Portable Monitoring Devices Using IR Technology and their Social Impact

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Abstract
Portable monitoring devices are widely used by people from different sectors of the society and their use is steadily increasing. Health monitoring and environmental monitoring have drawn the attention of many personnel as key monitoring areas that need major improvements. Targeting these advances, infrared (IR) technology has used to develop the imaging – type two – dimensional Fourier spectroscopy which has incredibly high potential to succeed in both areas.

Imaging – type two – dimensional Fourier spectroscopy is a simple optical configuration which used IR as input light source, a camera as the detecting device, a variable phase filter as phase changer, and few more lenses. First, sample is illuminated using light source and reflected or transmitted lights send through a lens called objective lens. Then, these lights are directed to the phase filter which has movable part and stationary part. Using this, part of the incident lights are delayed before sending to a camera through lens called imaging lens. The camera collects lights which have different intensities. Finally, absorbed wavelengths of light can be found using Fourier Transform and they can be used to calculate measurements.
In health monitoring, blood glucose measurement and haemoglobin testing are main targeted areas. Since the proposed system is non-invasive, it is pain-free method. Initially system was tested with biogenic substances obtained from mouse ear and then experiments were carried out for glucose measurement at laboratory conditions. This device will release painful experience of blood glucose measurement by millions of diabetic patients.

This system works like telescope. Therefore, broad views of environment can be taken and those tomographic images show the comprehensive details of heat distribution in that area. This heat pattern can be used for many predictions about selected environments and plants in that area. Therefore, portability, easy and accurate measurements will improve people's understanding about their surroundings.
Two portable systems, one has the size equivalent to human finger and other weighs around 500 g, have already been developed. Socially, this system has the potential to change many areas in our society from health monitoring to environmental monitoring.

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

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 where a phase shifter, known as variable phase filter has been installed at the optical Fourier transform plane. The variable phase-shifter has two mirrors. One is the movable mirror which is actuated by bimorph type piezoceramic and the other is the fixed mirror. The arbitrary phase difference can be given to the half of the light flux by the variable phase filter.

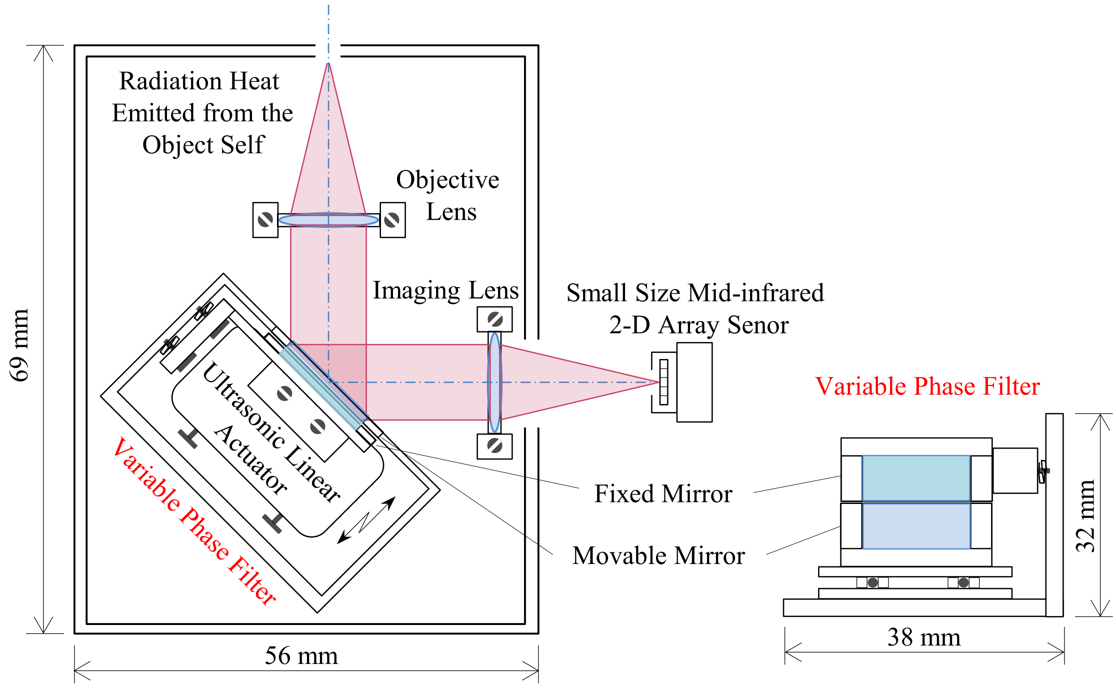


Figure 1. The schematic optical diagram of the imaging-type 2-dimensional Fourier spectroscopy

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 pixel 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.

General idea of the interferogram-generation by the spatial phase-shift

In this section, we explain the concept of the interferogram generation by the spatial phase-shift. The interferogram is formed with the interference phenomena of the multiple wavelengths. First, we describe the spatial-phase-shift interference phenomenon of the monochromatic light. In this case, the interference fringe is formed as the periodical change of the imaging intensity.

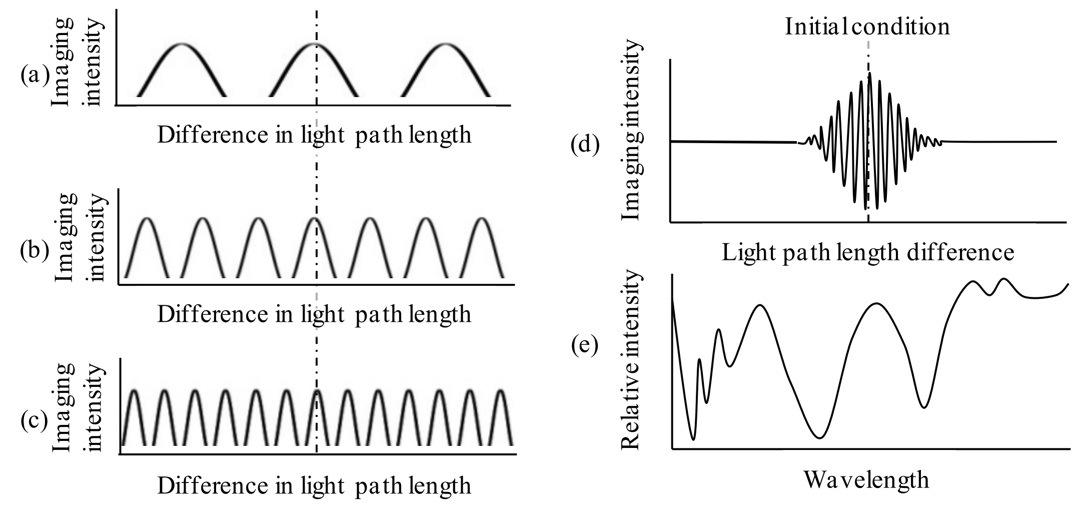
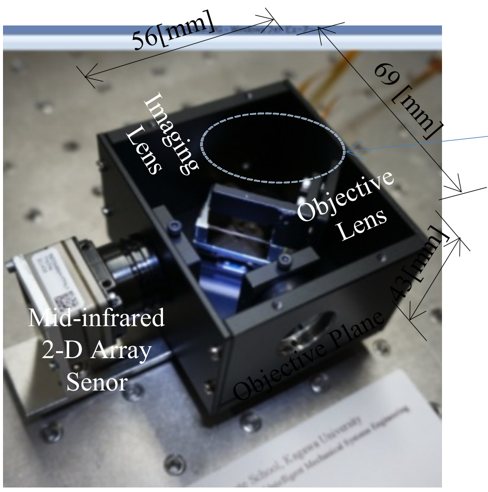


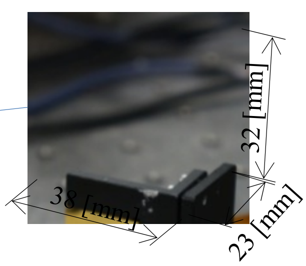
Fig.2 Principle of the generation of the interferogram.

The graph (a), (b), (c) in the figure 2 show the example of the imaging-intensity changes. The graph (a) shows the interference fringe of the long wavelength component. And the graph (b) illustrates the intensity distribution of the middle wavelength light. The graph (c) is the case of the short wavelength. The interferogram is the synthesized waveform that is formed as the summation of these multiple waveforms. In these graphs, the broken line points the initial condition with the no-phase difference. Because the phase-difference is zero for any kinds of wavelength at the initial condition, the interference intensity is strengthened in every wavelength. Thus, the amount of interferogram, that is the summation of these interference intensities, shows the maximum value at the initial state. Away from the initial state, the interference intensity is periodically changed as the sinusoidal wave in accordance with the amount of the spatial phase-shift. In case of the long wavelength component as shown in the graph (a), the interference intensities change in low frequency in accordance with the amount of the spatial phase-shift. Thus, the spatial frequency of fringe pattern of long wavelength component is low. On the contrary, the interference intensity changes spatially in high frequency in the short wavelength component as shown in the graph (c). The spatial frequencies of fringe pattern are different with the wavelength. Therefore, the summed waveform of these multiple spatial frequency becomes to be the DC component away from the initial state. As the result, the interferogram shown in the graph (d) is generated by the spatial phase-shift. And then, by computing the Fourier transform, we can obtain the relative intensities in each wavelength as shown in the graph (e). This distribution of the relative intensities describes the spectroscopic characters.

The portable Mid-infrared Fourier Spectroscopy Apparatus

The portable mid-infrared Fourier spectroscopy apparatus is shown in figure 3. 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.





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

Fig. 3 The portable mid-infrared Fourier Spectrometer and specification

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.

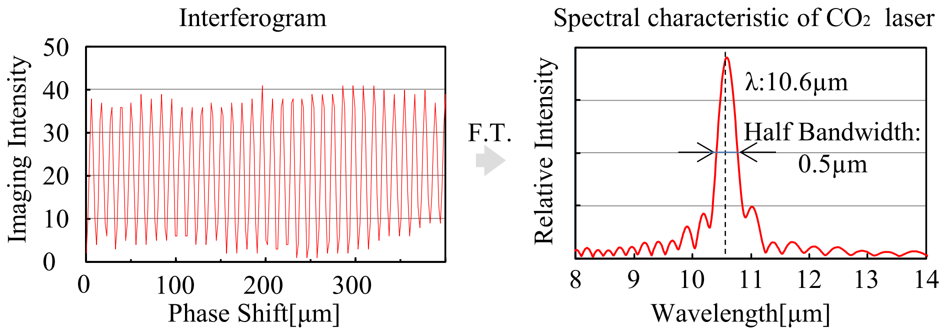


Fig. 4 Obtainedline spectrum of CO2laser by portable mid-infrared Fourier spectroscopy apparatus

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.

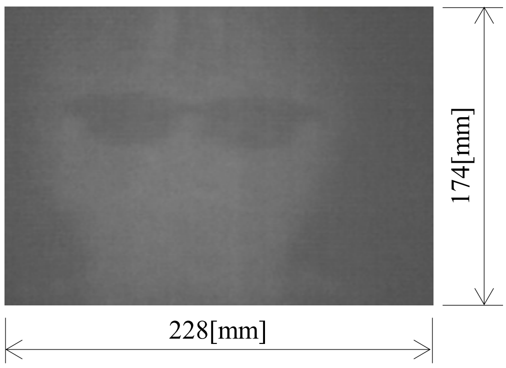


Fig. 5 The Mid-infrared observation image of whole human dace

One-shot Fourier Spectroscopic Imaging

Figure 6 shows the optical path of the proposed Fourier spectroscopic imaging that is based on the spatial phase-shift as the transmission type. The left side and the right side picture show the side and top view of the proposed method respectively. As shown in the side view, the objective beam is collimated by the objective lens and form the image in a line (perpendicular to the paper). And as shown in the top view, we introduce the relative-type phase-shifter into the infinity optical-imaging system. The objective beam reaches to the imaging plane to be inclined with respect to the principal axis. The relative-type phase-shifter is constructed with the two kinds of mirror as show in Fig.3. One is the reference mirror and another one is the tilt mirror. The tilt mirror is relatively inclined to the reference mirror. Thus, the relative phase-difference between the half fluxes of objective beams is given by the spatial phase-shift. Therefore, the wavefront of the two objective beams reach the imaging plane with arbitrary angle in accordance with the inclination of the tilt mirror. The relative incident angle between these beams gives the amount of spatial phase-shift proportional to the spatial distance on the imaging plane. Thus, without the mechanical phase-shifter as time-domain method, the change of interference intensity with the phase-shifted value, that is called interferogram, is spatially formed in a line on the imaging plane with high time resolution.

