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PROPOSAL OF IMAGING-TYPE 2-DIMENSINAL FOURIER SPECTROSCOPY

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Abstract – We proposed the imaging-type 2-D Fourier spectroscopy that is the phase-shift interferometry between the objective lights. The proposed method can measure the 2D spectral image at the limited depth. Because of the imaging optical system, the 2D spectral images can be measured in high spatial resolution. And in the depth direction, we can get the spectral distribution only in the focal plane. In this report, we mention about the principle of the proposed imaging-type 2-D Fourier spectroscopy.

Keywords : Fourier spectroscopy, phase-shift interferometry, infrared radiation

1. INTRODUCTION

We propose an imaging-type Fourier spectroscopic technology that enables two-dimensional spectroscopic images to be obtained within the focusing plane alone. This technology incorporates auto-correlational phase-shift interferometry that uses only object light generated by the bright points that optically make up the object.

We are currently involved in studies of non-invasive technologies used to measure blood components such as glucose and lipids, which are measured for use in daily living. Previous studies have investigated non-invasive technologies that measure blood glucose levels by utilizing near-infrared light that permeates the skin well. It has been confirmed that subtle changes in the concentration of a glucose solution, a sample used to measure the glucose level, can be measured by analyzing the spectroscopic characteristics of near-infrared light; however, when applied to a biomembrane, technology such as this is incapable of precisely measuring the glucose level because light diffusion within the skin disturbs the measurement. Our proposed technology enables two-dimensional spectroscopy to a limited depth below the skin covered by the measurement. Specifically, our technology concentrates only on the vascular territory near the skin surface, which is only minimally affected by light diffusion, as discussed previously; the spectroscopic characteristics of this territory are obtained and the glucose level can be measured with good sensitivity.

In this paper we propose an imaging-type Fourier spectroscopy method that is used as the measuring technology in producing a three-dimensional spectroscopic image.

2. MEASURING THE SPECTROSCOPIC CHARACTERISTICS OF A SINGLE VASCULAR TERRITORY NEAR THE SKIN SURFACE

Figure 1 shows that when light permeates a biomembrane consisting of complex distributions of components (distributions of refraction factors), such as those found in the human body, the light is diffused and passes through body tissues other than blood vessels in a very complex manner.

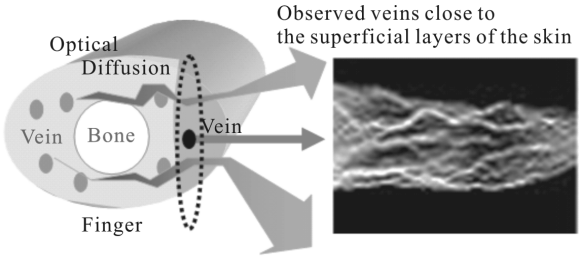

Fig. 1 Light diffusion inside a biomembrane

Traditional spectroscopic technologies obtain the average spectroscopic characteristics of all light that is detected within the area covered by the detection probe. In other words, the measurement area contains not only blood vessels, which are to be measured, but also other cells and biogenic substances that are not to be measured. This explains why existing technologies have been unable to detect subtle changes in blood glucose levels within a vascular territory with good sensitivity.

Some currently available commercial products for biometric personal authentication monitor the vein pattern in a finger or the palm, employing near-infrared light that permeates human skin well, and a CCD camera that obtains two-dimensional near-infrared images, as in the example mentioned above. The absorption rate of near-infrared light in veins differs from that of other biomedical tissues, causing the vein pattern to appear as a measurable shade of gray in a two-dimensional gray-scale image; however, these images are affected by diffusion caused by biomembranes. Therefore, in the case of measuring a finger, for example,

the observed images of vessels can be indistinct in the skin territory on the opposite side of the finger from the detector, as well as being affected by the shadow of the bone located in the middle of the biomembrane. Thus, vessels such as these are indistinguishable from bone; however, vessels that are close to the skin surface on the side of the finger near the detector are captured well by the detector, without being greatly affected by the diffusion caused by biomembranes. For this reason, vessels such as these are observed clearly in two-dimensional gray-scale images, which are a kind of clear-cut shadowgraph. Vein authentication technologies are based on this phenomenon. They optically select images of those vessels close to the skin surface of just one side of a finger, for example, and observe these images. In this type of observation image of blood vessels close to the skin surface, patterns that are created by bone and other unwanted elements within the body are blurred by optical diffusion. For this reason, binarization or some other simple image processing can extract the pattern and authenticate an individual vessel. Blurred images caused by the light diffusion of biomembranes can be a problem; however, these authentication technologies exploit this situation, and optically remove unwanted patterns by blurring. Thus, these technologies optically detect the vessel pattern only in the superficial layers of the skin, disregarding the deeper internal structure. There is one remaining problem with these traditional technologies: although they can identify the positions of the vessels in an image using near-infrared light, they are unable to measure the spectroscopic characteristics of the vessels because no existing technology enables three-dimensional spectroscopy.

We therefore propose a three-dimensional spectroscopic measurement technology that enables the measurement of spectroscopic characteristics. The observation area is highly focused using this technology. In terms of depth, it penetrates only the superficial skin surface; horizontally, it covers only the vascular territory. This proposed technology enables the measurement of the spectroscopic characteristics of a vascular territory that lies close to the skin surface, and is little affected by optical diffusion.

3. PROPOSED THREE-DIMENTIONAL SPECTROSCOPY MEASUREMENT TECHNOLOGY

3.1 Imaging-type Fourier spectroscopy method by phase-shift interferrence between object lights

Figure 2 shows the case of a sample that is illuminated from a single bright point that optically comprises an object and is emitted as a group of divergent light rays. The objective lens converts these light rays into a parallel beam of light. Some of the rays that comprise this parallel beam are called the “fixed group of light rays”, while the rest of the rays are called the “movable group of light rays”. Our technology incorporates a phase shifter that is installed on the Fourier transform plane of the objective lens, and can precisely add any given phase difference to both the fixed and movable groups of light rays. The technology concentrates these groups of rays using an imaging lens to produce an image on the detector.[1]-[4]

Figure 3(a) shows an example of observed changes in the intensity of the interfering light, at a single pixel, that is caused by phase shifting. This figure is commonly known as an “interferogram” in Fourier spectroscopy. Applying the Fourier transformation to this interferogram, we can obtain a spectroscopic characteristic; namely, the relative intensity of light for each wavelength (Fig. 3(b)). A two-dimensional detector such as a CCD camera can be used to obtain these characteristics for all pixels, thus enabling two-dimensional spectroscopy.

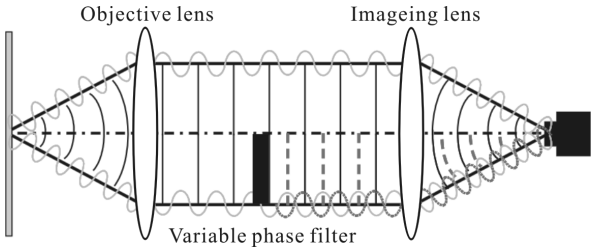

Fig. 2 Imaging-type Fourier spectroscopy method by phase-shift interference between object lights

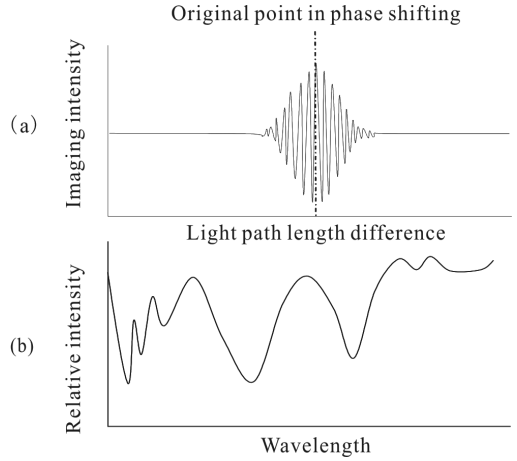

Fig. 3 Interferogram and Spectroscopic characteristics

3.2 How interferograms are generated

Here we discuss in detail the principle that creates changes in the intensity of interfering light, which is known as an interferogram. In Fig. 4, the horizontal axes denote the relative changes in the light path length between the fixed and movable groups of light rays, as caused by movement of the mirror of the phase shifter. These changes in light path length represent changes in phase. The vertical axes indicate the imaging intensity at a single point on the plane on which the image is produced.

Figures 4 (a), (b), and (c) show examples of three different wavelengths: (a) represents light with the longest wavelength, (b) that with a medium wavelength, and (c) that with the shortest. The dashed-dotted line running vertically through the middle of Fig. 4 indicates the states of the fixed and movable groups of light rays with no relative phase difference applied. In short, the vertical line denotes the original points in the phase shifting. In other words, at these original points the light states are the same as those of

common imaging optical systems. The two beams reach the imaging surface without a difference in phase, thereby strengthening the mutual interference. The beams thus create strong bright points that result in a high imaging intensity. Next, we set a relative difference in light path length between the two beams. As we make this differentiation, when the difference between the light path lengths of the two beams is equal to an odd-number-multiple of the half-wavelength, the mutual interference that occurs between the two beams causes weakness in each beam, resulting in a lower imaging intensity. When the difference in light path length is a whole-number multiple of the wavelength, the interference between the two beams again causes enhancement of both, thereby increasing the imaging intensity. Thus, as we increase the path length difference, the change in imaging intensity grows cyclically larger and smaller due to interference between the two beams. As shown in Fig. 4, this change in imaging intensity occurs with a longer cycle in the case of a long wavelength of light (Fig. 4 (a)); the shorter the wavelength of light, the shorter the cycle becomes (Fig. 4 (b) and (c)).

Corresponding to phase shifting for each wavelengthIn spectroscopic measurement that employs multiple wavelengths, changes in light intensity caused by interference among different wavelengths are added and detected as brightness changes; this is known as an interferogram, as shown in Fig. 3(a). At the original point of the phase shift (indicated by the dashed-dotted line in the middle of Fig. 3(a)), where there is no relative difference between the path lengths of light from the fixed and movable beams, there is constructive interference between the two beams regardless of wavelength. [Please check that this translation reflects your intended meaning.] Therefore, the imaging intensity is also very high in terms of the measurement value, which is the sum of the multiple wavelength intensity changes (Fig. 3(a)).

As the difference in light path length increases, however, the imaging intensity, which is the result of the summed intensity changes for each of the different wavelengths, remains relatively low because the intensity change for each wavelength has a different cycle. For this reason, in an interferogram the brightness gradually diminishes as the difference in light path length increases. These changes in imaging intensity are characteristic of those observed in an interferogram. An interferogram provides a waveform that is the sum of single-cycle changes in imaging intensity for different wavelengths; therefore, we can obtain the spectroscopic characteristic (shown in Fig. 3(b))—the intensity for each wavelength—by applying the Fourier transformation to the interferogram waveform data.

3. 3 Advantages of applying the proposed technology to blood glucose level sensors

According to imaging theory, only the group of light rays that leaves the focusing position can produce an image that is an interference figure, because these rays alone can share identical phase on the imaging surface. Seen from a different perspective, we can conclude that we can only measure the spectroscopic characteristics at the focusing position, because light rays arising from other positions do

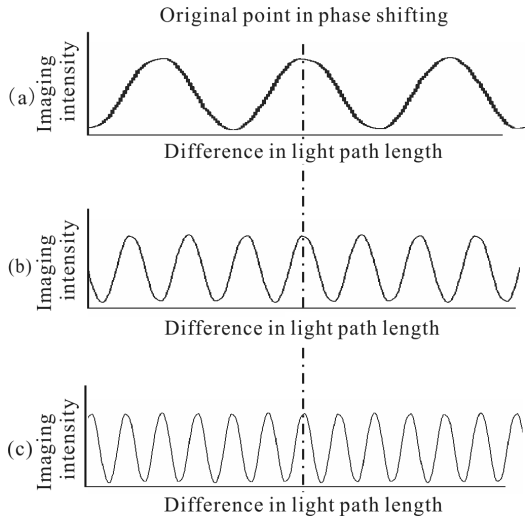

Fig. 4 Changes in imaging intensity

not contribute to the creation of a clear interferogram. Our proposed technology, which utilizes two-dimensional spectroscopic measurement within the focusing plane,enables a two-dimensional spectroscopic image of a biomembrane to be obtained with limited depth covered by the measurement. Biometric authentication technologies using vein pattern recognition take advantage of the image blurring that is caused by light diffusion inside a biomembrane to obtain near-infrared images of the superficial layers of the skin that are only weakly affected by light diffusion. Using these two effects, our technology is able to obtain clearer two-dimensional near-infrared spectroscopic images of the surface of the biomembrane, thereby enabling the measurement of spectroscopic characteristics in a limited space of a vascular territory; this in turn opens up a method for the measurement of blood glucose levels with improved sensitivity.Conventionally, it is known that the glucose

