Despeckle Filtering for Ultrasound Imaging and Video

Volume I

Algorithms and Software

Second Edition

Synthesis Lectures on Algorithms and Software in Engineering

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Despeckle Filtering for Ultrasound Imaging and Video

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SYNTHESIS LECTURES ON ALGORITHMS AND SOFTWARE IN ENGINEERING #14

ABSTRACT

It is well known that speckle is a multiplicative noise that degrades image and video quality and the visual expert's evaluation in ultrasound imaging and video. This necessitates the need for robust despeckling image and video techniques for both routine clinical practice and tele-consultation. The goal for this book (book 1 of 2 books) is to introduce the problem of speckle occurring in ultrasound image and video as well as the theoretical background (equations), the algorithmic steps, and the MATLAB™ code for the following group of despeckle filters: linear filtering, nonlinear filtering, anisotropic diffusion filtering, and wavelet filtering. This book proposes a comparative evaluation framework of these despeckle filters based on texture analysis, image quality evaluation metrics, and visual evaluation by medical experts. Despeckle noise reduction through the application of these filters will improve the visual observation quality or it may be used as a pre-processing step for further automated analysis, such as image and video segmentation, and texture characterization in ultrasound cardiovascular imaging, as well as in bandwidth reduction in ultrasound video transmission for telemedicine applications. The aforementioned topics will be covered in detail in the companion book to this one. Furthermore, in order to facilitate further applications we have developed in MATLAB™ two different toolboxes that integrate image (IDF) and video (VDF) despeckle filtering, texture analysis, and image and video quality evaluation metrics. The code for these toolsets is open source and these are available to download complementary to the two books.

KEYWORDS

speckle, despeckle, noise filtering, ultrasound, ultrasound imaging, ultrasound video, cardiovascular imaging and video, SAR, texture, image quality, video quality, carotid artery

To my Family

Christos P. Loizou

To my Family

Constantinos S. Pattichis

"Show thyself in all things an example of good works,
in teaching, in integrity and dignity;
let thy speech be sound and blameless,
so that anyone opposing may be put to shame,
having nothing bad to say for us.
Exhort slaves to obey their masters,
pleasing them in all things and not opposing them."

Titus 2:7–9.

Contents

Preface

Speckle can be modeled as a multiplicative noise source that degrades image and video quality and the visual evaluation in ultrasound and SAR imaging. This necessitates the need for robust despeckling techniques in a wide spectrum of the aforementioned imaging applications. Despeckle filtering is a rapidly emerging research area with several applications for ultrasound images and videos. The goal for this book is to introduce the theoretical background (equations), the algorithmic steps, and the MATLAB™ code for the following group of despeckle filters: linear filtering, nonlinear filtering, anisotropic diffusion filtering, and wavelet filtering. The filters covered represent only a snapshot of the vast number of despeckle filters published in the literature. Moreover, selected representative applications of image despeckling covering a variety of ultrasound image processing tasks are presented. Most importantly, a despeckle filtering and evaluation protocol is proposed based on texture analysis, image quality evaluation metrics, and visual evaluation by experts. The source code of the algorithms presented in this book has been made available on the web, thus enabling researchers to more easily exploit the application of despeckle filtering in their problems under investigation.

This book is organized into eight chapters. Chapter 1 presents a brief overview of ultrasound imaging and video, speckle noise, modeling, and filtering. Chapter 2 covers the evaluation methodology based on texture and statistical analysis, image quality evaluation metrics, and the experiments carried out for visual evaluation. The theoretical background (equations), the algorithmic steps, and the MATLAB™ code of selected despeckle filters are presented for linear despeckle filtering, for nonlinear despeckle filtering, for diffusion despeckle filtering and for wavelet despeckle filtering in Chapters 3–6, respectively. Chapter 4 presents the applications of despeckle filtering techniques in ultrasound images of the carotid and cardiac ultrasound images. Chapter 7 discusses, compares, and evaluates the proposed despeckle filtering techniques. Chapter 8 presents the summary and future directions, where a despeckling filtering protocol is also proposed. Finally, at the end of this book, an Appendix provides details about two different despeckle filtering MATLAB™ toolboxes for ultrasound imaging and video of the carotid artery.

This book is intended for all those working in the field of image and video processing technologies, and more specifically in medical imaging and in ultrasound image and video preprocessing and analysis. It provides different levels of material to researchers, biomedical engineers, computing engineers, and medical imaging engineers interested in developing imaging systems with better quality images, limiting the corruption of speckle noise.

We hope that this book will be a useful reference for all the readers in this important field of research and that it will contribute to the development and implementation of innovative imaging and video systems, enabling the provision of better quality images.