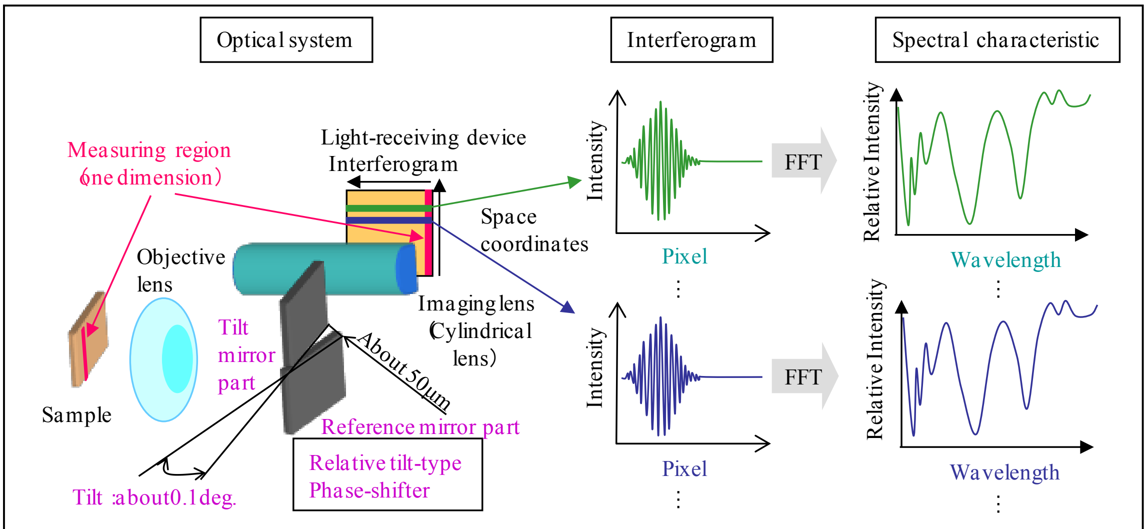


Fig.6 Conceptual diagram of one-shot real-time Fourier spectroscopic imaging.

As shown in Fig.3, in each horizontal pixel-line, the interferograms are formed as the interference fringes by the spatial phase-shift. In other words, the spectroscopic characters are expressed as the periodical line-and-space fringes. And then, after these interferograms are calculated by Fourier transform algorism, the spectral characteristics are obtained in each horizontal pixel-line. Thus, we can realize the one-dimensional Fourier spectroscopic measurement with one-shot imaging.

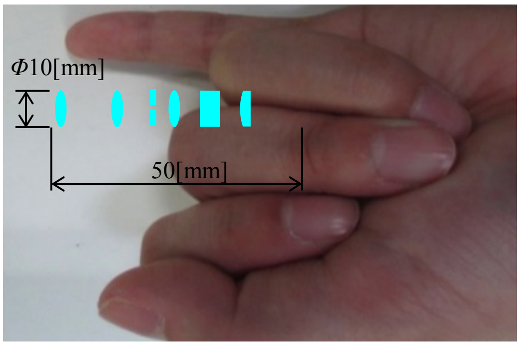


Fig.7 The trail product of the little-finger-size one-shot spectroscopic tomography.

Advantages of proposed method over the imaging type 2-dimensional Fourier spectroscopy

In previous study, we proposed the imaging type 2-dimensional Fourier spectroscopy. This is the time-domain phase-shift-interferometer between the object lights. Because the imaging-type 2-dimensional Fourier spectroscopy is the near-common-path interferometer, the one of the advantages is the strong robustness to the disturbance inside the optical system. And because this optical system doesn't use the reference light, the optical equipment can be constructed as the simple structure with high portability. And, based on the imaging optics, this spectroscopic imaging secures the high spatial-resolution.

But the disadvantage of this technology is the low time-resolution caused by the time-domain phase-shift operation. To apply this method into the unconstructed environment, the temporal fluctuation of the target object, such as atmospheric disturbance, is the main issue. To improve the low time-resolution, we introduce the spatial phase-shift interferometric method into this method. In this proposed method, the phase-shift interference phenomenon is generated spatially in a moment. For this purpose, we assign the one dimension of the light receiving device to the spatial-phase-shift space. Thus, this method is capable of the one-shot measurement of the one-dimensional spectroscopic imaging.

Social Impacts

Number of diabetic patient around the world has increased over 285 million in 2010. Controlling the blood sugar level of those diabetic patients has the utmost importance to avoid endangering their health further. Hence daily monitoring is the way to get a feedback about the current condition and non-invasive, quick method is preferable. However, main impediments of having daily monitoring are availability of simple and efficient equipment and the fear due to the pain of using existing systems. Most hospitals around the world uses needle to take out bloods for testing and which may be painful but amount of pain will mainly depend on the skill of nurse who is taking blood. Portable equipment that we propose here is mainly using non-invasive techniques which ultimately release the pain of patients. Moreover, portability and easiness, and sound technique will make our equipment more efficient. Therefore, it is quite obvious that this equipment will make huge impact on diabetic patients around the world.

One-shot Fourier spectroscopic tomography utilizes the advantage of confocal effect that can limit the measuring depth into the focal plane. Moreover, the spectral line-imaging with high time resolution can be realized by one frame data without mechanical phase-shift operation. In the result, the proposed method is suitable for multi-components and moving biological-tissues. And, the beans-sized and low-price spectroscopic unit that can be installed into smartphones will be available as commodity. It means that we can use this equipment as a healthcare sensor with smart phone or iPhone and ultimately 1.75 Billion smart phone users around the world have an incredible opportunity to check and track their health condition with mobile phones. This will improve the awareness about them and finally will boost the whole health care sector around the world.

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. One-shot type fourier spectroscopy was introduced and advantages and disadvantages were discussed. Finally social impact of these devices were discussed.

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