HYPERSPECTRAL BIOMEDICAL IMAGER

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Abstract

This paper describes the development of a signal and image processing system for the Hyperspectral Biomedical Imager (HBI). The HBI forms hyperspectral images of human tissue with high spatial and spectral resolution. The final goal of the research project is to develop a fully functional HBI image formation/processing system based on the TMS320C6X. This would permit fast and efficient data processing, enhancing the utility of the HBI.

Introduction

In the U.S. one of the leading causes of blindness in our aging population is age-related macular degeneration (ARMD). Recent research has provided evidence that certain subretinal biochemical and physical changes are related to increased risks of ARMD. Another area of strong interest for the medical community, given the documented increase in the overall (national) incidence of melanoma, is the development of improved imaging techniques for the early detection of malignant melanoma (MM). Since in both cases (ARMD and MM) these preclinical features can not be observed easily with today's imaging systems, Kestrel Corporation (Albuquerque, NM) with funding from the National Institutes of Health, has developed and built a hyperspectral imaging system (HBI) capable of imaging human tissue (retina, skin) with high spatial and spectral resolution. This is a distinct improvement over other medical imaging systems that typically offer a trade-off between spatial and spectral resolution. Because of its capability of imaging human tissue with high spectral (wavelength resolution of 4 nm at a wavelength of 500 nm) *and* spatial (~20 μm) resolution, the HBI represents a significant advance in the area of biomedical imaging.

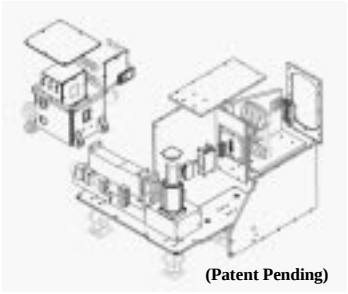

Figure 1. An "exploded" view of the Fourier transform interferometer used in the HBI.

The front-end optical system of the HBI generates interferograms (one per pixel) with high spatial resolution. The high spectral resolution of the final hyperspectral images is achieved by the digital signal/image processing algorithms employed. Each interferogram is made zero-mean, enhanced and then Fourier transformed, using high resolution algorithms such as the classic Chirp-Z (CZT) and others, to form the final set of images. This paper describes the signal processing involved and results using C code on SUN/PC workstations. The final objective of this project is the porting of this system to the TMS320C6X chip in order to make the process real-time (or near real-time) in order to make the HBI a functional diagnostic tool for the physicians.

HBI Imaging System

The successful application of high spatial and spectral resolution to the imaging of the human retina has been achieved by an approach which couples a fundus camera with an imaging spectrometer, referred to as the Hyperspectral Biomedical Imager (HBI) [1] as shown in Figure 1. The fundus camera is used to illuminate the retina and collect the light reflecting from the retina. In place of the standard 35 mm camera on the fundus camera, an imaging spectrometer and scene camera with relay optics were attached. The imaging spectrometer takes this reflected light and separates out the different wavelengths present over a relatively large bandwidth (450 – 750 nm), while preserving spatial information. In this project the imaging spectrometer of choice was a spatially modulated Fourier transform interferometric device, which is based on a Sagnac interferometer which creates an interferogram that contains the desired spectral information. The HBI is not the first device that has been built to take spectral measurements of the retina. A number of systems have been built that make point spectral measurements of various regions of the retina [2]. A major deficiency of these systems is that 1-2 degrees Field-of-View (FOV) point measurements within a narrow bandwidth (400-500 nm) usually spatially integrate over features of interest, making it hard to record a pure spectrum of a retinal vessel or small lesion . To circumvent the spatial averaging problem, other systems have been built that take 2-dimensional images in selective wavelength bands [3]. While recording the spatial features for a single narrow wave band, it requires significant effort to spatially register a large set of images measured at different wavelengths. In the HBI, spatial and spectral information are measured simultaneously. The same fundus camera system has also been used to collect hyperspectral imagery of skin lesions.

Hyperspectral images have been collected for over 30 subjects by Kestrel Corporation and their collaborators at the UNM Health Sciences Center (UNMHSC). A sample of normal and pathological images has been provided by Kestrel. The data samples include retinal tissue and pigmented and non-pigmented skin lesions. Skin lesions include malignant and benign tissue samples. Kestrel has received funding from the National Eye Institute to collect more human subject data over the next two years. Candidate human subjects will be recruited by UNMHSC. The approved protocol for human subjects will focus on individuals at risk or presenting with ARMD.

