Signal Improvement in Imaging Type Two-Dimensional Fourier Spectroscopy for Wild-Field Internal Non-Destructive Inspection

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***Abstract*—Imaging type two-dimensional Fourier spectroscopy is the wave front-division interferometer which limits the measurement depth into focal plane. This method has shown the potential in many areas such as measurement of biological substances and non-destructive inspections. Presence of noise in the signal may affect the end result of test. This paper proposes the algorithm for improving spectral data by finding low noisy point and filtering them. Cross correlation with median noisy signal is used to find the best signal to be considered. Experiment was conducted for testing fingerprint, alcohol measurement and measurement of ink. Proposed algorithm was conducted for the data obtained from ink measurement.**

***Index Terms*—Imaging Type Two-Dimensional Fourier Spectroscopy, Non-Destructive Inspection, Noise Filtering**

I. Introduction

Spectroscopic measurement for developing a non-invasive blood sugar sensor has been widely used in recent past. Near infrared spectroscopy, Mid-Infrared spectroscopy, Raman spectroscopy, Thermal spectroscopy and Ocular spectroscopy can be mentioned among those. Emission from transitions near the level excited is induced by using laser light in Raman Spectroscopy. This method has been attempted to estimate glucose concentration in human fluids such as blood, serum and plasma solutions. However, instability of laser wavelength and intensity, and long spectral acquisition times are the main setbacks remain before human studies can be performed. Various other techniques such as photo acoustics spectroscopy, fluorescence technology, ultrasonic technology has been tested for estimating glucose concentration [1].

One of the main disadvantages of above method is that its inability to limit the measuring depth into focal plane. Imaging type two-dimensional spectroscopic tomography is the spectroscopic technique which limits the measurement depth into focal plane [2]. It is also a near common path interferometer which exhibits a high robustness for the mechanical vibration [3]. In imaging type two-dimensional Fourier spectroscopy, 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 [4]. Several approaches have been reported to compensate the errors due to light source fluctuation and phase shift uncertainty [5]. In this approach, author has considered individual issues separately within the framework of unique algorithm. However, at the end, both these two errors cause to have a noisy signal.

Nondestructive inspection or Non-destructive testing (NDT) is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage. Several researches regarding to non-destructive tests have been reported. FTIR and Raman spectroscopic method to the study of paper ink interaction in digital print [6], Metabolic fingerprint in disease diagnosis [7], Non-destructive techniques to assess mechanical and physical properies of soft calcarentic stones [8], and Non-destructive terahertz imaging of illicit drugs using spectral fingerprints [9] can be mentioned as examples. Having noisy signal would deteriorate the spectral characteristics. Even though several approached for signal enhancement and noise filtering is reported [10], [11], those methods are less effective for our system. Therefore, in this paper, improvement of noisy signal for imaging type two-dimensional spectroscopy is addressed. Novel algorithm using Savitzky-Golay filters and cross correlation is presented here.

II. Imaging Type Two-Dimensional Fourier Spectroscopy

Imaging type two-dimensional Fourier spectroscopy is the wave front-division interferometer, as shown in Fig. 1. This optical system has been designed with optical plane, objective lens, variable phase filter, imaging lens and

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imaging plane. CCD camera is used as recording device. Using this method, three dimensional spectral characteristics can be obtained by scanning the focal plane mechanically.

From the optical point of view, the surface of the object is covered by many bright points. Out of many, only single bright point is considered. The rays that are emitted to the multiple directions are collimated by objective lens. And collimated rays are concentrated into single bright point on the imaging plane by the imaging lens. Therefore, the substantial bright point on the focal plane is optically formed as the conjugate bright-point image. Variable phase filter has been newly introduced here and it can give the arbitrary phase difference to the half of objective rays. This phase difference allows having a phase shift between objective beams without reference beam. As a result of this phase shift, the sum of these cyclic imaging intensity changes of multiple wavelengths and are detected by CCD camera. Variation of these intensities is called Interferogram in Fourier spectroscopy. Using mathematical Fourier transform technique such as FFT, spectral characteristics can be found.

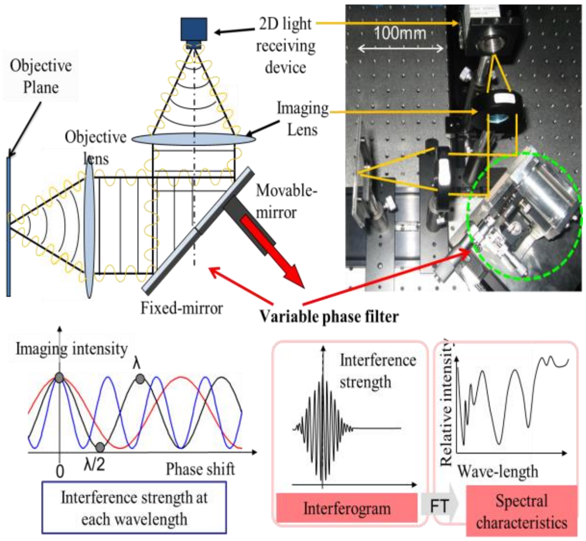


Figure 1. Imaging type two-dimensional spectroscopic tomography; Phase filter installation and waveform construction.

Main advantage of imaging type two-dimensional Fourier Spectroscopy is that the ability to limit the measuring depth to focal plane which the conventional method does not have. The conventional FTIR which is configured with the Michelson interferometer is the amplitude division interferometer. Here, an incident beam is divided into two beams by the half mirror and those beams are reflected by these mirrors, and recombined. The interference phenomenon occurs within a ray.

However in imaging type two-dimensional Fourier Spectroscopy is a wave front division interferometer, where two beams are crossed and the interference occurs at the point of intersection. Only the beams emitted from the focal plane can interfere each other on the imaging plane. The intensity of the interference depends on the path difference.

Even if the beams are emitted from the out-of-focal plane, the amplitude division interferometer such as FTIR can observe the interference phenomenon on the imaging plane because the beams can interfere each other. But the proposed method cannot observe the interference phenomenon because beams cannot intersect on the imaging plane. So, the rays emitted from the out-of-focal plane cannot interfere each other. That's why Imaging type two-dimensional Fourier spectroscopy can limit the measuring depth into the focal plane only. Fig. 2 illustrates the how the measuring depth can be limited to a focal plane.

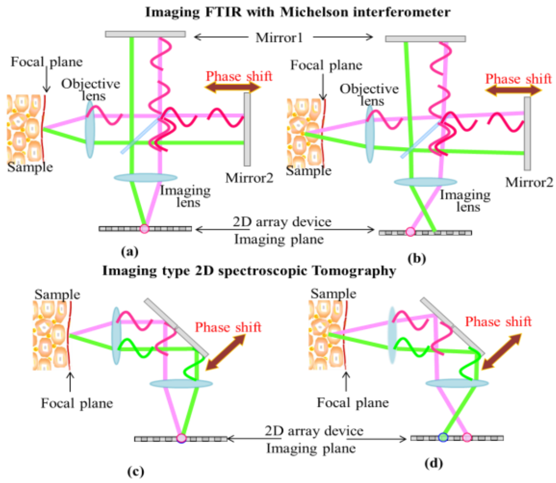


Figure 2. Imaging type two-dimensional spectroscopic tomography; limiting the measurement depth focal point.

III. Feasibility Demonstration of Non-Destructive Inspection

A wide range of non-destructive testing methods such as IR thermography or fluorescent penetration rely on the detection of light to measure a physical change in the material under inspection. FTIR (Fourier Transform Infrared) spectroscopy extends the use of light in the mid-infrared wavelength region to monitor chemical changes on the surface of a material that can affect the strength and/or performance of that material.

Imaging type two-dimensional Fourier spectroscopy used for non-destructive inspections with different applications; namely, Inspection of finger print, inspection of Japanese alcohol, and inspection of ink. These feasibility studies showed that tomographic imaging is possible for above mentioned non-destructive tests.

Fig. 3 illustrates the image obtained of a fingerprint using this method in the mid-infrared region. Optical magnification of one and transmission illumination were used with a halogen lamp as light source. By using the mid-infrared light absorption, it is possible to obtain a high resolution image. Interferogram and spectral characteristics are shown in Fig. 3. A Japanese drink, Sake, which includes 13% alcohol was measured and shown in Fig. 4. In this experiment 2mm liquid cell was used. In the graph, green line shows the absorbance of the alcohol obtained from the present experiment and pink line shows the absorbance when measuring the same sample by dispersive spectrometer. If the absorbance of sake was measured using both the proposed method and conventional FTIR, absorption can be seen at 1200 [nm] near characteristic of ethanol. In addition, significant absorption was shown at 1400nm which corresponds to water. Therefore, it is clear that the feasibility of component measurement of liquids that multi-component is mixed. Moreover, accuracy is depends on the thickness of liquid cell and the type of light source. Hence, it is obvious that more accurate result is possible with equipment.

As a third test, spectral image of a paper with ink was obtained. Sometimes, old documents cannot be clearly seen due to blurred conditions. Further, there may be a requirement to identify the fake documents which might be altered with different inks. In these situations the fact that different materials show the absorption of light at different wave numbers can be used. During the experiment, white paper with some test was used as shown in Fig. 5. It was possible to obtain the intereforogram and spectral characteristics clearly. Fig. 5 shows the spectral image, interferogram and spectral characteristics.

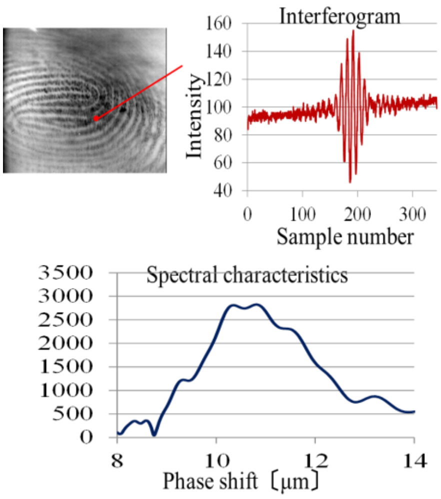


Figure 3. Fingerprint inspection.

IV. Algorithm for Signal to Noise Improvement for Non-Destructive Inspection of Imaging Type Fourier Spectroscopy

Standard Fourier spectroscopy involves random noises in the spectroscopic images. Common practice of improving signal to noise ratio is to take the moving average of the spectral data. In our previous studies, 5 by 5 pixel area was averaged. However, in this case, intensity of the signal is becoming weak. Therefore, in this algorithm, we proposed a new method by selecting the best point where they have low noises compared to other points.

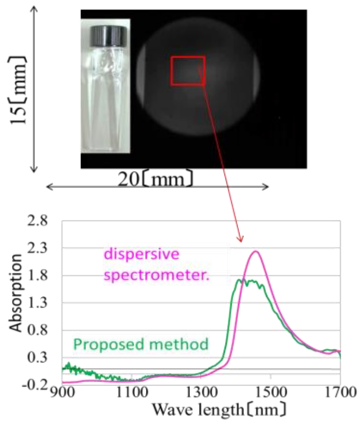


Figure 4. Inspection of alcohol.

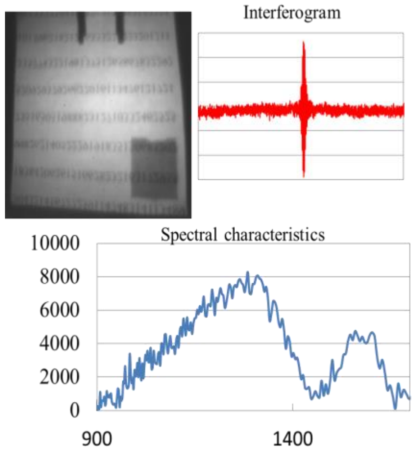
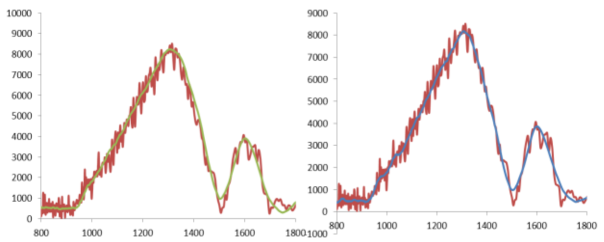
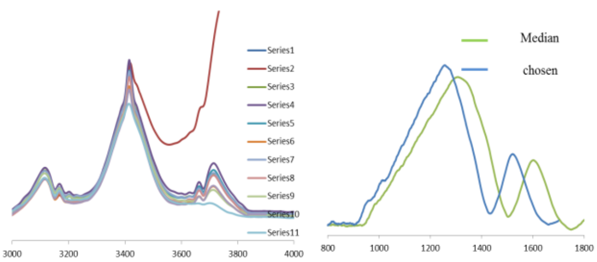


Figure 5. Inspection of ink on paper.



