RESOLUTION ENHANCEMENT ASPECTS IN B - SCAN ULTRASONOGRAPHY

SATPAL SINGH

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CERTIFICATE

This is to certify that the dissertation, "Resolution Enhancement Aspects in B – Scan Ultrasonography" being submitted by Mr. Satpal Singh for the award of the degree of Doctor of Philosophy at the Indian Institute of Technology, Delhi, is a record of bonafide research work carried out by him under our supervision and guidance.

This dissertation has reached the standard fulfilling the requirements of the regulations relating to the degree. The results contained in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

S.N. Tandon
Professor, Centre for Biomedical Engineering
Indian Institute of Technology,
New Delhi 110016,
INDIA

H.M. Gupta
Professor
Department of Electrical Engineering
Indian Institute of Tech.,
New Delhi 110016,
INDIA

Dated_____

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ABSTRACT

Ultrasonic B scan is a widely used non - invasive method for obtaining the cross sectional images of soft tissues. The diagnostic utility of a B scan image depends on its resolution or its ability to show up the details corresponding to the morphology of the tissue. The resolution in B scan is primarily limited due to lateral blurring and speckle. The former lowers the sharpness or contrast of the image and the latter manifests as a granular texture which tends to mask the true details of the tissue. This thesis is concerned with the improvement of resolution in B scan images in the presence of above degradations.

The loss in resolution due to lateral blurring results due to the non - zero beam spread used in B scan imaging. This is modelled as a convolution process. Therefore, the natural recourse to resolution improvement is by the process of deconvolution. The existing deconvolution techniques are computationally expensive and hence a new iterative technique with rapid convergence has been formulated. The computer simulation results have been presented to demonstrate the efficacy of the proposed technique.

The degradation due to speckle has been modelled as a complex interference phenomena. The study of various models show that the speckle depends amongst other factors, on the pulse used for echo imaging. The effect of pulse bandwidth and the use of FM pulses for speckle reduction have been investigated in this thesis. Computer simulation results have been presented to justify the use of wide

band FM pulses for speckle reduction. A comparitive study between frequency compounding and axial compounding has been presented. It has been concluded that for a given time bandwidth product, axial compounding with wide band pulses is superior to frequency compounding.

An extension of the sequential mode of data acquisition and employing the method of backprojection for image reconstruction has also been investigated. A scheme utilising an analogue scan converter for speedy image reconstruction has been suggested.The resolution obtained by this method has been compared to the diffraction limited resolution obtained by other techniques .

Finally, the work presented in this thesis has been summarised and suggestions for further work have been given in the last chapter.

LIST OF SYMBOLS

The symbols used in the thesis represent the following unless stated otherwise.

a_n — amplitude of backscattered wave from the nth scatterer.

A — operator in Ch. III
Chirp rate in Ch. IV

b — inter element spacing

$b_{i,n}$ — time taken by the wave to travel from ith scatterer to the nth element of an array.

$b_n (y_o, z_o)$ — Backprojection at (y_o, z_o) from the nth element of array.

B — Bandwidth

B_o, B_k, B_o^*, B_k^* = Operators

c — Velocity of sound

C — Constraining Operator

C_n — arc of radius r_n from the nth element of linear array (or the nth position of a scanning transducer).

d_n — wave propagation time from the transducer to nth scatterer.

$d_{m,\,i}$	wave propagation time from the mth element of array to ith scatterer
$d(f,g)$	distance between elements f and g of a vector space.
D	aperture of a linear transducer.
$e(t)$	pulse envelope
$\{e_k\}$	error sequence in $[f_k]$, Eq. (3.4)
$\{e_{g,k}\}$	error sequence, eq. (3.7)
$E(\omega)$	Fourier transform of e(t)
$E\{\ \}$	Expected value of quantity enclosed within the brackets
$f(n)$	signal
$\underline{f}$	signal vector
f_k	kth estimate of f
$f(r,\theta)$, $f(y,z)$ =	specimen reflectivity
$f_b\,(y_o, z_o)$	Image reconstruction at $(y_o,\ z_o)$ by backproject
$\{f_k\}$	sequence of f_k , for k = 1, 2, 3...
$F(\mu)$	Fourier transform of f(n)
$F(U,V)$	Fourier transform of f(y,z)

$F(r, \Phi)$ Fourier transform of $f(r, \theta)$ with respect to θ.

$F(\Phi)$ $F(r, \Phi)$ at a fixed value of r.

FM Frequency modulation

$g(t)$ signal received by the transducer

$g_n(t)$ signal received by the nth element of a linear array.

$g(r, \theta)$ signal received from a range r when the transducer is directed at an angle θ.

$G(\omega)$ Fourier transform of $g(t)$

$G(r, \Phi)$ Fourier transform of $g(r, \theta)$ with respect to θ

$G(\Phi)$ $G(r, \Phi)$ at a fixed value of r.

$h(n)$, $h(\theta)$ blur function.

$h(Y, z)$, $h(r, \theta)$ = radiation spread function

$h(\underline{r}, t)$ acoustical impulse response of transducer

$h_{rx}(r, \theta)$ receive aperture function

$h_{tx}(r, \theta)$ transmit aperture function

H distortion operator

$\underline{\underline{H}}$ distortion matrix

$H(u)$	Fourier transform of $h(x)$
$H(r, \phi)$	Fourier transform of $h(r, \theta)$ with respect to θ
$H(\phi)$	$H(r, \phi)$ at a fixed value of r.
inf	infimum
I	Identity operator
j	$\sqrt{-1}$ = complex quantity
k	wave number
k_c	denotes the complex wave number
L	Time delay for excitation between the successive elements of a linear array
LPF	low pass filter.
M	bound of operator T
n	noise
N	number of elements of a linear array
$p(t)$	pulse
$P(\omega)$	Fourier transform of $p(t)$
r	axial distance or range
$\underline{r}$	position vector

r_n	distance of the point of interest (y_o, z_o) from the nth element of a linear array
R	enhancement factor
R_f, R_g, R_p	Autocorrelations of functions f, g and p respectively
RHS	Right hand side
s_{cy}, s_{cz}	Speckle size along the y and z axes respectively
s(t)	effective backscatter strength, eqs. (2.81) and (2.82)
s(r)	equivalent specimen reflectivity at range r, eq. (4.2)
$s_n(r_n)$	equivalent specimen reflectivity at range r_n from the nth element of an array, eq. (6.4)
S	Vector space
SNR	Signal to noise ratio
t	time variable
T	pulse duration
T^k	Operator – in Ch. III only denots an operator applied k times
T_c	correlation length along time axis, eq. (4.5)
U	spatial frequency along the y axis
$U_T(t)$	rectangular window, eq. (4.11)

W_B	lateral spread function width in a backprojected image eq. (6.37)
W_d	Lateral beam width at the focal point of a linear array.
W_s	Lateral spread function for a synthetic aperture technique.
W_y	lateral spread function width in a demodulated, backprojected image, eq. (6.46)
y	lateral axis co ordinate
z	depth axis co ordinate
z_{tr}	transition range

Greek and Special Symbols

α	Angular co ordinate used as $f(r, \alpha)$ perturbation in H, eq (3.37) in Ch. III only.
θ, θ_n, ϕ	angular co ordinate
ϕ	zero operator in Ch. III only
ϕ_n	phase of the nth backscattered wave
$\delta(\,)$	kroneker delta function
ξ	perturbation in T, eq. (3.12) in Ch. III only

ϵ	belongs to
Φ	Fourier domain variable corresponding to θ.
λ	wavelength of ultrasound in the specimn at angular frequency ω
σ , σ_z	standard deviations of gaussian functions.
τ , τ_n, $\tau_{n,s}$	= time delays.
μ	Fourier domain variable corresponding to variable n
μs	micro seconds
ω	angular frequency
∞	infinity
$\lvert\ \rvert$	absolute value of quantity enclosed
$\lVert\ \rVert$	norm of quanity enclosed
$\langle\ \rangle$	sample average of quanity enclosed
*; f * h	denotes convolution of f and h
T^*	superscript star denotes the perturbed quantity T in Ch. III only
f^*	superscript star denotes the complex conjugate of quanity f
$\forall$	for all

LIST OF FIGURES

CONTENTS

CHAPTER IV

A STUDY ON SPECKLE REDUCTION BY THE TECHNIQUES OF FREQUENCY COMPOUNDING AND AXIAL COMPOUNDING (TIME AVERAGING)