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Spectroscopic imaging with uncooled microbolometer camera and step-scan FTIR

Malamas, Sitthichai.

Monterey, California. Naval Postgraduate School

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THESIS

SPECTROSCOPIC IMAGING WITH UNCOOLED MICROBOLOMETER INFRARED CAMERA AND STEP-SCAN FTIR

by

Sitthichai Malamas

December 2006

Thesis Advisor:	Gamani Karunasiri
Thesis Co-Advisor:	D. Scott Davis

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13. ABSTRACT (maximum 200 words)

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SPECTROSCOPIC IMAGING WITH AN UNCOOLED MICROBOLOMETER INFRARED CAMERA AND STEP-SCAN FTIR

Sitthichai Malamas
Lieutenant, Royal Thai Navy
B.E., Royal Thai Naval Academy, 2000

Submitted in partial fulfillment of the
requirements for the degree of

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December 2006

Author: Sitthichai Malamas

Approved by: Gamani Karunasiri
Thesis Advisor

D. Scott Davis
Thesis Co-Advisor

James H. Luscombe
Chairman, Department of Physics

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ABSTRACT

The purpose of this thesis research was to explore the feasibility of spectral imaging using a microbolometer infrared camera and a step-scan Fourier transform infrared spectrometer (FTIR). Spectral imaging is usually carried out using cryogenically cooled semiconductor based focal plane arrays (FPAs) which provide higher sensitivity compared to microbolometer FPAs based on thermal sensors. The key advantage of spectral imaging is the ability to extract spatial variations of spectral information. During the measurement, images were collected as the moving mirror of the FTIR stepped across the zero crossings of the on-axis portion of the interferogram. The preliminary data indicate that interferograms can be successfully recorded using the microbolometer camera, and that data from individual pixels of the camera showed the expected intensity profile. The interferograms from the individual pixels were inverse Fourier transformed to recover the intensity of the broadband infrared source of the FTIR at different pixels. The initial data showed relatively low signal to noise ratio indicating that signal averaging is necessary at each mirror step by collecting several images as well as optimizing the image collecting optics.

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I. INTRODUCTION

Spectroscopy is a study of the interaction of light with matter, such as a solid, liquid, or gas, from which light is emitted, absorbed, or scattered. (http://speclab.cr.usgs.gov/PAPERS.refl-mrs/refl4.html, 1 November 2006). Once light has been shone on a material, it will only absorb some wavelengths of light and the rest will either transmit or reflect. Each material possesses its own absorption characteristics, which can be used to identify the material.

Infrared spectroscopy primarily deals with infrared wavelengths of the electromagnetic spectrum (see Figure 1) approximately 1-100 μm or between 10000 cm^{-1} to 100 cm^{-1} wavenumbers. Most free molecules have their characteristic vibrational spectra in the infrared wavelengths, and infrared spectra are often used for spectrochemical identification, (http://www.scienceofspectroscopy.info/edit/index.php?title=Infrared_Spectroscopy, 1 November 2004).

Infrared spectroscopy is typically carried out using Fourier transform infrared (FTIR) spectrometers (Griffiths, 1975) which use a two-beam interferometer with a moving mirror to record an interferogram. After the interferogram is taken, the infrared energy as a function of wavenumber is extracted by inverse Fourier transformation of the interferogram.

Research grade FTIR spectrometers can acquire absorption spectra in two different ways: continuous scanning and step scanning. For continuous scanning, the moving mirror of spectrometers moves continuously, and the fixed mirror always remains in the same position. For step scanning, the moving mirror behaves in the same manner as in continuous scanning but the fixed mirror moves discontinuously, keeping the optical path difference constant for an interval. A detailed description of the step-scan process will be described in Chapter II.

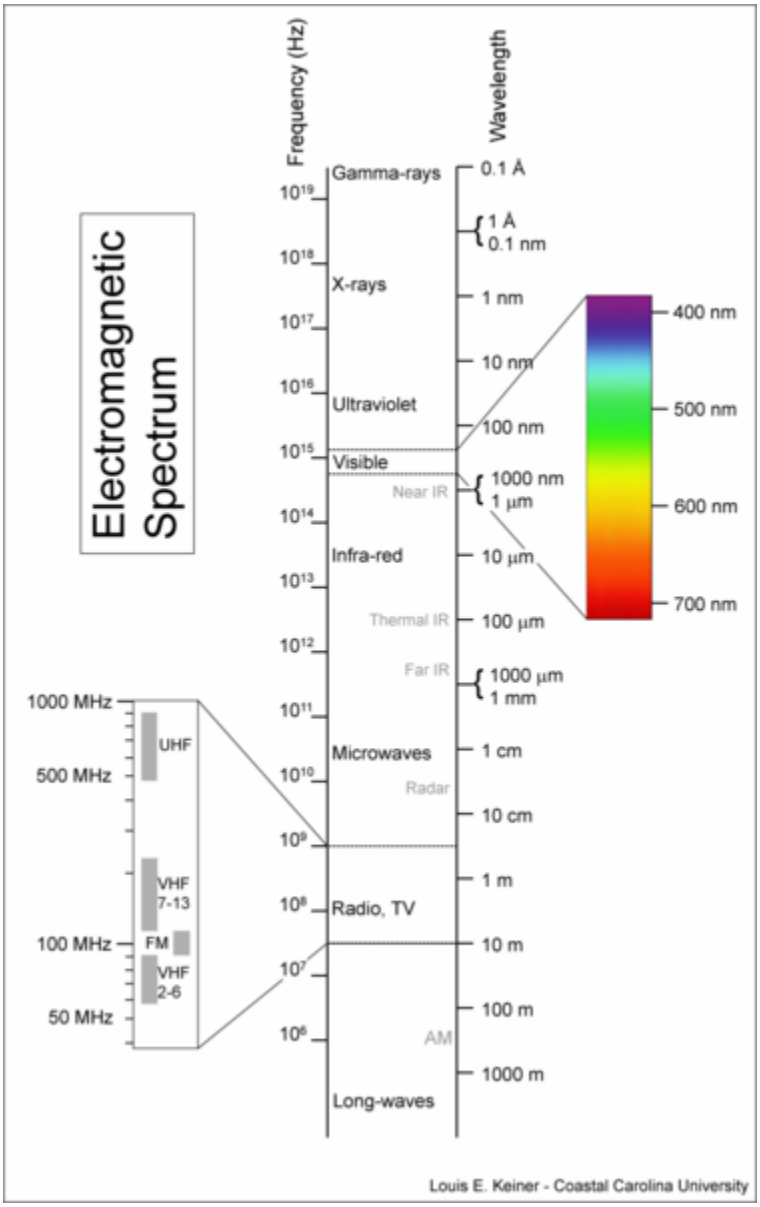

Figure 1. Electromagnetic Spectrum (From: http://en.wikipedia.org/wiki/Image:Electromagnetic-Spectrum.png, 7 November 2006).

Chapter II covers the basic information of FTIR interferometers, spectroscopy, and the step-scan process. Chapter III describes the experimental set up and methods used. Finally, Chapter IV and Chapter V discuss experimental works, data analysis, and conclusions.

II. BACKGROUND

A. THE MICHELSON INTERFEROMETER

Fourier Transform spectroscopic technology has been around since 1891, the year Michelson built the interferometer prototype as illustrated in Figure 2. (Wolfe, 1917) Current FTIR spectrometers are based on Michelson interferometers. The interferometer uses a collimated light source with a beamsplitter, which is installed 45° from the light beam as illustrated in Figure 2. The ideal beamsplitter is 50% transmission and 50% reflection for all incoming wavelengths. Half of the light beam transmits through the beamsplitter and the other half reflects. The transmitted half reflects off a movable mirror, and the reflected half reflects off a fixed mirror. Then, the light beams return to the beamsplitter. Transmission and reflection occur again at the beamsplitter. One part returns to the source and the other part travels to the detector via a portion lens. The light incident on the detector forms an interference pattern as shown in Figure 3.

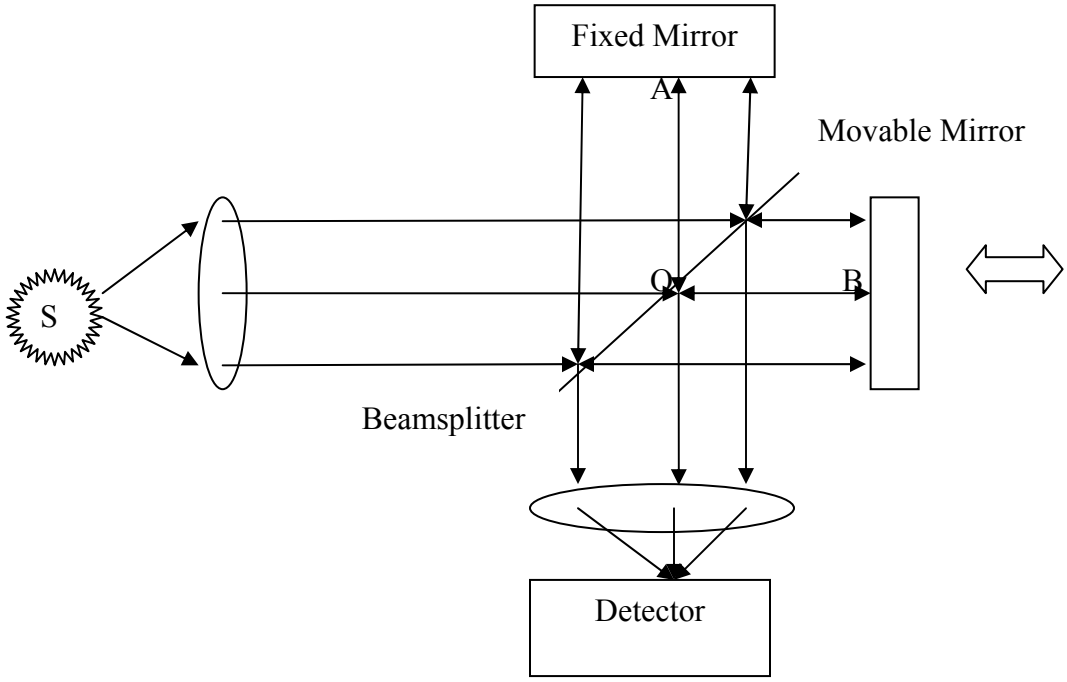

Figure 2. Michelson Interferometer.

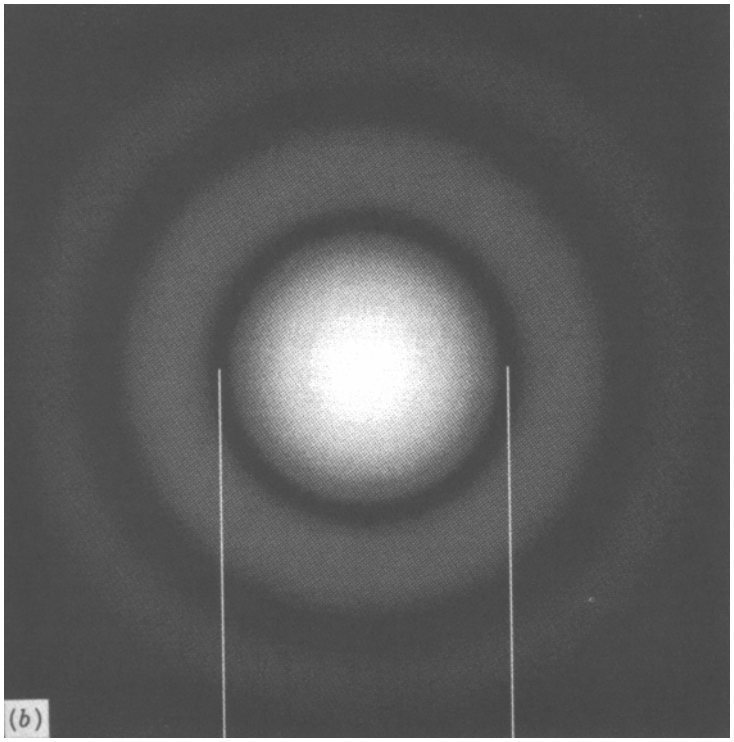

Figure 3. Intensity image of two light beam interference (From: Dereniak, 1996).

B. FT-IR SPECTROSCOPY

In a FTIR spectrometer, a broadband Globar is used as the infrared source. The interferogram of the infrared source depends on the type of beamsplitter and detector used and usually in the 4000 cm^{-1} to 400 cm^{-1} wavenumber range.

1. Spectral Variables

In FTIR spectroscopy, it is customary to use centimeters (cm) as a unit of distance. Therefore, the unit of wavenumber in spectrometry is cm^{-1} and is sometimes called wavenumber kayser (σ). (Wolfe, 1997)

$$\sigma[cm^{-1}] = \frac{1}{\lambda[cm]} = \frac{k}{2\pi} \quad \text{where k = radian wavenumber.} \tag{1}$$

The optical path difference (OPD), also called retardation (δ), is another significant factor in spectrometry. From Figure 2, it can be measured by twice the length differences between the distance of the moving mirror from the beamsplitter (OB) and one of the fixed mirrors from the beamsplitter (OA).

$$\delta[cm] = 2\left|OA - OB\right|[cm]. \tag{2}$$

2. Two-beam Interference

Irradiance of two-beam interference is calculated by the following equation. (Pedrotti, 1993)

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\theta . \tag{3}$$

I, in the above equation, is the total irradiance by two-beam interference. I_1 and I_2 are the irradiances of the first and second beams, respectively, and θ is the phase difference between the beams.

Once both beams have the same irradiance (I_1 and I_2 are equal), Eq. (3) can be reduced to Eq. (4).

$$I = 2I_1(1+\cos\theta) . \tag{4}$$

The maximum value of total irradiance (I) is $4I_1$, which occurs when cos θ = 1. Therefore, the first beam irradiance can be written in terms of total maximum irradiance (I′).

$$I = 0.5I'(1+\cos\theta) \tag{5}$$

The total irradiance is composed of a DC component (0.5I′) and an AC component (0.5I′ cos θ). Only the AC component will be considered as the interferogram.

The phase difference in the Michelson interferometer depends on the OPD. At zero path difference (ZPD) (δ = 0) as shown in Figure 4(a), the interferogram is maximum. The interferogram is minimal once the OPD is a half wavelength ($\delta = \lambda/2$) as shown in Figure 4(b). The highest intensity is found again at the path difference of one wavelength ($\delta = \lambda$) as illustrated in Figure 4(c). Therefore, the phase difference can be written in terms of the OPD as:

$$\theta = \frac{2\pi n\delta}{\lambda}, \tag{6}$$

where n is the refractive index of the medium, usually air.

From Eq. (5), the interferogram and the AC component of total irradiance can be described in terms of OPD in Eq. (7).

$$I(\delta) = 0.5I'(\sigma)\cos\left(\frac{2\pi n\delta}{\lambda}\right) \tag{7}$$

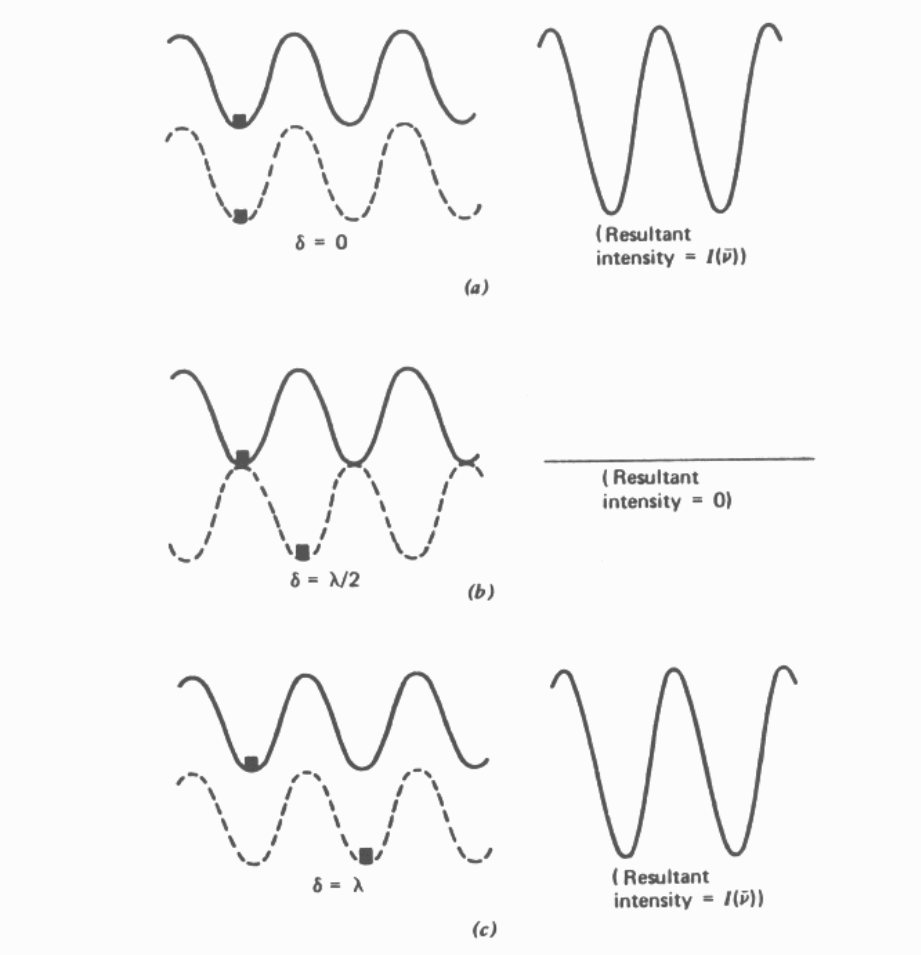

Figure 4. Illustration of phase difference by different OPD of the fixed mirror (solid line) and the moving mirror (broken line) (a) at ZPD (b) at one-half wavelength (c) at one wavelength (From: Griffiths and de Haseth, 1986).

From Eq. (1), the cosine term depends on the wavenumber and the path difference as shown in the following equation.

$$I(\delta) = 0.5I'(\sigma)\cos(2\pi n\sigma\delta) \tag{8}$$

Under imperfect beamsplitter conditions, Griffiths and de Haseth stated in *Fourier Transform Infrared Spectrometry* that beamsplitter efficiency, detector response,

and amplifier characteristics were three important factors that render measured interferograms less than ideal. (Griffiths and de Haseth, 1986) Consequently, Eq. (8) can be rewritten.

$$I(\delta) = 0.5H(\sigma)I'(\sigma)\cos(2\pi n\sigma\delta) \tag{9}$$

H(σ) in the above equation is a single wavenumber-dependent correction factor. (Griffths and de Haseth, 1986) The measured interferogram is related to the spectral intensity (B) at wavenumber (σ) by the following equation:

$$I(\delta) = B(\sigma)\cos(2\pi n\sigma\delta)\,. \tag{10}$$

The above equation is only for monochromatic sources. For incoherent continuum sources (polychromatic sources), Eq. (10) needs to be integrated over all wavenumbers:

$$I(\delta) = \int_0^\infty B(\sigma)\cos(2\pi n\sigma\delta)d\sigma\,. \tag{11}$$

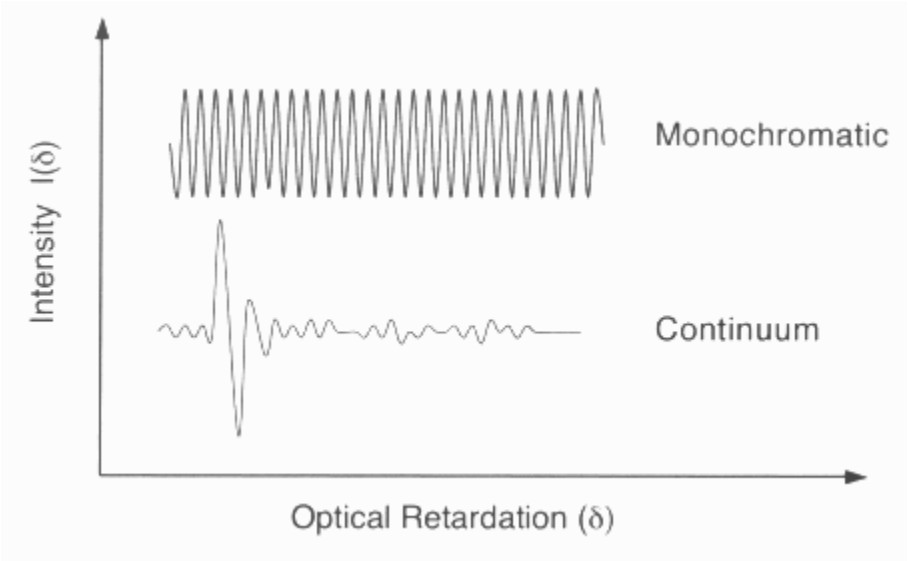

Figure 5. Interferograms of a monochromatic source and a continuum source (From: Jiang, 2003).