4. EXPERIMENTAL MEASUREMENT OF A NEAR-INFRARED SPECTROSCOPIC IMAGE OF FINGER VEINS

Figure 5 shows the structure of the optical system we employed in measuring three-dimensional spectroscopic images. To observe veins close to the superficial layers of the skin, this optical system radiates near-infrared light onto the skin and detects the reflected light. A xenon lamp is used as the light source in this system because of its efficiency in near-infrared emission. The objective lens of the system focuses the group of light rays reflected from a single point on the focusing plane into a beam of parallel rays. The phase shifter is a partly movable mirror that we manufactured ourselves, in which half of the mirror surface can move with good precision. We installed this mirror at an angle of 45 degrees to the light axis of the parallel beam; the reflected light is concentrated through the imaging lens and onto the detector. By radiating half of the parallel beam onto this movable section of the mirror, we can create a relative phase difference between this half of the beam and the remaining half that reaches the fixed portion of the mirror. Figure 6

shows a near-infrared image of a finger vein that was obtained using this optical system. The figure clearly shows that the system enabled the finger vein pattern to be observed in the territory close to the skin surface. In the future, we plan to obtain interferograms corresponding to phase shifting and carry out another experiment of spectroscopic evaluation.

5. CONCLUSION

This paper discussed an imaging-type Fourier spectroscopy technique that we propose as a measuring technology for three-dimensional spectroscopic images. The proposed technology divides into two portions the single beam of light rays from a single bright point that optically makes up an object, and causes the two portions to interfere with each other, thus creating an interferogram. The technology is termed auto-correlational phase-shift interferometry. Because no light from any position other than the focusing position contributes to the formulation of a clear interferogram, we can conclude that the technology can measure the spectroscopic characteristics of the focusing position alone. In other words, because it comprises two-dimensional spectroscopic measuring technology within the focusing plane, our proposed method obtains two-dimensional spectroscopic images of a biomembrane with limited depth covered by the measurement. For instance, the technology can obtain spectroscopic characteristics of a single vascular territory close to the skin surface, which is little affected by light diffusion caused by the biomembrane. Therefore, we consider that this technology is well suited for use as a blood glucose level sensor.

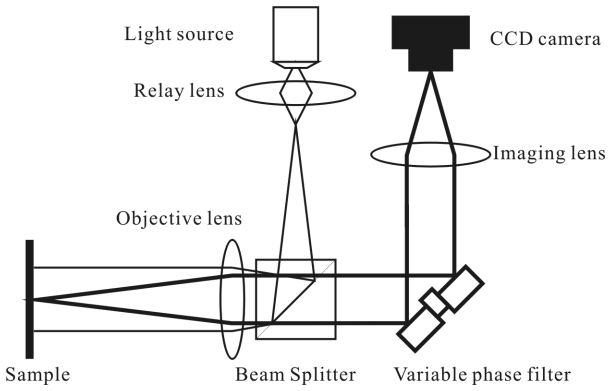

Fig. 5 Structure of the optical system used to measure Three-dimensional near-infrard spectroscopic images

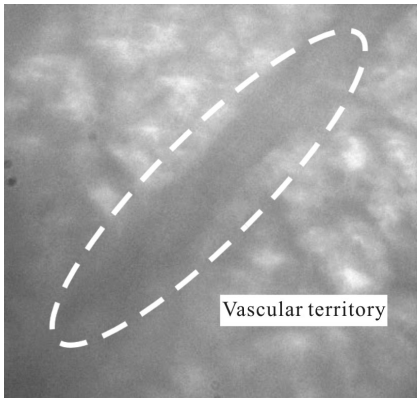

Fig. 6 Example of near-infrared image measurement of finger veins

REFERENCES

[1] Y. Inoue, I. Ishimaru, T. Yasokawa, K. Ishizaki,M. Yoshida, M. Kondo, S. Kuriyama, T. Masaki,S. Nakai, K. Takegawa, and N. Tanaka, “Variable phase-contrast fluorescence spectrometry for fluorescently stained cells”, *APL* 89, 121103(2006).

[2] T.Harada, I.Ishimaru, K.Yamamoto, M.Kondo, K.Gesho "Spectroscpy Optical Coherence Tomography of Biomedical Tissue", Proc. of SICE Annual Conference 2007,pp.3056-3057(2007)

[3] Ichirou Ishimaru "Revolutionary Spectroscopic Tomography for Noninvasive Measurement of Bio-Membrane" Plenary Talk 3, ,Proc. of 7th France-Japan congress on Mecatronics(2008)

[4] T. Kawajiri, K. Yanogawa, K. Yamamoto, M. Kondo, T. Harada, and I. Ishimaru, "3-dimensional spectroscopic-tomography of biological membrane with high spatial resolution by the imaging-type 2-D Fourier spectroscopy" Proc. of SPIE Optomechatronic Technologies 2008, Vol. 7266,pp.72660G-1- 72660G-9(2008)