Signal / Image Processing

The fundamental unit of HBI data is an interferogram. A series of interferograms are collected for each spatial transect (or stripe) on the fundus. Each interferogram, when processed with a Fourier transform (FFT), produces spectral data for one pixel. A 1024 X 1024 charged couple device (CCD) camera is used to record the spatial-spectral data. Figure 2 illustrates the data format. The 30° field of view of the retina is sampled with 310 interferograms, resulting in a pixel field of view of 0.0625 milliradians. Typically, before applying the Fourier transform to the interferogram, the data are preprocessed to maximize its information content and reduce noise and other artifacts. The preprocessing algorithms developed operate on one interferogram at a time. The data are first made zero mean by subtracting a smoothed version of itself as illustrated in Figure 3. The first plot in this figure shows the original interferogram, the middle trace represents the smoothed (lowpass filtered) replica while the third trace is the difference – original minus the smoothed replica. Next, the zero mean interferogram data is enhanced using an open loop adaptive signal enhancement algorithm [4] that essentially improves the signal-to-noise ratio of correlated signal components. For this data enhancement stage we intend to study two alternate algorithms as well - LMS adaptive algorithm and a spectral subtraction technique [5]. Once these preprocessing

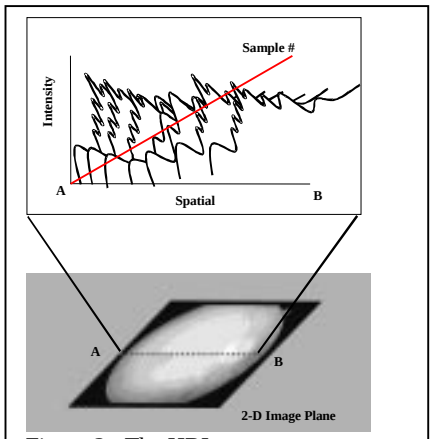

Figure 2. The HBI captures an interferogram for each pixel along the spatial line (A, B)

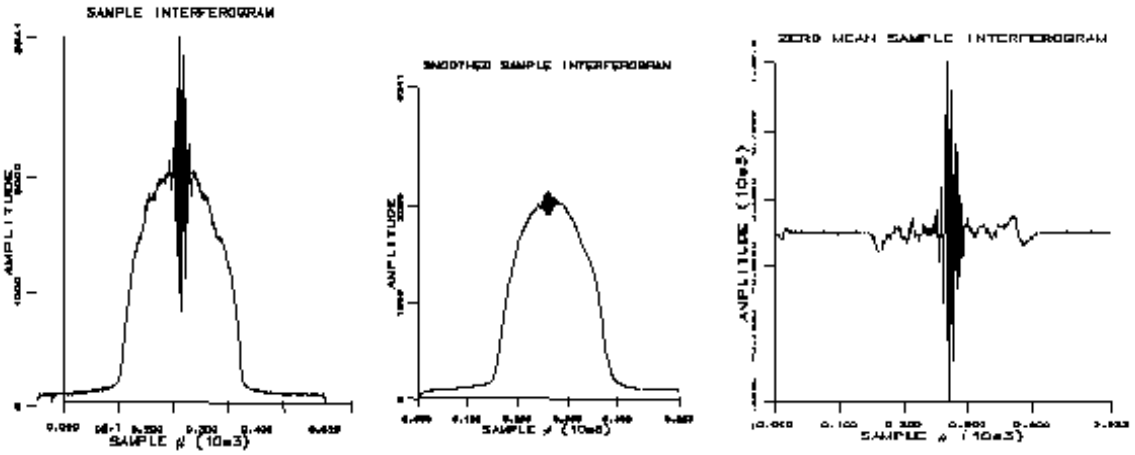

Figure 3 Illustration of interferogram preprocessing

steps are completed, each interferogram (corresponding to each individual pixel) is windowed and then Fourier transformed. Note, that the window size is picked so as to eliminate the noisy data in the tails of the zero-mean interferogram (third plot in Figure 3). Since the frequency resolution of the Fourier transforming process determines the final spectral resolution of the hyperspectral imagery, the choice of window function can be quite critical. We propose to use a Taylor window based on past experience in radar image formation, which also utilizes FFTs. One way to perform the Fourier transform would be to use a standard radix 2 (R2-FFT) algorithm.

However, the frequency region that is critical to the task at hand is, approximately, from 0.5 Fs to 0.75 Fs (where Fs represents the sampling frequency) and a standard FFT algorithm distributes the data samples in the frequency domain evenly from d.c. to Fs. If more resolution is required in this limited frequency band, some alternative algorithm such as the Chirp Z Transform (CZT) algorithm [6] could be employed instead of the simple R2-FFT. An algorithm such as the CZT can produce spectral information in a specified frequency band with a specified resolution. The CZT algorithm in essence dramatically improves the resolution in the frequency domain. This is extremely critical if the data analysis is being conducted in the frequency domain and there is only a limited amount of data available in the spatial domain. It does require more FFTs and thus increases the computational load on the processor.

Figure 4 illustrates the advantage of using the CZT algorithm. A signal consisting of the sum of three sinusoids was synthesized, the three frequencies selected were 0.25, 0.257, 0.316 (in normalized frequency units) and each sinusoid had unit amplitude. The top trace in Figure 4 shows the 128 time samples of the synthetic signal that were input to a FFT algorithm and the CZT algorithm. The FFT output is illustrated in the second trace in Figure 4, note that the two closely spaced frequencies cannot be distinguished and the magnitude of the peaks are not equal (even though all 3 sinusoids had equal power). The third trace shows the CZT output where the output frequency range specified was from $w_{start} = ¼\pi$ to $w_{stop} = ¾\pi$. As this trace illustrates, the CZT algorithm is able to distinguish the presence of all three frequency components and also note that the magnitude of the three peaks is the same, indicating that the frequencies have the same power.

Current Status

At present Kestrel Corporation has collected data from several subjects. Simultaneously the algorithms described above have been tested on synthetic as well as subject acquired data on SUN workstations. These algorithms are being ported to the PC environment enroute to being compiled to run on the TMS320C6X platform. Once this is accomplished, we will also develop the necessary software interface required to enable the clinicians to operate the system.

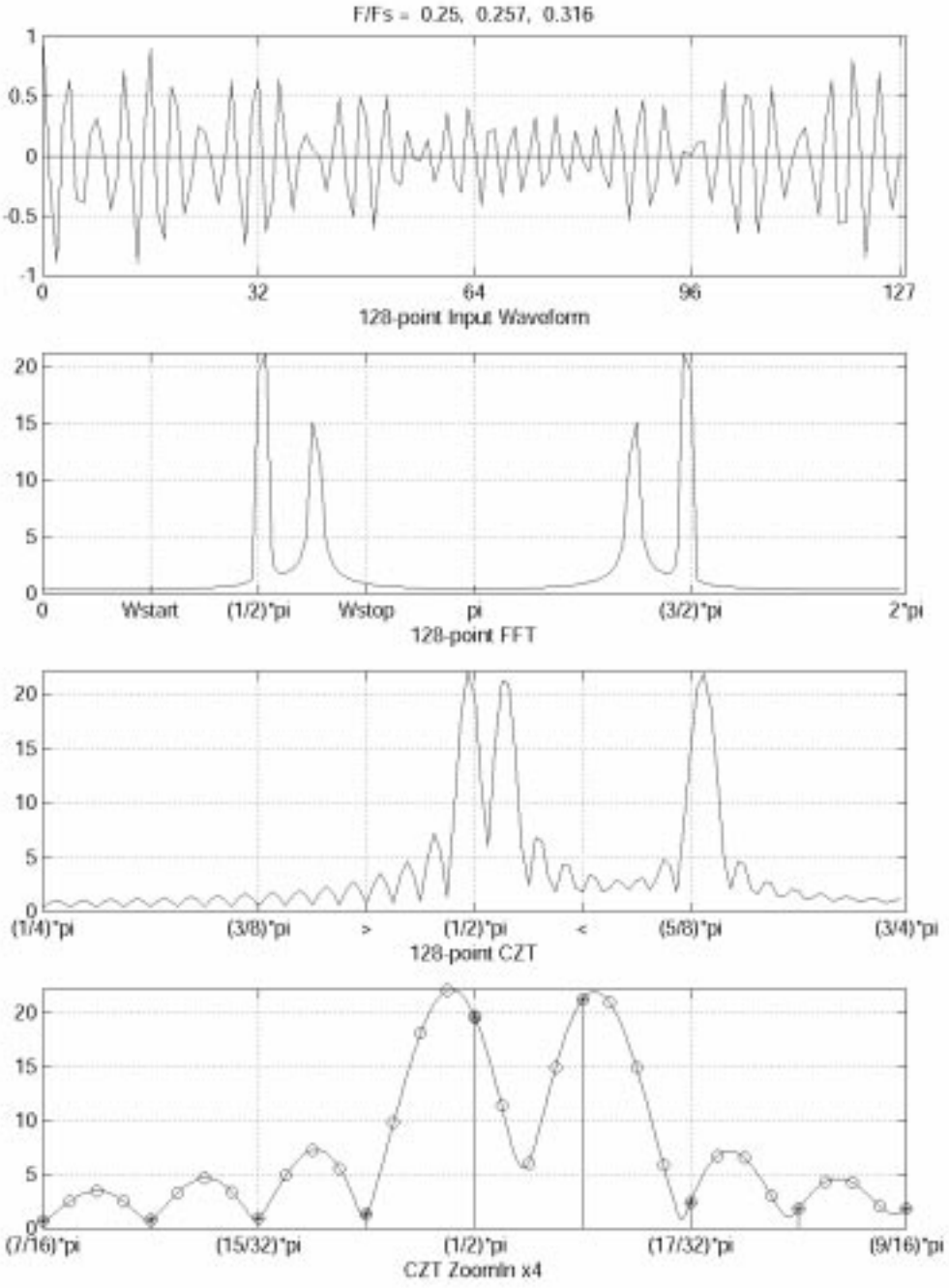

Figure 4 Simulation results for the CZT algorithm

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