Spectral intensity is reversed from a measured interferogram by performing an inverse Fourier transformation.

$$B(\sigma) = \int_0^\infty I(\delta)\cos(2\pi n\sigma\delta)d\delta \tag{12}$$

In general, the spectrometer calculates intensities of interferogram and spectra by discrete Fourier transform (DFT) where Eq. (12) is transformed into: (Jiang, 2003)

$$B(k\Delta\sigma) = \sum_{m=0}^{M-1} I(m\Delta\sigma)\cos\left(\frac{2\pi kmn}{M}\right). \tag{13}$$

If interferograms are recorded by continuously moving the interferometer's mirror, great care must be taken to keep the mirror velocity (v) constant. During the scanning, the movable mirror moves continuously with constant speed as schematically illustrated in Figure 6. The mirror location is accurately determined using reference interference fringes generated by a He-Ne laser which passes through the same optics. The retardation is twice the distance that the moving mirror moves.

$$\delta = 2vt. \tag{14}$$

Thus, from Eq. (10), the interferogram can be expressed in terms of time as

$$I(t) = B(\sigma)\cos(2\pi\sigma 2vt). \tag{15}$$

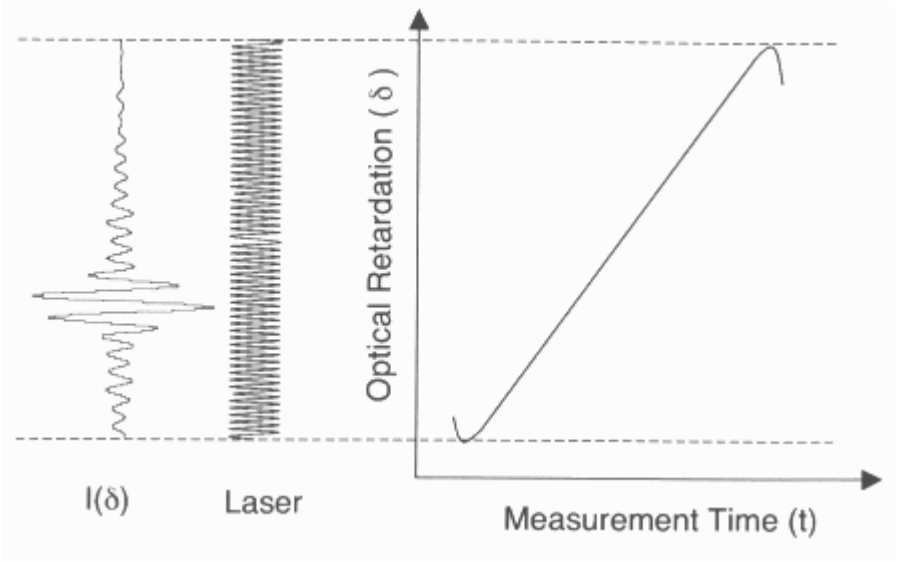

Figure 6. Schematic illustration of continuous-scan interferometric data collection (From: Jiang, 2003).

For continuous scanning, each spectral component of wavenumber σ is encoded as a temporal frequency (f), related by

$$\sigma = \frac{f}{2v} = \frac{1}{2vt}. \tag{16}$$

3. Absorption

When the infrared beam is shined through a sample, the spectral intensity will be absorbed depending on the chemical composition. This absorption, $A(\sigma)$, reduces the spectral intensity, $B(\sigma)$. Therefore, the spectral intensity incident on the detector is $B(\sigma)\cdot A(\sigma)$.

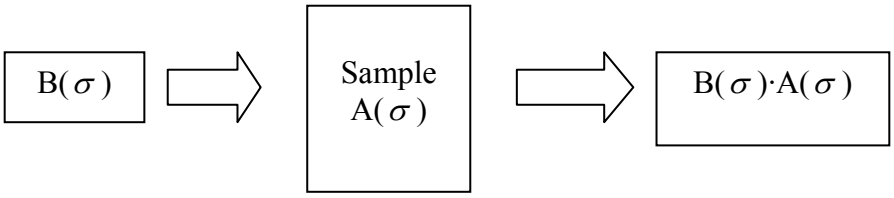

Figure 7. Reduction of source spectral intensity at the detector due to absorption.

In order to retrieve absorption due to the sample, the spectral intensity without a sample, $B(\sigma)$, must be collected and then it is necessary to complete the spectral intensity with sample, $B(\sigma)\cdot A(\sigma)$. Once both spectral intensities are collected, the sample's absorption can be calculated by the following equation.

$$A(\sigma) = \frac{B(\sigma)\cdot A(\sigma)}{B(\sigma)} \tag{17}$$

C. STEP-SCAN TECHNIQUE

A step-scan allows the movable mirror to move continuously as in continuous scanning. The fixed mirror, however, moves backward at the same speed as one of the moving mirrors to maintain the same path difference for a predetermined time. During this time the detected signal is integrated. During the next step, the fixed mirror moves forward to the original position abruptly and then moves backward with the moving mirror's speed as schematically illustrated in Figure 8. In more recent FTIR spectrometers, the moving mirror itself moves in steps, keeping the fixed mirror unchanged. In this thesis, the latter approach is employed.

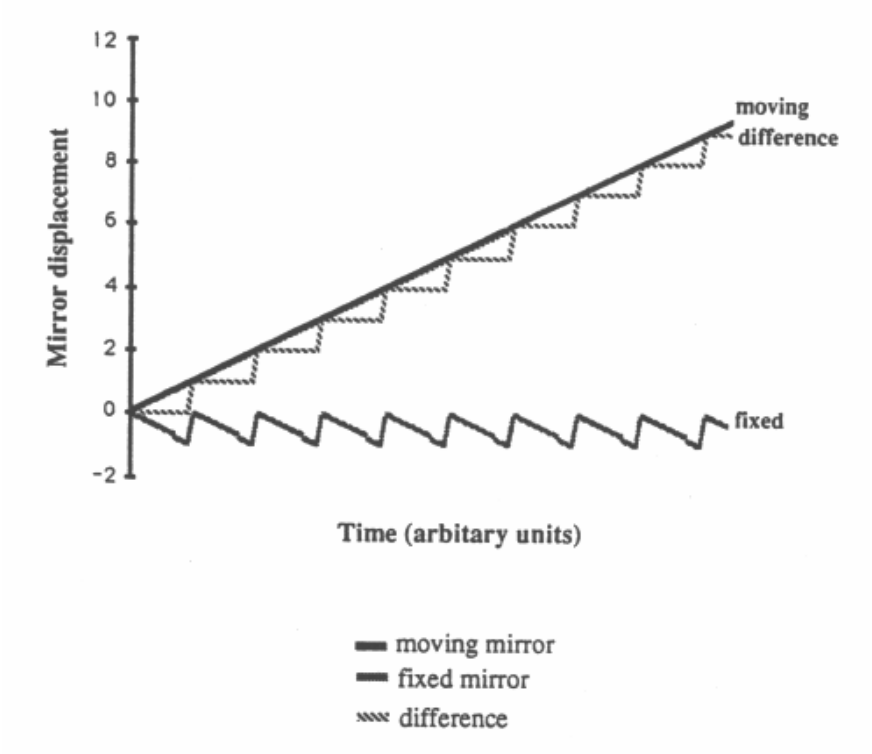

Figure 8. Step-scan diagram (From: Crocombe and Compton, 1991).

For spectroscopic imaging, during each retardation step, the intensity of the infrared source is collected by an infrared camera without the focusing mirror of the FTIR. The camera captures the intensity of the IR beam passing through the sample and without passing through the sample as shown in Figure 9 in the last circle. When the interferogram intensity has been recorded, the sample's absorption will be found as mentioned previously.

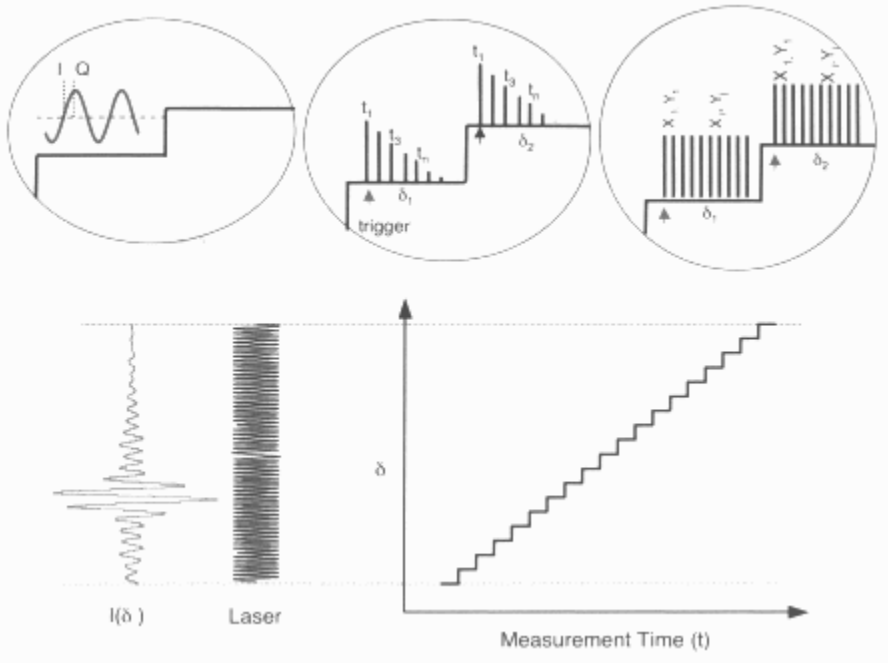

Figure 9. Data acquisitions for phase-, time-, and space- resolved step-scan (from left to right) (From: Jiang, 2003).

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III. EQUIPMENT AND CONTROL SOFTWARE

A. HARDWARE

1. Nexus™ 870 Spectrometer

The spectroscopic imaging experiments were carried out using a Nexus™ 870 Fourier transform infrared spectrometer from Thermo-Nicolet as depicted in Figure 10.

Figure 10. The front view of Nexus™ 870 FTIR spectrometer.

The Nexus™ 870 is capable of step-scan which is required for the experiment. Its sample compartment is large enough to hold the microbolometer IR camera, which captures interferograms as the moving mirror steps. Figure 11 illustrates the optical layout demonstrating that the IR beam passes through the sample compartment where the IR camera can be installed.

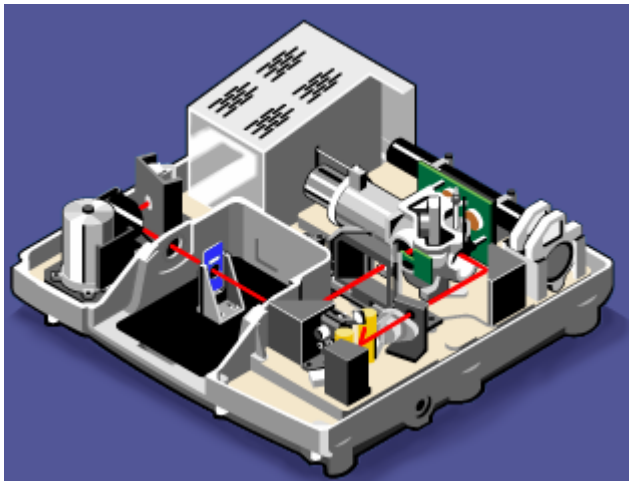

Figure 11. An image of the optical layout of Nexus™ 870 (From: Thermo Nicolet).

2. Framegrabber (NI PCI-1411)

The interferograms are captured at each mirror position using a framegrabber from National Instruments as shown in Figure 12. It can capture NTSC video frames sent from an analog camera via the RF channel. To synchronize the frame at a given moving mirror position, the trigger signal generated by the spectrometer is fed to the framegrabber.