Christos P. Loizou and Constantinos S. Pattichis
April 2015

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Christos P. Loizou and Constantinos S. Pattichis
April 2015

List of Symbols

$a_{i,j}$	Additive noise component on pixel i, j
$\alpha_{comp}, \beta_{comp}$	Logarithmic compression parameters
$\beta(s)$	Snake stiffness of the energy functional
β_{GVF}	GVF snake rigidity parameter
C	Speckle Index
$CV\%$	Coefficient of variation
$cd(\|\nabla g\|), c_{i,j}$	Diffusion coefficient
c_{adsr}	Speckle reducing anisotropic diffusion coefficient
c	Constant controlling the magnitude of the potential
$c_{s\sin\_1}, c_{s\sin\_2}$	Constants used to calculate the SSIN
c_2	Positive weighting factor
Γ	Number of directions, which diffusion is computed
γ	Signal-to-noise ratio (SNR)
$D \in \Re^{2x2}$	Symmetric positive semi-definite diffusion tensor representing the required diffusion in both gradient and contour directions
D_f	Fractal dimension
D	Matrix used to calculated the image energy of the snake, $E_{image}(v)$
$D_{viewing}$	Viewing distance
DR	Dynamic range of input ultrasound signal
$d(k)$	Wavelet coefficient for the wavelet filtering
Δf	Frequency shift (Doppler frequency shift)
Δr	Distance between two pixels
∇g	The gradient magnitude of image $g(x, y)$(gradient)
$\nabla g_{i,j}$	Directional derivative (simple difference) at location i, j
$f_1 \ldots f_{13}$	SGLDM texture measures from Haralick
$f_x(x, y)$	First order differential of the edge magnitude along the x-axis
$f_{i,j}$	Noise-free signal ultrasound signal in discrete form (the new image) on pixel i, j
v	Frequency of ultrasound wave
f_0	Transmitted frequency of ultrasound signal
$feat\_dis_i$	Percentage distance
$g_{i,j}$	Observed ultrasound signal in discrete formulation after logarithmic compression

$g(x, y)$	Observed ultrasound signal after logarithmic compression, representing image intensity at location (x, y)
G	Linear gain of the amplifier
$G\sigma * g_{i,j}$	Image convolved with Gaussian smoothing filter
$G\sigma$	Gaussian smoothing filter
$\bar{g}_i$, $\bar{f}_i$	Mean gravity of the searching pixel region in image g or f
$g_{\max}$,$g_{\min}$	Maximum and minimum gray level values in a pixel neighborhood
Hz, KHz, MHz	Hertz, Kilohertz, Megahertz
HX, HY	Entropies of p_x and p_y
$H^{(k)}$	Hurst coefficients
$H(x, y)$	Array of points of the same size for the HT
HD	Hausdorff distance
η_s	Spatial neighborhood of pixel i, j
$\lvert\eta_s\rvert$	Number of neighbors (usually four except at the image boundaries)
θ_i	Phase shift relative to the insonated ultrasound wave
θ	Angle between the direction of movement of the moving object and the ultrasound beam
I	Identity matrix
$I_0(x)$	Modified Bessel function of the first kind of order 0
IMT_{mean}	Mean value of the IMT
$IMT_{\min}$	IMT minimum value
$IMT_{\max}$	IMT maximum value
IMT_{median}	IMT median value
k	Coefficient of variation for speckle filtering
λ	Wavelength of ultrasound wave
λ_π	Lai & Chin snake energy regularization parameter, $E_{snake}(v)$
$\lambda_d \in \Re^+$	Rate of diffusion for the anisotropic diffusion filter
m_{i1},m_{i2}	Mean values of two classes (asymptomatic, symptomatic)
cm/s, cm/s	Meters per second, centimeters per second
μ	Mean
N	Number of scatterers within a resolution cell
N_{feat}	Number of features in the feature set
$n_{i,j}$	Multiplicative noise component (independent of $g_{i,j}$, with mean 0) on pixel i, j
$nl_{i,j}$	Multiplicative noise component after logarithmic compression on pixel i, j
$n(s)$	Normal force tensor
ξ_i	Amount of ultrasound signal backscattered by scatterer $W2LOK$

