Despeckle Filtering for Ultrasound Imaging and Video

Volume II

Selected Applications

Second Edition

Synthesis Lectures on Algorithms and Software in Engineering

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Christos P. Loizou
School of Sciences and Engineering, Intercollege, Cyprus

Constantinos S. Pattichis
University of Cyprus

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ABSTRACT

In ultrasound imaging and video visual perception is hindered by speckle multiplicative noise that degrades the quality. Noise reduction is therefore essential for improving the visual observation quality or as a pre-processing step for further automated analysis, such as image/video segmentation, texture analysis and encoding in ultrasound imaging and video. The goal of the first book (book 1 of 2 books) was to introduce the problem of speckle in ultrasound image and video as well as the theoretical background, algorithmic steps, and the MATLAB™ code for the following group of despeckle filters: linear despeckle filtering, non-linear despeckle filtering, diffusion despeckle filtering, and wavelet despeckle filtering. The goal of this book (book 2 of 2 books) is to demonstrate the use of a comparative evaluation framework based on these despeckle filters (introduced on book 1) on cardiovascular ultrasound image and video processing and analysis. More specifically, the despeckle filtering evaluation framework is based on texture analysis, image quality evaluation metrics, and visual evaluation by experts. This framework is applied in cardiovascular ultrasound image/video processing on the tasks of segmentation and structural measurements, texture analysis for differentiating between two classes (i.e. normal vs disease) and for efficient encoding for mobile applications. It is shown that despeckle noise reduction improved segmentation and measurement (of tissue structure investigated), increased the texture feature distance between normal and abnormal tissue, improved image/video quality evaluation and perception and produced significantly lower bitrates in video encoding. 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 monographs.

KEYWORDS

speckle, despeckle, noise filtering, ultrasound, ultrasound imaging, ultrasound video, cardiovascular imaging and video, texture, image and video quality, video encoding, mobile health, carotid artery

To my Family, and
in memory of my father Panayiotis and my mother Eleni
Christos P. Loizou

To my mother, and
in memory of my father Stephanos, and my sister Revecka
Constantinos S. Pattichis

"This is the way we should see Christ. He is our friend, our brother; He is whatever is good and beautiful. He is everything. Yet, He is still a friend and He shouts it out, "You're my friends, don't you understand that? We're brothers. I'm not...I don't hold hell in my hands. I am not threatening you. I love you. I want you to enjoy life together with me."

"Love Christ and put nothing before His Love. He is joy, He is life, He is light. Christ is Everything. He is the ultimate desire, He is everything. Everything beautiful is in Christ."

"The life of the parents is the only thing that makes good children. Parents should be very patient and 'saintlike' to their children. They should truly love their children. And the children will share this love! For the bad attitude of the children, says father Porphyrios, the ones who are usually responsible for it are their parents themselves. The parents don't help their children by lecturing them and repeating to them 'advices', or by making them obeying strict rules in order to impose discipline. If the parents do not become 'saints' and truly love their children and if they don't struggle for it, then they make a huge mistake. With their wrong and/or negative attitude the parents convey to their children their negative feelings. Then their children become reactive and insecure not only to their home, but to the society as well."

Saint Porphyrios (Bairaktaris) the Kapsokalyvite

Source: Wikipedia

Contents

Preface

Speckle is a multiplicative noise that degrades image 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 applications has been a rapidly emerging research area in recent years. The goal of the first book (book 1 of 2 books) was to introduce the problem of speckle in ultrasound image and video as well as the theoretical background, algorithmic steps, and the Matalb™ code for the following group of despeckle filters: linear despeckle filtering, non-linear despeckle filtering, diffusion despeckle filtering, and wavelet despeckle filtering. The goal of this book (book 2 of 2 books) is to demonstrate the use of a comparative evaluation framework of these despeckle filters (introduced on book 1) on cardiovascular ultrasound image and video processing. More specifically, the despeckle filtering evaluation framework is based on texture analysis, image quality evaluation metrics, and visual evaluation by experts. The filters covered represent only a snapshot of the vast number of despeckle filters and applications published in the literature. 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.

The book is organized in five chapters. In Chapter 1 an introduction and review of different despeckle filtering techniques for ultrasound imaging and video is presented, a despeckle filtering evaluation protocol is proposed and selected applications for ultrasound image and video despeckle filtering techniques are outlined. In Chapter 2 we present the application and results of the segmentation of the intima-media complex (IMC), the media-layer (ML) and the intima layer (IL) of the common carotid artery as well as the segmentation of the atherosclerotic carotid plaque from ultrasound images and videos following despeckle filtering. In Chapter 3, we present the results on image and video texture analysis. We provide results from the texture analysis of the IMC and the atherosclerotic carotid plaque performed on a large number of ultrasound images and videos. In Chapter 4 we present results on ultrasound wireless video encoding and transmission which is performed before and after despeckle filtering. Chapter 5 discusses, compares and evaluates the proposed despeckle filtering techniques for image and video and provides an outline of future directions. Finally, at the end of this book, appendices provide details about the IDF and VDF despeckle filtering MATLAB™ toolboxes.