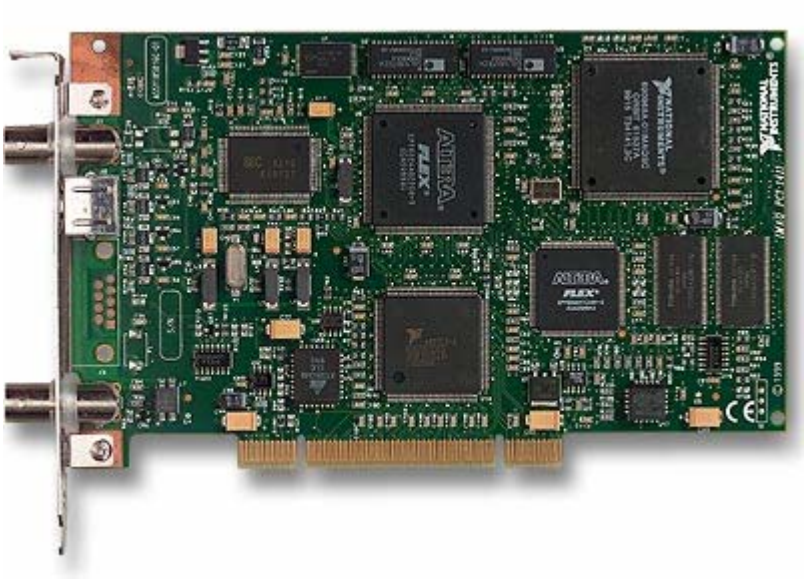

Figure 12. NI PCI-1411 (From: http://sine.ni.com/images/products/us/pci1411_09120012_l.jpg. 16 November 2006).

3. IR-160™ Thermal Imager

Figure 13. IR-160™ thermal imager (From: http://www.infraredsolutions.com/images/downloads/ImagerDS.pdf, 16 November 2006).

The IR-160 thermal imager (see Figure 13) is an uncooled infrared camera composed of a 160x120 pixels mircrobolometer focal plane array. It is sensitive to the spectral range of 8 μm to 14 μm, which is in the mid-IR range. It is capable of capturing images at 30 frames per second.

B. CONTROL SOFTWARE

1. OMNIC

OMNIC is a Nicolet software program used to control the spectrometer to perform a variety of functions. One of its useful functions in the experiment is Step-Scan Technology (SST). It allows the spectrometer to be operated in the step-scan mode, permitting the optical path difference to be stable for a pre-specified period of time necessary to capture images using the camera.

2. Spectroscopic Imaging Program (Based on LabView)

To capture frames, the framegrabber was interfaced to the camera and the spectrometer using LabView programming software from National Instruments.

There are two versions of the Spectroscopic Imaging program. The first version only captures one frame from the camera per trigger signal from the spectrometer. However, for improving the signal-to-noise ratio by averaging frames at the same location of the moving mirror, a second version of the program was developed to capture multiple images per trigger from the spectrometer. Figures 14 and 15 show the command

windows from the spectroscopic imaging programs versions 1 and 2 based on using LabView. Appendix A contains the LabView codes of the spectroscopic imaging program in both versions.

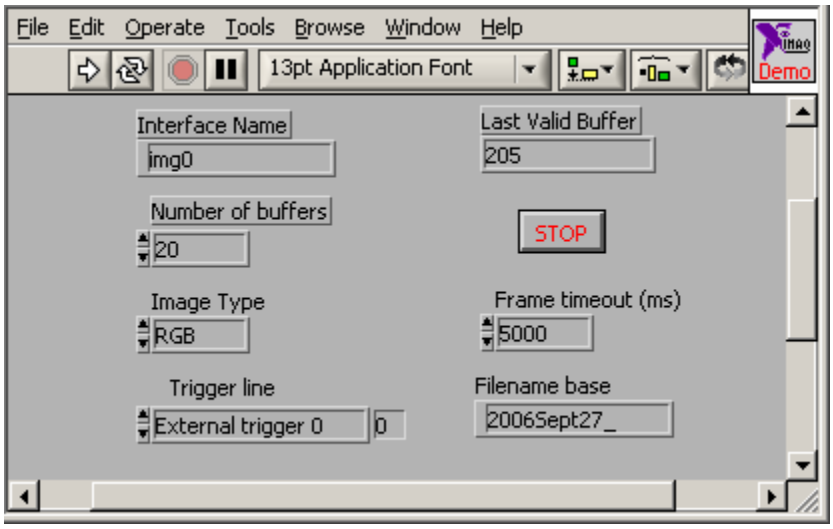

Figure 14. Command window of spectroscopic imaging program version 1.

The spectroscopic imaging program allows the users to enter a name to save images using the TIF format, select how long to wait before the first trigger signal from the spectrometer, the number of images per moving mirror step, the number of step to capture, and indicate the number of the pictures taken thus far. The output of the spectroscopic imaging program is a series of image files which are taken but is limited by the number of triggers and buffers.

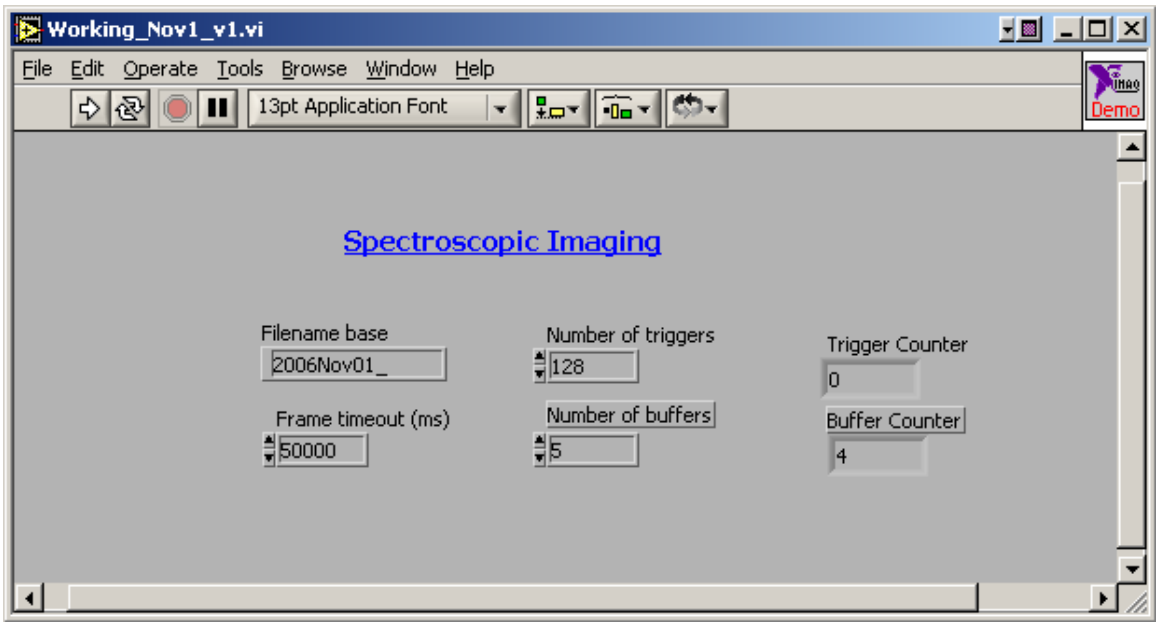

Figure 15. Command window of spectroscopic imaging program version 2.

C. EXPERIMENTAL SET UP

The experimental set-up required OMNIC, the spectroscopic imaging software, to be installed on a personal computer based on Windows as well as the LabView drivers for the NI PCI-1411. Figure 16 is a block diagram of the experimental set-up used for collecting images.

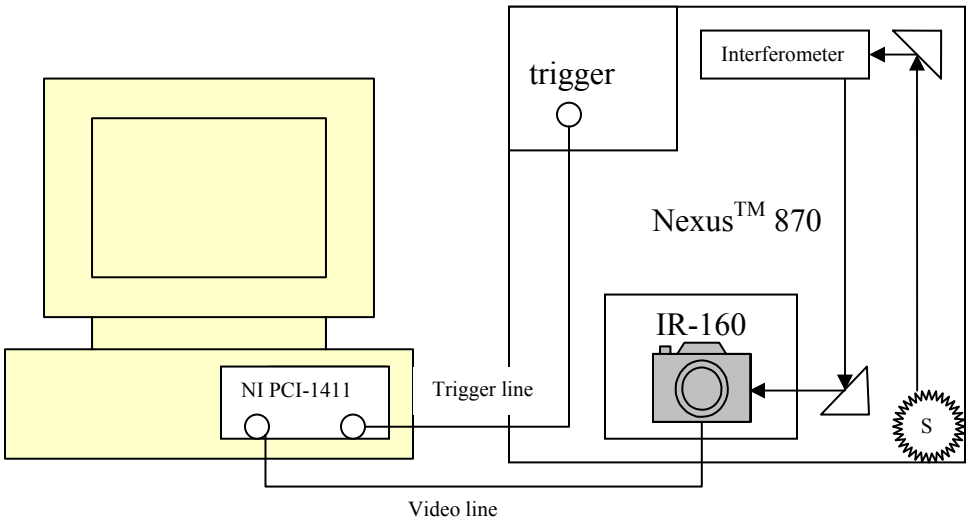

Figure 16. Schematic of the experimental set-up.

Firstly, the IR-160 Thermal Imager needs to be in the sample compartment of the Nexus^{TM} 870. The side view of the infrared camera with focusing optics looking into the spectrometer is shown in Figure 17.

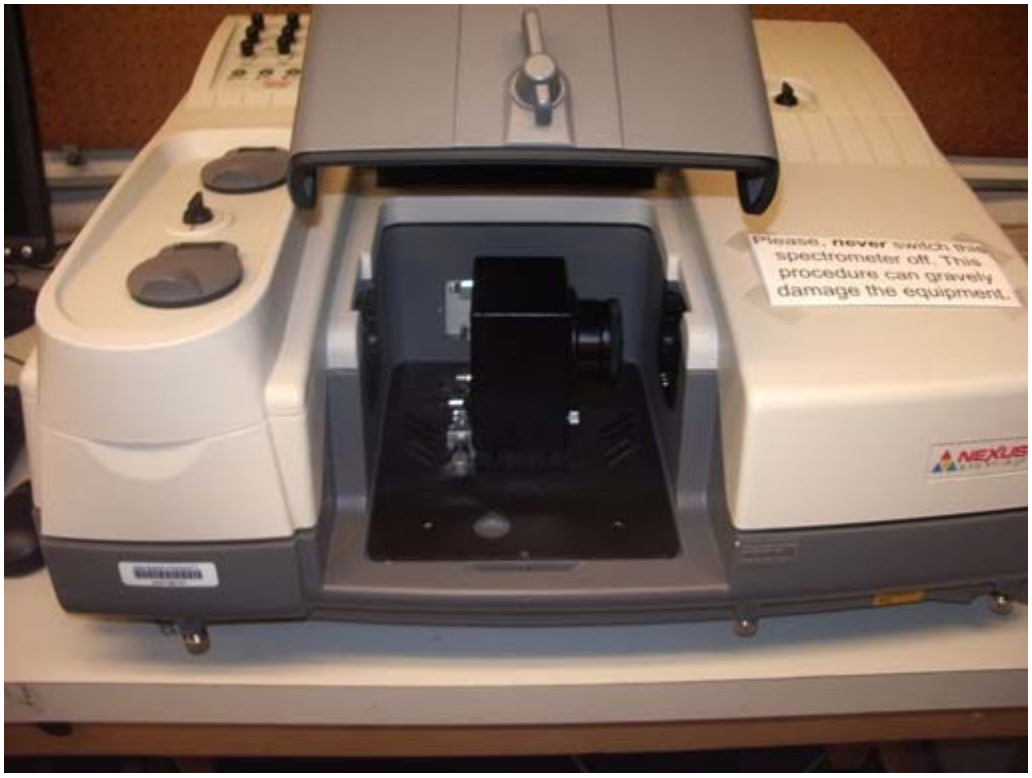

Figure 17. IR-160 in the sample compartment of the spectrometer.

Then, the video output (RF) of the camera is connected to the video input of the framegrabber. Finally, the trigger channel of the framegrabber is connected with the trigger output of the spectrometer on the SST panel shown in Figure 18.

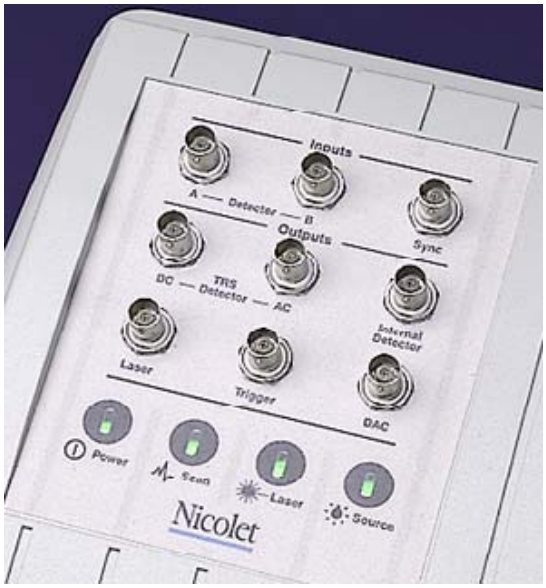

Figure 18. SST panel of the Nexus™ 870 spectrometer (From: Thermo Nicolet).

D. DATA ACQUISITION

The FTIR used in this research can perform many step-scan experiments as illustrated in Figure 19. These can be set to amplitude modulation (AM), phase modulation (PM), and time-resolved spectroscopy (TRS). The OMNIC software provides control windows for the three approaches and the AM window was the most suitable for setting the parameters for spectroscopic imaging.

The experiment requires that the optical path difference be completely stationary while the camera captures the pictures.

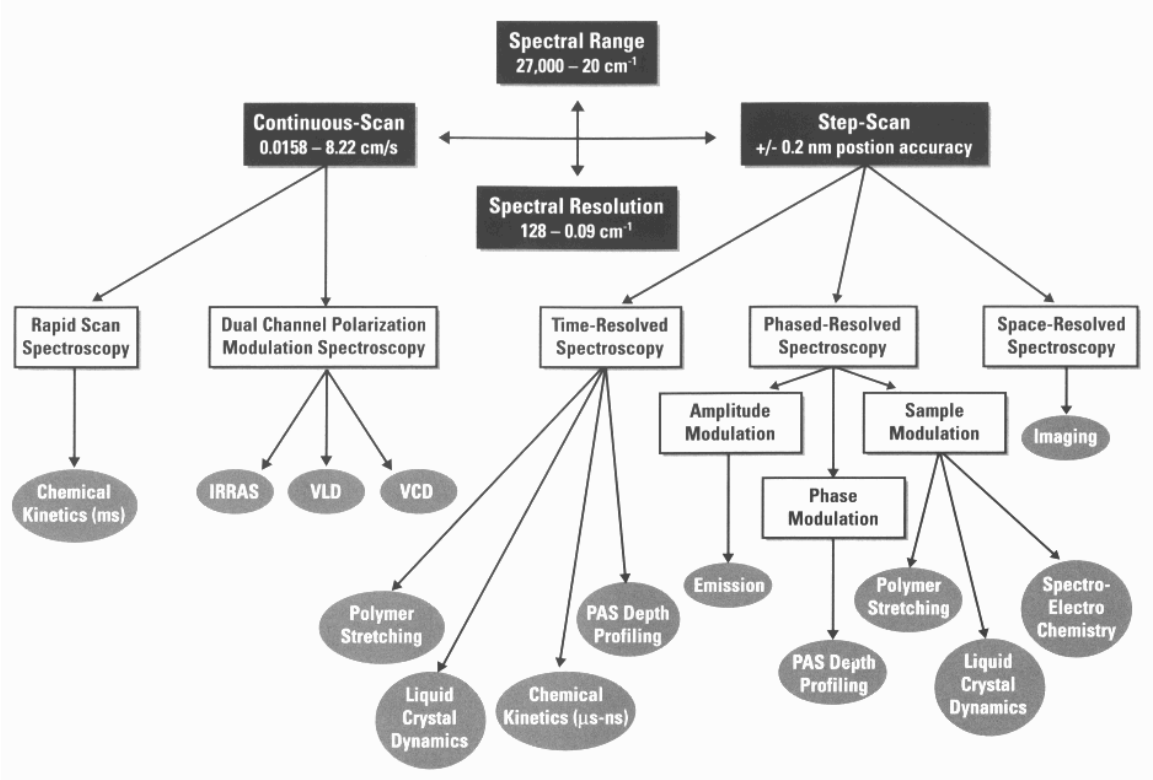

Figure 19. Advanced step-scan experiments on Nexus 870 spectrometer (From: Jiang, 2003).

1. Collection of Images

The image collection begins by selecting SST from the main OMNIC window, and then choosing the amplitude modulation, and then the sub-window to be displayed, as shown in Figure 20. There are seven adjustable parameters: spectral resolution, points before peak (zero-crossing), sample spacing, detector settling time, settling factor, time per data point, and the number of scans. When all parameters are set, click OK to prepare to collect the data. Spectral resolution depends on the number of collecting data points and sample spacing. The more data points, the higher the resolution will be.

The points-before-peak-parameter assigns the number of data points to collect before the interferogram peaks. The number of points after the interferogram peak is the same as that before the peak.

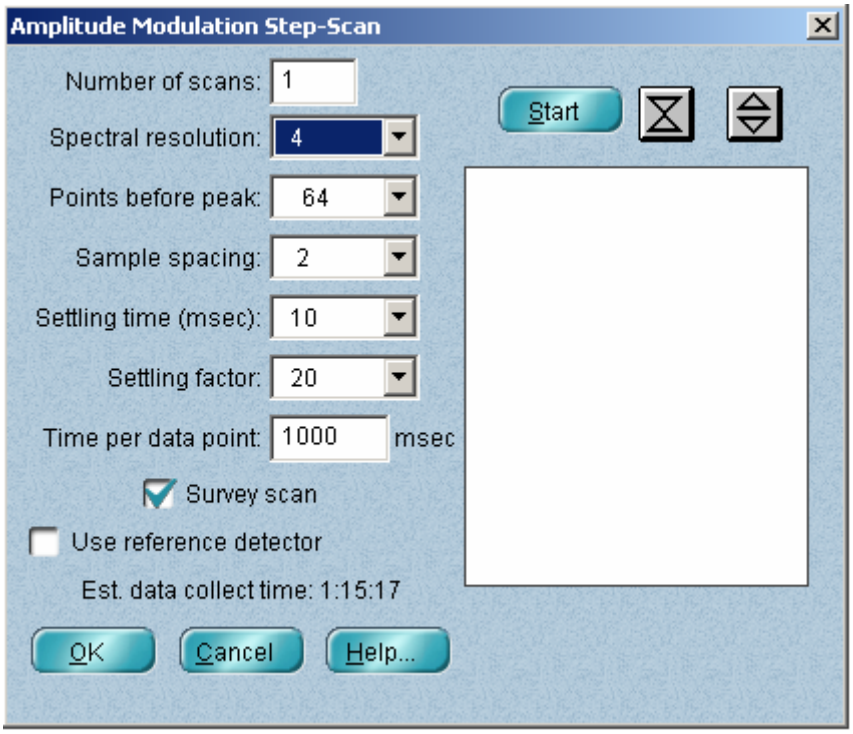

Figure 20. Amplitude modulation step-scan set-up window.

Sample spacing controls data collecting for each sampling. Number 1 is for collecting data of every zero crossing of the laser reference interferogram. Number 2 is for every other zero crossing. Number 4 collects data at every fourth zero crossing. The detector settling time defines the time to stabilize the fixed mirror at each retardation step. The time per data point parameter is to allow enough time for data collection at each mirror step. Increasing the time per data point improves the signal to noise ratio (SNR) due to the better average with a higher number of images as schematically illustrated in Figure 21.

After setting the AM parameters, one of the LabView programs shown in Figures 14 and 15 can be used to collect images. It is important to give enough time before the first trigger signal from the spectrometer, since the two programs (OMNIC and LabView) run independently. The number of triggers and buffers depends on the number of pictures to be taken.

A typical interferogram collected using this approach is depicted in Figure 22, where the dark shadow in the middle is due to the HeNe laser detector obstructing the infrared beam of the FTIR.

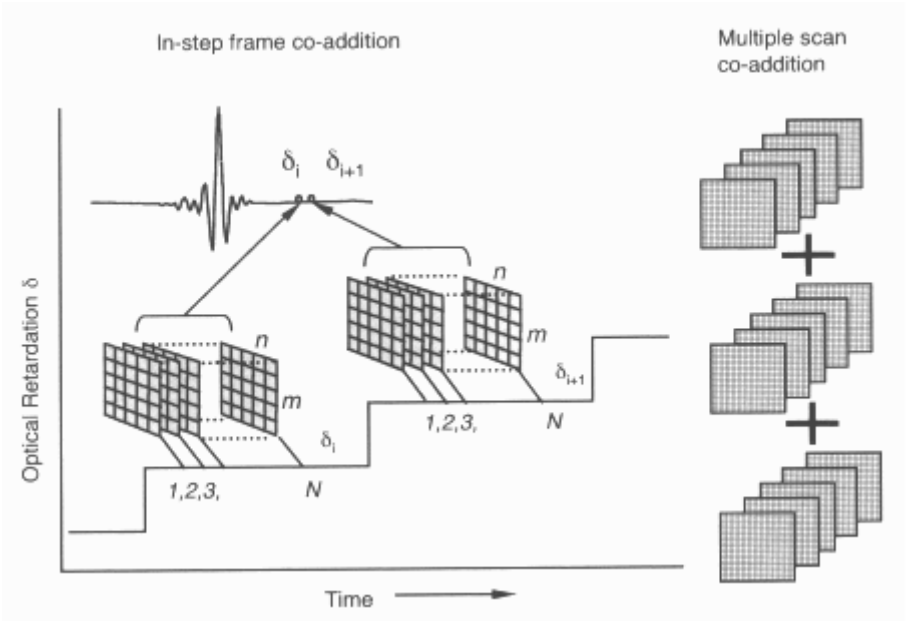

Figure 21. Step-scan spectroscopic imaging experiment diagram (From: Jiang, 2003).

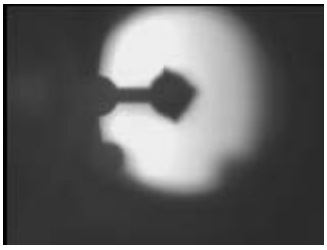

Figure 22. One of the collected images using the setup.

IV. DATA ANALYSIS

A. DATA ANALYSIS

During the initial measurement, 128 sampled interferogram images were collected with the zero-crossing (or centerburst) at the middle of the set. It was observed that the brightness of the images was weak in the beginning, grew brighter around the centerburst region, and then became the same as in the beginning.

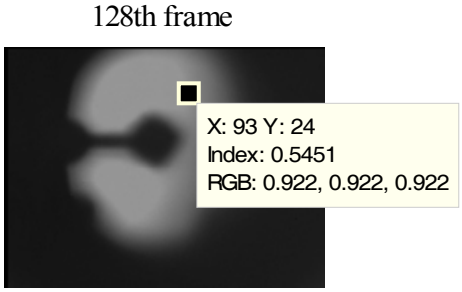

Figure 23. Position of the chosen pixel (93,24).

Figure 23 shows the last frame of the data set, and it is obvious that the center of the IR beam is blocked by the detector assembly for the HeNe laser of the spectrometer. In this case, the pixel position (93,24), away from the center, was chosen to construct the interferogram as shown in Figure 24. The data from each image was extracted by developing the necessary Matlab codes given in Appendix B. The pixel data shows a typical interferogram observed in FTIR spectroscopy using a single detector but with a smaller signal-to-noise ratio due to the distribution of infrared power of the spectrometer among many pixels.

As mentioned in Chapter II, only the AC component is considered during the reconstruction of absorption data from the interferogram. The interferogram in Figure 24, however, contains both AC and DC components. The DC component is usually eliminated by subtracting the average from the raw data as illustrated in Figure 25. Once the inverse Fourier transform of the interferogram in Figure 25 has been performed by the Mertz method (Griffiths and de Haseth, 1986), the result is the spectral intensity, $B(\sigma)$, of all wavenumbers as shown in Figure 26.

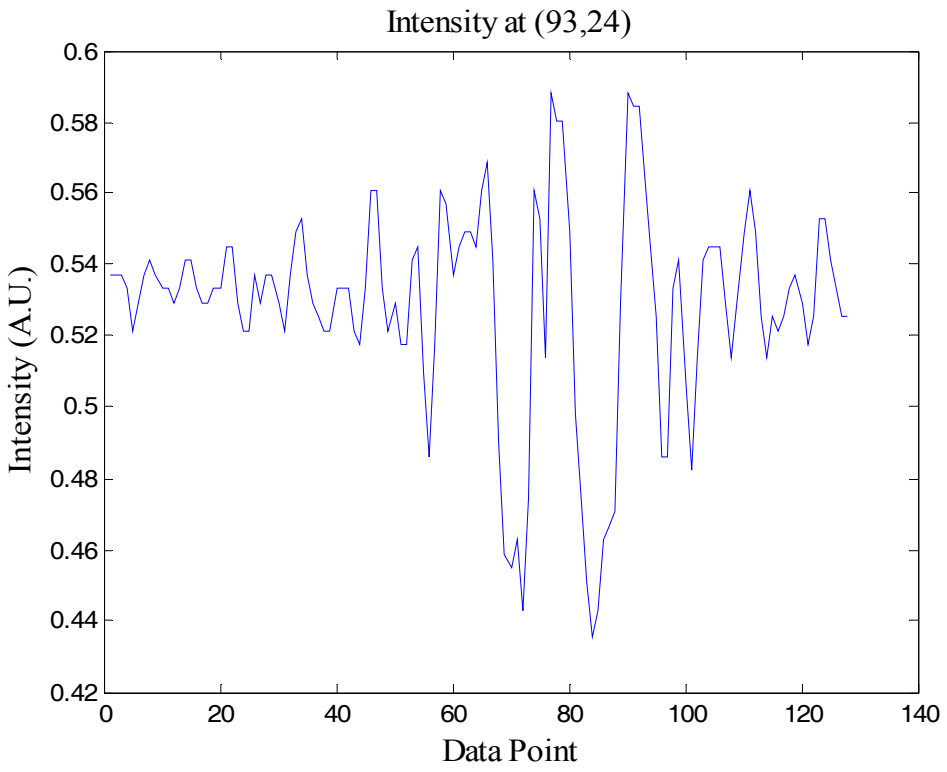

Figure 24. Interferogram at the pixel (93,24), 128 samples.

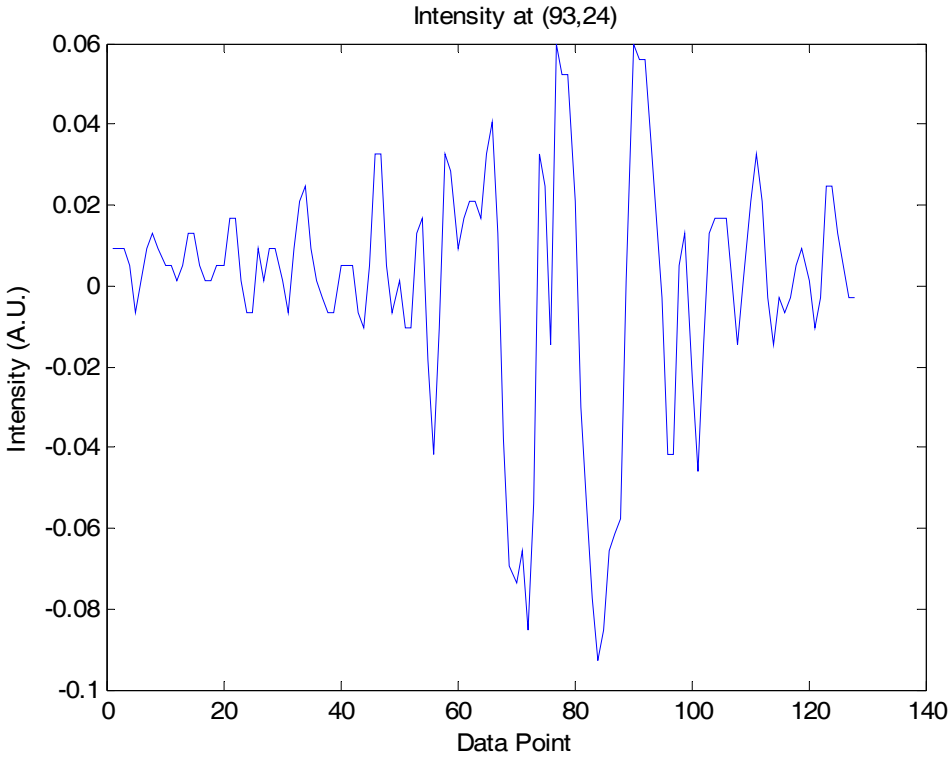

Figure 25. The interferogram after removing average (DC component) from the raw data in Figure 24.

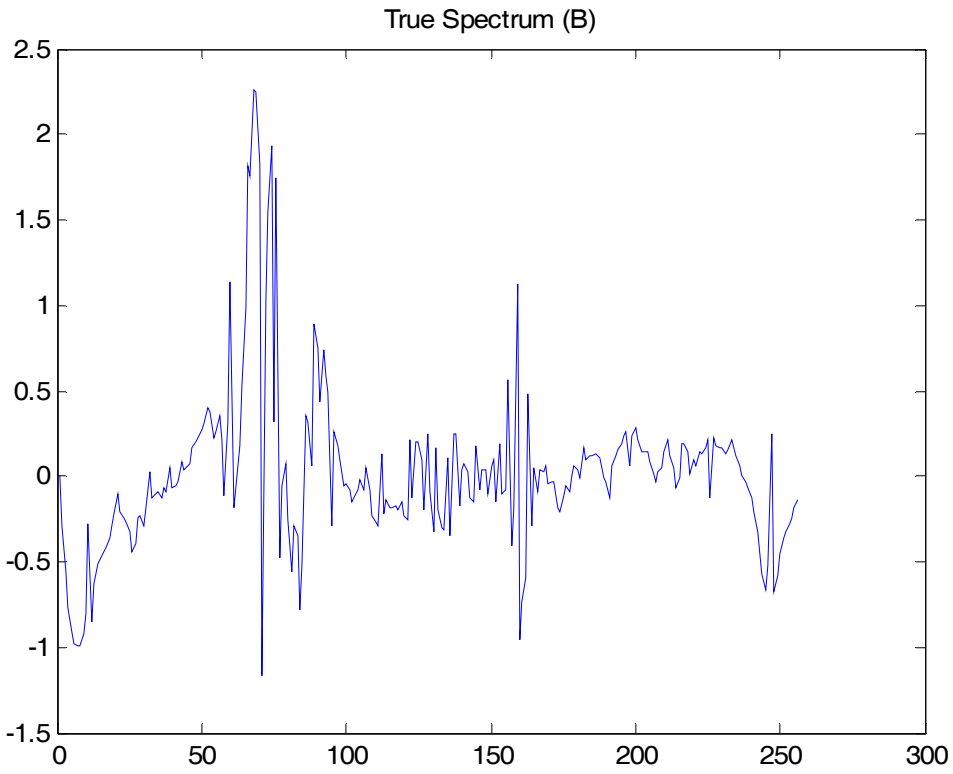

Figure 26. Inverse Fourier transform of the interferogram in Figure 25.

In order to test the system's capability of collecting a large number of images, in subsequent experiments, the frame count was increased to 256. Also, the spatial distribution of infrared power from the spectrometer was monitored by plotting the interferograms arising from four corners of each image as shown in Figure 27. The intensity of the IR source was detected by four-pixel data collection on four edges of the pictures, and then their interferograms were plotted. For a uniform infrared beam the interferograms should be nearly the same, provided that optical phase variations, mirror alignment and electronic read-out delays are all well matched across the field of view, or frame.

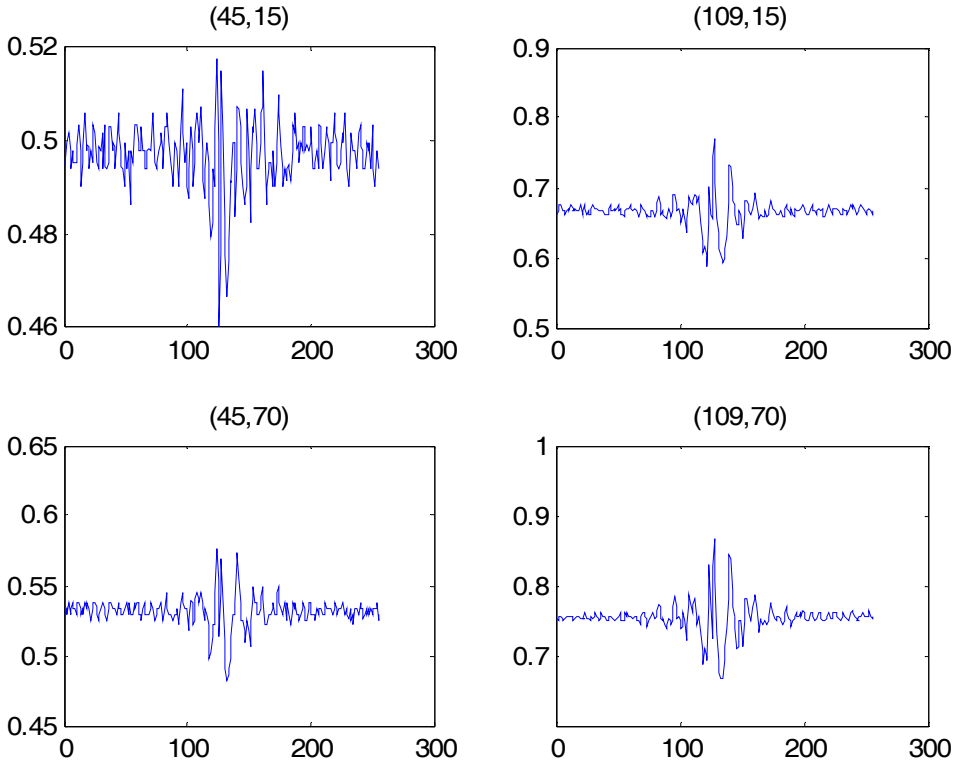

Figure 27. Four interferograms using different pixels at the edge of the images.

For increasing the resolution of the spectrograph, it is necessary to increase the total optical path difference per scan, thereby increasing the number of images per scan. The current setup is found to be limited to about 512 frames primarily due to the available buffer of the framegrabber. At 512 frames, the interferogram in Figure 28 shows a much finer variation of intensity as the moving mirror scans compared to the one given in Figure 25.

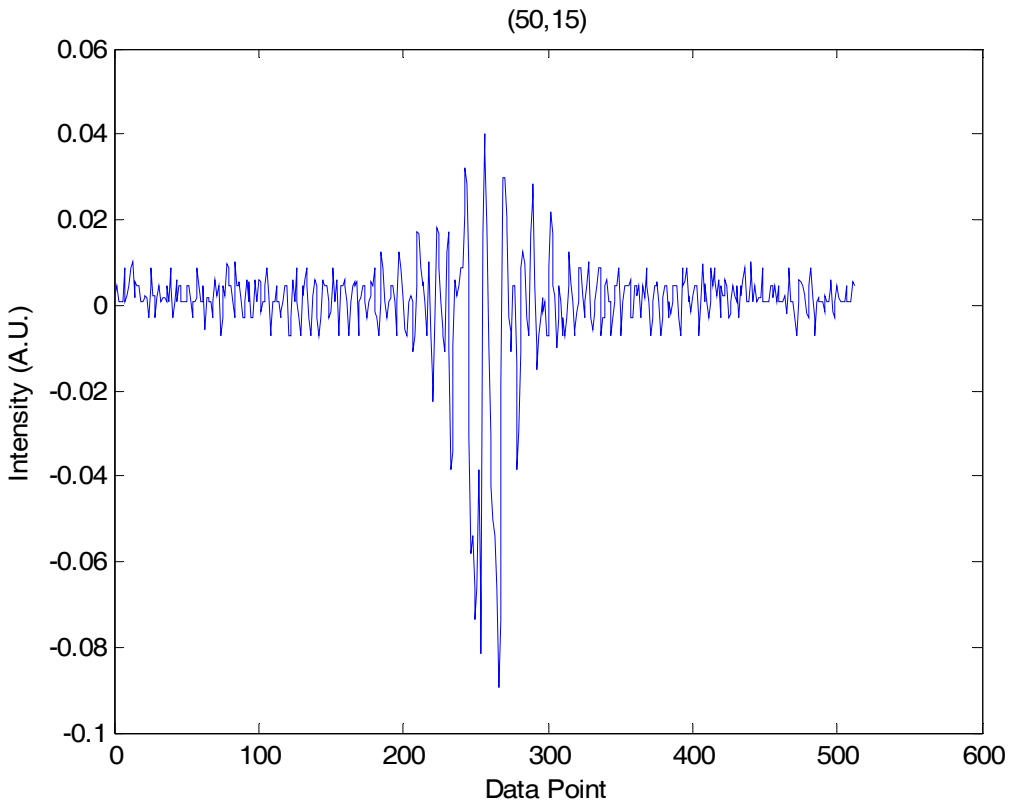

Figure 28. The interferogram using 512 frames.

The image obtained at the peak of Figure 28 is shown in Figure 29.

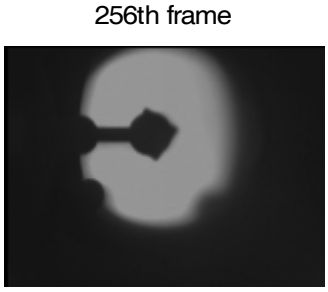

Figure 29. The 256th image of the experiment on 10/17/06.

1. Averaging Frames at each Mirror Position

The spectroscopic imaging program was further developed so that the framegrabber can take more frames at the same moving mirror position. The multiple images on each step will be averaged and thus it increases SNR. Figure 30 and 31 show

interferograms with single frame per step and 16 frames per step, respectively. It shows an improvement of the S/N ratio as the number of frames averaged is increased.

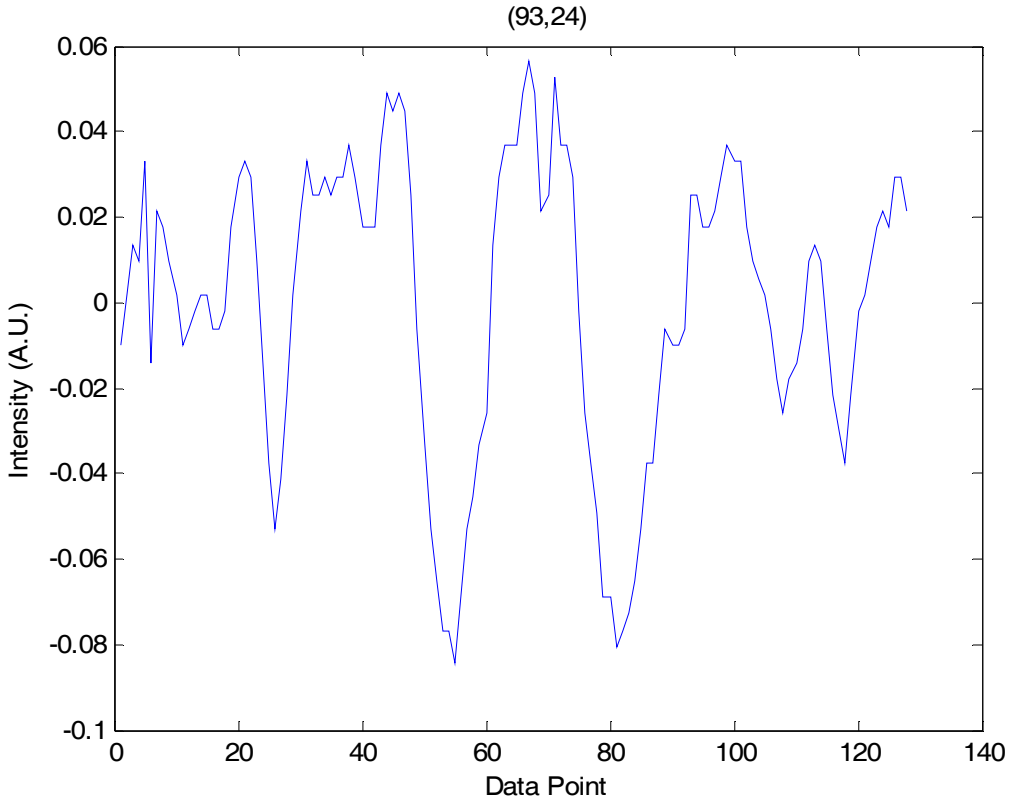

Figure 30. An interferogram of 128 frames with 1 frame per step.

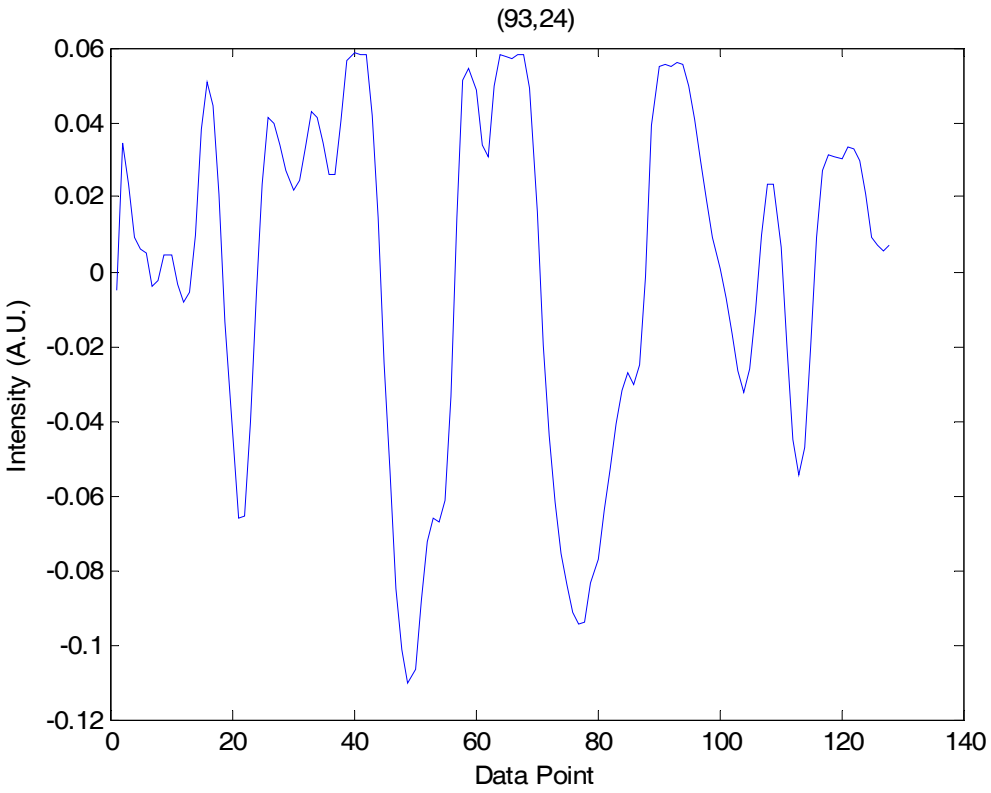

Figure 31. An interferogram of 128 frames with 16 frames averaged per step.

A further increase of the number of frames per step and the higher number of steps should produce interferograms with a higher S/N ratio with good spectral resolution. The next step of the analysis requires the development of Matlab programs to inverse Fourier transform the datacube generated by the experiment.

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V. CONCLUSION AND FUTURE WORK

Fourier transform infrared spectroscopic imaging provides details about the spatial variation of spectroscopic information. Based on experimental observations presented in this thesis, the use of an IR-160 thermal imager Nexus^{TM} 870 spectrometer can be used for the development of an infrared spectral imaging system. The interferograms with improved S/N ratio were achieved by averaging multiple frames taken at each mirror step.

In future work, the data acquisition program needs to be modified to incorporate frame averaging at each mirror step to be carried out by the framegrabber and the generation of a datacube within LabView. This will provide room for collecting images from a large number of mirror steps which will enhance the spectral resolution at each pixel. The software needs to be developed to extend the analysis to obtain the spatial variation of spectral information using the datacube. Finally, the corner-to-corner sampled interferograms, as shown in Figure 27, indicate the probable presence of opto-mechanical instabilities that must be examined further. These can be characterized by performing additional experiments using isolated emission line sources, which, at the low resolving powers used here, are good impulse response (δ-function) diagnostics for measuring the FTIR's optical transfer characteristics.

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APPENDIX A. LABVIEW CODE

A. SPECTROSCOPIC IMAGING VERSION 1

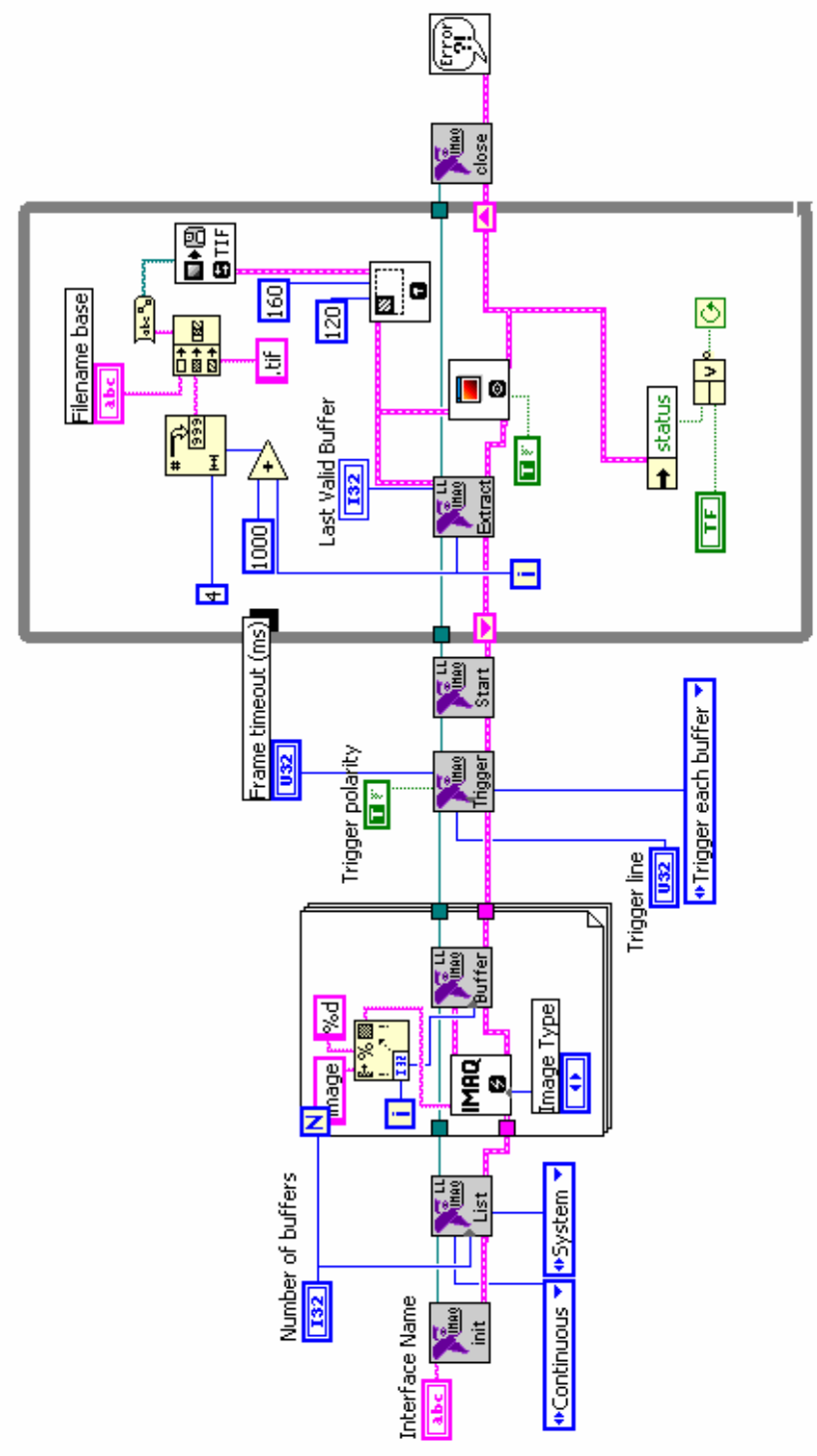

Figure 32. LabView code of Spectroscopic Imaging program version 1.

B. SPECTROSCOPIC IMAGING VERSION 2

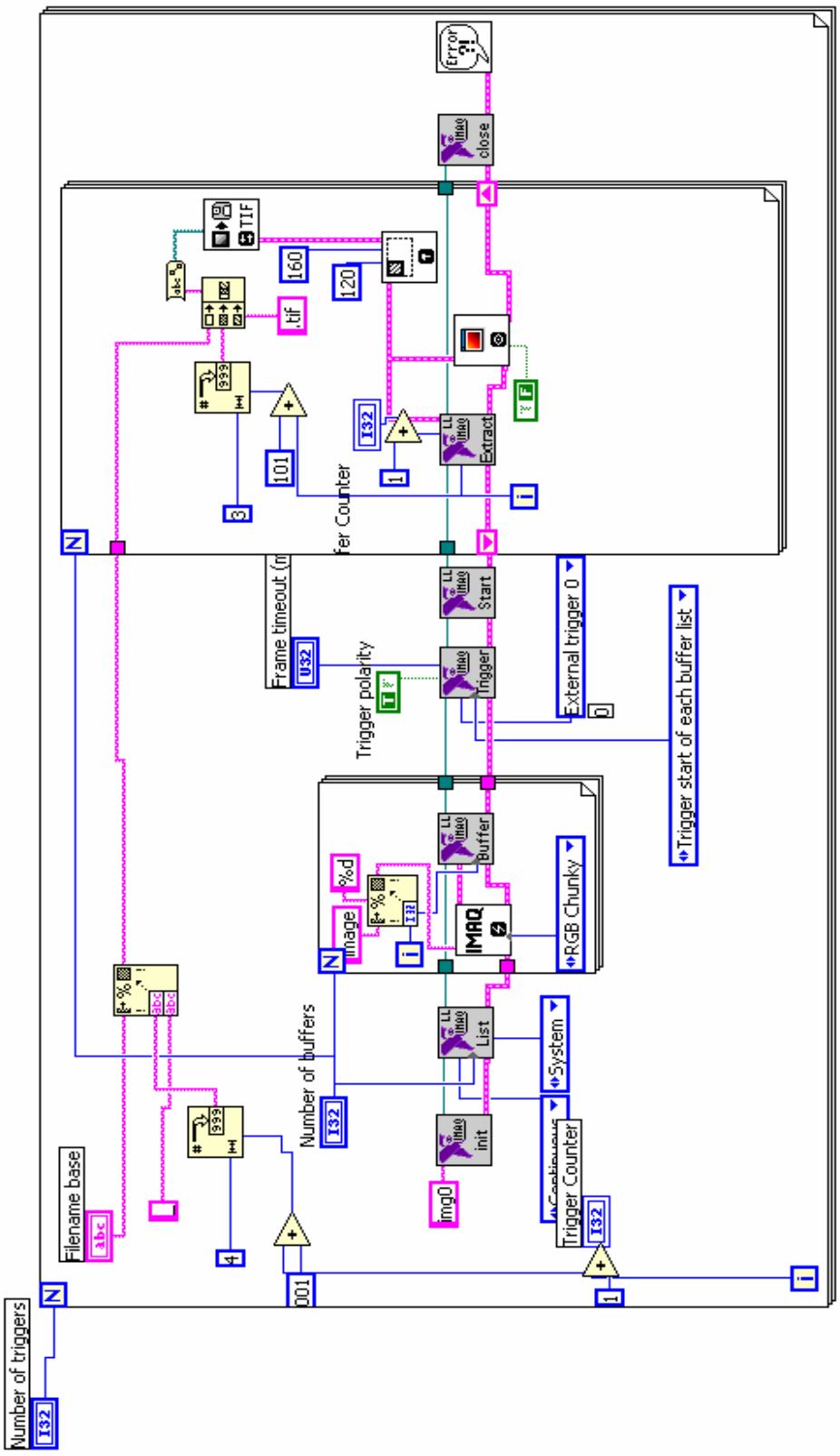

Figure 33. LabView code of Spectroscopic Imaging program version 2.

APPENDIX B. MATLAB CODES

A. MATLAB CODE FROM 10/16/06 TO 10/25/06

```
clc
clear
N=128;
mri=(zeros(120,160,3,N));
a=24;
b=93;
c=0;
for frame=(1+c):(N+c)
    cframe=frame-c;
    if frame<10
        file=(['image100',num2str(frame),'.tif']);
    elseif frame>=10 & frame<100
        file=(['image10',num2str(frame),'.tif']);
    elseif frame>=100 & frame<1000
        file=(['image1',num2str(frame),'.tif']);
    end
file;
    mri(:,:,:,cframe)=rgb2ntsc(imread(file));
    y(:,:,cframe)=mri(:,:,1,(cframe));
    Y(cframe)=y(a,b,cframe);

end

X=[1:N];
title(['Intensity at ','(',num2str(b),',',num2str(a),')'])
xlabel('Data Point')
ylabel('Intensity (A.U.)')
```

B. MATLAB CODE ON 11/01/06

```
clc
clear
N=128;
M=16;
bmri=(zeros(120,160,3,M));
a=24;
b=93;

for trigger=1:N
    for buffer=1:M
        if trigger<10 & buffer<10
            file=(['image100',num2str(trigger),...
                ' _10',num2str(buffer),'.tif']);
        elseif trigger<10 & buffer>=10
            file=(['image100',num2str(trigger),...
                ' _1',num2str(buffer),'.tif']);
        elseif trigger>=10 & trigger<100 & buffer<10
            file=(['image10',num2str(trigger),...
                ' _10',num2str(buffer),'.tif']);
        elseif trigger>=10 & trigger<100 & buffer>=10
            file=(['image10',num2str(trigger),...
                ' _1',num2str(buffer),'.tif']);
        elseif trigger>=100 & trigger<1000 & buffer<10
             file=(['image1',num2str(trigger),...
                 ' _10',num2str(buffer),'.tif']);
        elseif trigger>=100 & trigger<1000 & buffer>=10
             file=(['image1',num2str(trigger),...
                 ' _1',num2str(buffer),'.tif']);
        end

        bmri(:,:,:,buffer)=rgb2ntsc(imread(file));
        bY(buffer)=bmri(a,b,1,buffer);

    end

    Y(trigger)=mean(bY);

end


X=[1:N];
cY=Y-mean(Y);

Figure(1)
plot(X,cY)
title(['(',num2str(b),',',num2str(a),')'])
xlabel('Data Point')
ylabel('Intensity (A.U.)')
```

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