We demonstrated the feasibility of the mid-infrared imaging of the whole human face without active illuminations. The radiation light was emitted from human heat (Temperature: around 300K). In this evaluation, to measure the whole face area, the optical magnification of the conjugate imaging unit was set to 0.025×. Using the mid-infrared camera (Maker: FILR, Type: Quark 336). The observation image of a whole human face is shown in the figure 7. In the future, the spectroscopic image of a whole human face will be obtained and the quantitative measurement will be conducted.

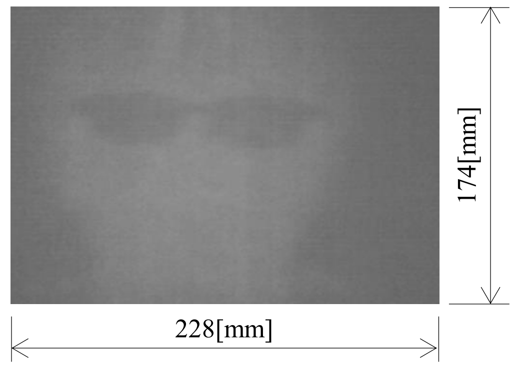


Figure 7. The mid-infrared observation image of whole human face

6. CONCLUSION

The portable mid-infrared Fourier spectroscopy apparatus has been proposed. The high performance evaluations of the portable spectroscopy apparatus have been discussed by using the CO_2 laser spectroscopy results in the mid-infrared region. For improving to the short wavelength spectroscopic measurement, the phase shift correction method was explained. At the end, we demonstrated the feasibility of the mid-infrared imaging of whole human faces without active illuminations. In the future, the phase shift correction will be conducted and the spectroscopic image of a whole human face will be obtained.

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