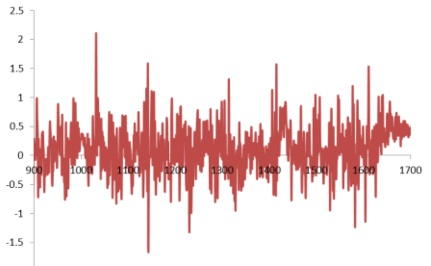
(a) Noisy spectra with median (b) Noisy spectra with noise filtered signal

Figure 6. Median and noise filtered signal with noise spectra.

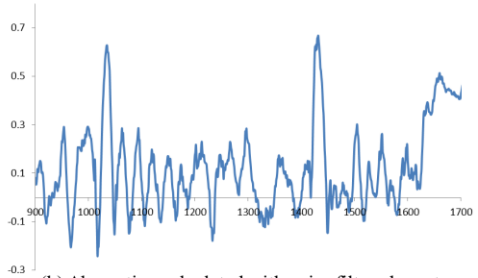


(a) Cross correlation results (b) Filtered median signal and chosen signal

Figure 7. Cross correlation results and its impact.



-2(a)Absorption calculated using spectrum with noise



(b) Absorption calculated with noise filtered spectrums

Figure 8. Absorption spectra of filtered signal and unfiltered signal.

Here, first, several points where interference occurred is selected. Then the median of all those points is calculated. This median spectrum separated the higher noisy signal half from lower noisy signal half. In the meantime, noise filtering using Savitzky-Golay filter is done for each point separately. A Savitzky–Golay filter is a digital filter that can be applied to a set of digital data points for the purpose of smoothing the data. The advantage of this filter is that it can improve signal-to-noise ratio without greatly distorting the signal. This is achieved, in a process known as convolution, by fitting successive sub-sets of adjacent data points with a low-degree polynomial by the method of linear least squares.

Consider the data sets $n\{x_j, y_j\},.....(j = 1,2...., n)$ where x is an independent variable and y is observed variable.

$$Y_j = \sum_{i=-(m-1)/2}^{i=(m-1)/2} C_i y_{j+i} \qquad \frac{m+1}{2} \le j \le n - \frac{m-1}{2} \qquad (1)$$

Equation (1) gives the calculation of Savitzky-Golay filter with *m* convolution coefficients and Ci is decided according to the expression.

After that, cross correlation will be calculated with median signal for each noise filtered data sets. Most correlated signal with median signal will be taken as the best signal. This algorithm will be applied for background and signal separately. Spectral characteristics of two best points were taken for absobtion coefficient calculation. Fig. 6 shows the filtered signals with noise. Fig. 6(a) illustrates the noise eliminated median signal with noise and Fig. 6(b) is given the chosen signal based on the cross correlation results. Fig. 7 is given to elaborate the importance of cross correlation. Fig. 7(a) shows how each date series have dependencies among series and Fig. 7(b) proves that use of cross correlation has improved the result. Basically, it has reduced the time lag that could be occurred during signal processing. With noise, no major peaks can be visible after Fourier transform however very clear spectra was obtained after applying proposed method and results are shown in Fig. 8.

V. Conclusion

A feasibility demonstration for non-destructive inspection of fingerprint, alcohol and ink was conducted using imaging type two-dimensional Fourier spectroscopy. Presence of noise is the main is advantage of getting good results. A new algorithm for improving signal to noise ratio was proposed and tested with the data obtained from experiment. Results show clear improvement. Apparently, no peaks can be seen in the absorption calculation with noises. Nonetheless, two main peaks can be seen when the signals are proposed with proposed algorithm.

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