Efficient Signal Processing Algorithms for Optical Doppler Tomography

Literature Survey

University of Texas at Austin

Department of Electrical and Computer Engineering

Milos Milosevic

Wade Schwartzkopf

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Milos Milosevic and Wade Schwartzkopf

University of Texas at Austin

Department of Electrical and Computer Engineering

Abstract – *Optical Doppler tomography (ODT) is an imaging technique, which uses the Doppler shift observed in the spectrum of backscattered light to calculate the pixel values of the sample being imaged. Using this technique, one can obtain an image that contains structural information and an image that contains the location of movement in the image. As data acquisition rates for ODT systems become faster, the need arises for faster algorithms with which to process this data and create the structural and velocity images. However, since this area is very young, the signal processing aspects of ODT have been largely unexplored. The goal of this project is to develop efficient algorithms for producing velocity image in ODT systems. In this paper, we propose researching several methods of making the signal processing aspects of ODT system more efficient.*

I. Introduction

Optical Doppler tomography (ODT) is a non-invasive imaging technique which incorporates laser Doppler flowmetry and optical coherence tomography to produce images of the static and dynamic components in highly-scattering biological samples. In ODT light is emitted from a partially coherent source and the intensity of the backscattered light is measured. Any flow in the tissue collinear with the source beam will result in backscattered light whose spectrum is Doppler-shifted and broadened from the spectrum of the source signal. Combining information from the reflected signal and the reference signal produces an interference fringe pattern. Different pixel values in one dimension can be obtained by moving the light source at a constant velocity along the surface of the sample. To determine a pixel value at a different depth, the source beam can be moved closer to or farther away from the object being imaged. This procedure has the ability to image the biological tissue in all three spatial dimensions. Because the lateral movement of the source beam can be controlled very precisely, high spatial resolution (2-15μm) of the images can be obtained. The structural and velocity images of the observed sample produce by ODT are shown in Figure 1.

In this paper, we will briefly review the short history of this imaging technique in Section II. In Section III, we will discuss current data processing methods used in ODT, and, finally, in Section IV, we will propose several methods to speed of ODT data processing.

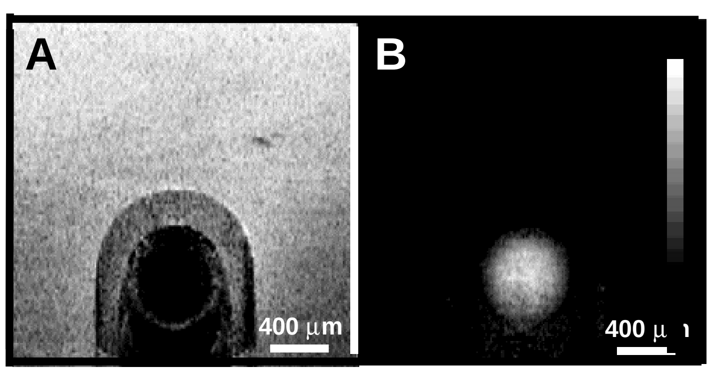

Figure 1: ODT images of polystyrene microspheres in a polyethylene conduit submerged 1 mm below the surface in a turbid sample: A: ODT structural image of flowing microspheres: B: ODT velocity image of flowing microspheres.

II. History

Some optical Doppler techniques date back to shortly after the invention of the laser in the 1960's. Early references to optical Doppler tomography are found in the 1970's [1]. However, for many years, this method of imaging was plagued by low-resolution and inaccuracy. Because of these difficulties, this method had limited application.

But in 1995, a completely new method of optical Doppler tomography was developed in [2] that solved many of the problems with earlier systems. Research into this area is still young, but since the discovery of this new type of optical Doppler tomography, the two most active groups in this area are at the University of California at Irvine [2, 3] and Case Western University [4, 5]. At the University of Texas at Austin, Thomas Milner is currently building a new group to study optical Doppler tomography. His group seeks to run ODT systems at much higher frame rates. While typical data acquisition rates on previous generation ODT systems are generally in the range of several minutes, Milner's group is working on a system that will be capable of capturing enough data to produce ten frames per second. With higher and higher frame rates comes the need for more sophisticated signal processing techniques, but, to date, very little has been published on the signal processing aspects of this imaging technique. This leaves many opportunities for those doing research in this area.

III. Current Signal Processing Techniques

Optical Doppler tomography systems measure the interference fringe pattern at each discrete position of the source beam. Interference fringe intensity is a function of time and is detected by a single photovoltaic detector. This analog signal is amplified, highpassed and digitized (20KHz) using a 16-bit analog-to-digital converter. The length of the interference fringe pattern for one pixel is approximately 10ms, or 200 samples. With this method, the acquisition time for a 128x128-pixel image is currently around 2-3 minutes.

Because the response of the backscattered light varies with position and time, a time-frequency representation is used to obtain values for pixels at different locations in the image. A good summary of several time-frequency representations is found in [6]. The short-time Fourier transform (STFT) is used in this application. It is a good choice for the time-frequency representation of ODT signals because it has high time-frequency resolution on modulated signals [7] such as typical signals from the backscattered light. The method employing the STFT that is currently used to calculate the structural and velocity images is described below.

The grayscale value of the pixel at the location (i,j) in the structural image is given by the squared magnitude of the short-time fast Fourier transform of the interference fringe intensity evaluated at the frequency of the source in the time interval, where i corresponds to the depth of probing and j corresponds to the lateral position. Due to the exponential attenuation of the signal with the probing depth, the grayscale pixel values in structural ODT images are logarithmically corrected.

The grayscale value of the pixel at the location (i,j) in the ODT velocity image is proportional to the Doppler frequency shift of the temporal interference fringe intensity. The constant of proportionality is a function of the wavelength of the source and the angle between the source wave vector and the flow direction vector. The Doppler frequency shift is calculated as the difference between the source signal frequency and the centroid of the short-time fast Fourier transform of the interference fringe intensity in the time interval when the source beam is around point *(i, j)*.

IV. Future Work

The goal of this project is to make ODT more efficient by reducing the calculations necessary to produce the velocity image. One area in which too many calculations may be being done is in flow velocity measurement. During the imaging process, blood vessels likely will be positioned randomly compared to the line-of-sight of the source beam. This means that only a fraction of the true flow will be detected, the fraction whose flow direction vector is collinear with the source wave vector. Hence accurately measuring the component of the flow velocity that is collinear with the source beam may not necessarily render accurate information about the actual flow in the blood vessel. The important information is just whether or not there is flow at a given location. It is hoped that this information can be extracted from the multitude of the gathered data with a procedure that is more efficient than the one currently used.

With this hope in mind, we propose several methods to accelerate data processing and velocity image creation in ODT systems. One possible way to do this might be to reduce the precision of the digitized data. Currently, the system uses 16-bit precision. It would be instructive to see how well flow could be detected with the present algorithm if a lower number of bits of precision was used. It might also be useful to determine exactly how many bits are needed, in a particular class of images, to accurately detect flow. If it is established that lower precision is sufficient for detection of the flow and if it consistently detects flow across classes of images, this use of fewer bits would certainly results into computational savings. Gallois Field arithmetic provides ways to do mathematical operations like fast Fourier transforms (FFT) on low bit and binary images. Some methods for using Gallois Field arithmetic are described in [9, 10].

The second approach might be to downsample the incoming data (currently clocked at the rate of 20KHz) since it may be possible to detect the flow with fewer samples. The frequency resolution would drop but the features of the Doppler shift may be prominent enough to overcome this impediment for the purposes of detection.

The third approach could deal with the algorithmic scheme behind the creation of ODT structural and velocity images. It might be enough to process only a certain number of interference fringe patterns. In effect it would "sample" the structural and velocity image at pre-determined locations (pick out pixels) such that the distance between the samples is maximized (maybe a rectangular *nearest-neighbor* scheme).

With any of these approaches, it may be possible to construct some kind of a pyramidal scheme, whereby the images could processed using lower precision and then segmented into regions of possible flow and regions which were unlikely to have flow. The regions with the indications of flow may be processed again with higher precision in order to assess the desired parameters better. The measure of performance of any new algorithm tried on the ODT signals could be assessed through the number of calculations needed and the accuracy of flow detection.

It is our hope that, with this project, we can help develop efficient algorithms that will help the signal processing side of ODT systems keep up with their increasing data acquisition rates.

V. References

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