$p_x(i)$	*ith* entry in the marginal probability matrix obtained by summing the rows of $p(i, j)$
Q	Mathematically defined universal quality index
$R = 1 - \frac{1}{1+\sigma^2}$	Smoothness of an image
Score_Dis	Score distance between two classes (asymptomatic, symptomatic)
$s_e = \sigma_{IMT}/\sqrt{2}$	Inter-observer error
$s_{\max}$	Maximum pixel value in the image
s^2	Structural energy
σ_{IMT}	IMT standard deviation
σ_{fg}	Covariance between two images f and g
σ	Standard deviation
σ^2	Variance
σ^3	Skewness
σ^4	Kurtosis
$2\sigma^2$	Diffuse energy
σ_n	Standard deviation of the noise
σ_w^2	Variance of the gray values in a pixel window

List of Abbreviations

ACSRS	Asymptomatic Carotid Stenosis
DsFad	Perona and Malik anisotropic diffusion filter
DsFadsr	Speckle-reducing anisotropic diffusion filter
ASM	Angular second moment
ATL HDI-3000	ATL 3000 ultrasound scanner
ATL HDI-5000	ATL 5000 ultrasound scanner
DsFca	Linear scaling of the gray-levels despeckle filter
CAT	Computer-assisted tomography
CCA	Common carotid artery
CSR	Contrast-to-speckle ratio
CT	Computer tomography
CW	Continuous wave
DR	Dynamic range
DS	Despeckled
DSCQS	Double stimulus continuous quality scale
DSIS	Double stimulus impairment scale
DVD	Digital video
DWT	Discrete wavelet transform
E	Effectiveness measure
ECA	External carotid artery
ECST	European carotid surgery trial
Err	Error summation in the form of the Minkowski metric
FDTA	Fractal dimension texture analysis
FFT	Fast Fourier transform
FPS	Fourier power spectrum
GAE	Geometric average error
GF	Geometric filtering
DsFgf4d	Geometric despeckle filter
DsFgfminmax	Geometric despeckle filter utilizing minimum maximum values
GGVF	Generalized gradient vector flow
GLDS	Gray level difference statistics
GVF	Gradient vector flow
HD	Hausdorff distance

HF	Maximum homogeneity
HM	Homomorphic
DsFhomo	Homomorphic despeckle filter
DsFhomog	Most homogeneous neighborhood despeckle filter
HVS	Human visual system
ICA	Internal carotid artery
IDM	Inverse difference moment
IDV	Intensity difference vector
IMC	Intima-media complex
IMT	Intima-media thickness
IVUS	Intravascular ultrasound
kNN	The statistical k-nearest-neighbor classifier
DsFlecasort	Linear scaling and sorting despeckle filter
LS	Linear scaling
DsFls	Linear scaling of the gray level values despeckle filter
DsFlsmedcd	Lee diffusion despeckle filter
DsFlsminsc	Minimum speckle index homogeneous mask despeckle filter
DsFlsminv1d	Minimum variance homogeneous 1D mask despeckle filter
DsFlsmv	Mean and variance local statistics despeckle filter
DsFlsmvsk2d	Mean variance, higher-moments local statistics despeckle filter
DsFlsmvske1d	Mean, variance, skewness, kurtosis 1D local statistics despeckle filter
M	Manual
DsFmedian	Median despeckle filter
DsFhmedian	Hybrid median filter
MF	Multi-resolution fractal
MMSE	Minimum mean-square error
MN	Manual normalized
MRI	Magnetic resonance imaging
MSE	Mean square error
N	Normalized
ND	Normalized despeckled
NE	North east
NF	No filtering
NGTDM	Neighbourhood gray tone difference matrix
NIE	Normalized image energy
DsFnldif	Nonlinear coherent diffusion despeckle filter
NS	Not significant difference
NST	North south
NTSE	Normalized total snake energy

P	Precision
PDE	Partial differential equation
PDF	Probability density function
PET	Positron emission tomography
PSNR	Peak signal-to-noise ratio
PW	Pulsed wave
R	Sensitivity (or recall)
RF	Radio frequency
RMSE	Root mean square error
ROC	Receiver operating characteristic
S	Significant difference
Sp	Specificity
SAR	Synthetic aperture radar
SD	Standard deviation
SE	South east
SFM	Statistical feature matrix
SGLDM	Spatial gray level dependence matrices
SGLDMm	Spatial gray level dependence matrix mean values
SGLDMr	Spatial gray level dependence matrix range of values
SNR	Signal-to-noise ratio
SPECT	Single photon emission computer tomography
SSIN	Structural similarity index
TEM	Laws texture energy measures
TGC	Time gain compensation
TIA	Transient ischemic attacks
TV	Television
DsFwaveltc	Wavelet despeckle filter
WE	West east
DsFwiener	Wiener despeckle filter
WN	West north
WS	West south
WT	Wavelet transform
β_{err}	Minkowski error coefficient
1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional