SOME SIGNAL PROCESSING TECHNIQUES FOR ULTRASONIC TISSUE CHARACTERISATION

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DEDICATED

TO

MY MOTHER, FATHER AND BROTHER

CERTIFICATE

This is to certify that the thesis entitled "Some Signal Processing Techniques for Ultrasonic Tissue Characterisation" by Mahalovya Gauba is a record of original bonafide research carried out under our supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

The interest in ultrasound as a medical diagnostic tool stems from the fact that it is harmless at diagnostic levels and can be non-invasively used. Earlier applications of ultrasound in medical diagnosis were limited to imaging and blood flow measurements. But in the recent past, with medical diagnosis becoming more objective, a general need has been felt to express the tissue state in quantitative terms. This involves the identification of suitable parameters which can quantitatively express the condition of the tissue. The identification and study of the parameters which characterise the ultrasound tissue interaction is referred to as 'ultrasound tissue characterisation'. The present work has identified some of these parameters. The discussion of each of these parameters has been presented as a study in this thesis. Following are the studies which have been conducted.

A. Applicability of the technique proposed by Kuc for the estimation of attenuation coefficient slope of tissues with small thickness and also discusses some of the applicational aspects of the technique.

B. Study of the applicability of various deconvolution techniques to the problem of identification of interfaces in the tissue.

C. Feasibility of estimating propagation velocity in tissues with small thickness using unwrapped phase spectrum.

A. Study of Various Applicational Aspects of Kuc's Technique

The study presents a statistical technique proposed by Kuc and Schwartz for the estimation of attenuation coefficient slope of liver tissue, whose thickness typically in adult humans is of the order of 10.0 cms. It then discusses some of the applicational aspects of the technique which till now had been overlooked and they are (i) window length; (ii) window shift; and shape of the window to be used for segmentation. These aspects have been studied using wide ranging signal to noise ratios (SNRs). By means of a hypothetical example, the feasibility of this technique for characterising tissues of the order of 1.5 cms has been discussed. It then finally presents the results for the normal and the pathology induced muscle tissues.

The simulative study undertaken has shown that

(i) the estimate improves as the total numbers of segment pairs increase;

(ii) Hanning window gives better performance than the hybrid window; and

(iii) The technique can be used for estimating attenuation coefficient slope of tissues with small thickness but at the cost of increased computational effort.

The estimates of attenuation coefficient slope obtained from normal and pathology induced muscle tissue have been shown to be statistically different.

B. Deconvolution Techniques for the Identification of Interfaces in the Tissues

The study of localised changes in a tissue involves the detailed investigation of its structure. This can be carried out by identifying and studying those parameters which vary spatially in the tissue. Acoustic impedance (hence forth referred simply as impedance) is one such parameter. The impedance difference between two adjacent regions in the tissue could be both small or large. The large scale impedance differences give rise to interfaces. Identification of spatial locations of these interfaces is one of the tissue characterisation problems.

The problem of identification of interfaces in a tissue has been approached by studying the tissue backscatters. The tissue backscatter can be regarded as the convolution of the unit sample response of the tissue and the input

pulse. The problem then reduces to deconvolution of the unit sample response, which is a sequence of unit samples (reflection sequence). Each unit sample corresponds to the spatial location of the interface in the tissue.

The objective of this study is to investigate the suitability of the existing deconvolution techniques and to develop some new approaches for the purpose of spatial identification of these interfaces. Different types of techniques studied are as follows -

(i) Frequency Domain Techniques;

(ii) Homomorphic Filtering;

(iii) Linear Prediction Techniques; and

(iv) White Noise Estimator.

Frequency Domain Techniques

This includes the application of two standard deconvolution techniques i.e. inverse and Wiener filtering and a more recently proposed approach -'spectral equalisation'. Spectral equalisation is basically heuristic in nature and involves the compression of overlapping pulses into narrow pulses, which are now easier to resolve.

Homomorphic Filtering

Two aspects of homomorphic filtering i.e. complex cepstrum and power cepstrum have been studied. These aspects

are relevant to the underlying convolutional model assumed for tissue backscatter. Complex cepstrum has been used both for recovering the basic pulse and the reflection sequence. Power cepstrum is conventionally computed using FFT. Following new approaches have been suggested for its computation –

(a) Adaptive Linear Prediction; and

(b) Parameter Estimation.

These approaches, unlike FFT, assume a certain model for the signal. Thus they do not assume the signal to be zero or periodic outside the interval being studied.

Linear Prediction Techniques:

Adaptive linear prediction algorithms based on recently proposed escalator structure have been used for the deconvolution of the reflection sequence. These algorithms are adaptive escalator predictor (AEP) and adaptive least squares escalator predictor (ALSEP).

These are in general recursive techniques and can be effectively used for data whose characteristics are changing with time. The adaptive dynamics of these algorithms is disturbed when ecountered with a delayed signal and the disturbance manifests itself as a large error in the output.

Adaptive escalator predictor is based on an escalator type structure whose weights are updated using a steepest descent method. Adaptive least squares escalator predictor uses Kalman filter equations to update its weights. Their respective performances have been studied as a function of the critical parameters involved and wide ranging SNRs. These studies have been carried out on both simulated and real data.

White Noise Estimator

This technique considers the deconvolution problem as a white noise estimation problem and is very much relevant to the present context as the occurrence of interfaces in a tissue is a random phenomenon having random coefficients. Since the technique assumes the state space representation of the observed signal, the input signal is first modelled in the state space using singular value decomposition procedure. The performance of the technique has been studied as a function of different orders of the input pulse, smoothing lags and SNRs.

The results obtained from the application of frequency domain techniques and homomorphic filtering show that these techniques in general are very sensitive to noise

and break down at SNRs as low as 25 db. In complex situations it has been observed that the reflection sequences obtained using homomorphic filtering especially, are beyond any meaningful analysis. Since these techniques involve the use of FFT at one stage or the other for their implementation, they can only be applied to stationary data. Also associated with the use of FFT are the basic assumptions that the data outside the interval being studied is either zero or periodic. These two conditions are rarely met. It has also been shown that the use of a window function for segmenting and smoothing the data has a lowpass filtering effect on it.

The use of later two techniquesi.e. linear prediction and white noise estimator is intutively justifiable as they are modelling based and are adaptive in nature. It has been shown that the linear prediction algorithms used in the present study are not very suitable for deconvolving the reflection sequences. This is because they are unable to adapt themselves to the changes occurring in the signal. It may be pointed out that these algorithm only model the signal as an autoregressive (AR) process, which largely explains their unsuitability to the present problem. The application of white noise estimator using suitable system

model has been shown to be very effective and insensitive to noise at low SNRs. This technique has been applied to both simulated and real data. The reflection sequences obtained from the real data show the occurrence of closely packed interfaces in the tissue.

Estimation of Propagation Velocity Using Unwrapped Phase Spectrum

Interest in the estimation of propagation velocity has grown from the fact that changes occurring in a tissue effects its composition and structure. This has a corresponding effect on the elastic modulus of the tissue. Since propagation velocity is a function of the elastic modulus of the medium, its value would naturally change with any changes occurring in the composition or the structure of the medium. Researchers in the past have reported the sensitivity of propagation velocity to the changes occurring in the tissue.

Propagation velocity in most of the techniques is computed by estimating the delay caused by the medium to the signal propagating through it. Very recently the use of unwrapped phase spectrum for the estimation of propagation velocity has been proposed. This technique compares the unwrapped phase spectra of the pulses which have propagated through the coupling medium with and without the specimen

being investigated. The results reported were for thick specimens. The present study has extended its application to tissues with small thickness. It has been shown that the technique is sensitive enough to measure propagation velocity in specimens of thickness of the order of 2.00 mm and its results are comparable to that of the pulse-transit-time method.

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