Furthermore, it is noted that for those practicing engineers/scientists whose principal need is to use existing image despeckle filtering technologies and apply them on different type of images or video, there is no simple answer regarding which specific filtering algorithm should be selected without a significant understanding of both the filtering fundamentals, and the application environment under investigation. A number of issues would need to be addressed. These

include availability of the image/video to be processed/analyzed, the required level of filtering, the application scope (general-purpose or application-specific), the application goal (for extracting features from the image or for visual enhancement), the allowable computational complexity, the allowable implementation complexity, and the computational requirements (e.g., real-time or offline). We believe that a good understanding of the contents of this book can help the readers make the right choice of selecting the most appropriate filter for the application under development. Furthermore, the despeckle filtering evaluation protocol documented in Table 1.4 could also be exploited.

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 wish to thank all the members of our carotid ultrasound imaging team, for the long discussions, advice, encouragement, and constructive criticism they provided to us during the course of this research work. First of all we would like to express our sincere thanks to Emeritus Prof Andrew Nicolaides, of the Faculty of Medicine, Imperial College of Science, Technology and Medicine, UK, and founder of the Vascular Screening and Diagnostic Centre in Cyprus. Furthermore, we would like to express our thanks to Dr Marios Pantziaris, consultant neurologist, at the Cyprus Institute of Neurology and Genetics, Dr Theodosis Tyllis, consultant physician in the private sector in Cyprus, Associate Professor Efthyvoulos Kyriakou, at the Frederick University, Cyprus, Dr Christodoulos Christodoulou, Research Associate at the University of Cyprus, and Associate Professor Marios Pattichis, University of New Mexico, USA. Last but not least, we would like to thank, Prof Andreas Spanias, Arizona State University, USA, for his proposal and encouragement in writing this book, and to Joel Claypool, and the rest of the staff at Claypool publishing house, for their understanding, patience and support in materializing this project.

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We hope that this book will be a useful reference for all the readers in this important field of research and to 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
August 2015

List of Symbols

C	Speckle Index
σ	Standard deviation
σ^2	Variance
σ^3	Skewness
σ^4	Kurtosis
σ_n	Standard deviation of the noise
ρ	Correlation Coefficient
β	Shape parameter
IMT_{mean}	Mean value of the IMT
$IMT_{\min}$	IMT minimum value
$IMT_{\max}$	IMT maximum value
IMT_{median}	IMT median value
Q	Mathematically defined universal quality index
$feat\_dis_i$	Percentage distance
$Score\_Dis$	Score distance between two classes (asymptomatic, symptomatic)
dis_{zc}	Distance between asymptomatic and symptomatic images
m_{i1},m_{i2}	Mean values of two classes (asymptomatic, symptomatic)
$\sum Var$	Sum variance
$\sum Entr$	Sum Entropy
p	Significance level for a statistical test
Hz, KHz, MHz	Hertz, Kilohertz, Megahertz
cm/s, cm/s	Metres per second, centimetres per second
μ	Mean
N	Number of scatterers within a resolution cell
N_{feat}	Number of features in the feature set
$s_e = \sigma_{IMT}/\sqrt{2}$	Inter-observer error
σ_{IMT}	IMT standard deviation

List of Abbreviations

IDF	Image despeckle filtering toolbox
VDF	Video despeckle filtering toolbox
IVUS	Intra Vascular ultrasound
OCT	Optical coherence tomography
SAR	Synthetic aperture radar
FFT	Fast Fourier Transform
DsFlsmv	Mean and variance local statistics despeckle filter
DsFlsmvsk1d	Mean, variance, skewness, kurtosis 1D local statistics despeckle filter
DsFlsmvsk2d	Mean variance, higher moments local statistics despeckle filter
DsFlsminsc	Minimum speckle index homogeneous mask despeckle filter
DsFwiener	Wiener despeckle filter
DsFmedian	Median despeckle filter
DsFls	Linear scaling of the gray level values despeckle filter
DsFca	Linear scaling of the gray-levels despeckle filter
DsFlecasort	Linear scaling and sorting despeckle filter
DsFhomog	Most homogeneous neighbourhood despeckle filter
DsFgf4d	Geometric despeckle filter
DsFhomo	Homomorphic despeckle filter
DsFhmedian	Hybrid median filter
DsFkuwahara	Kuwahara despeckle filter
DsFgfminmax	Geometric despeckle filter utilising minimum maximum values
DsFnlocal	Nonlocal filter
DsFad	Perona and Malik anisotropic diffusion filter
DsFsrad	Speckle reducing anisotropic diffusion filter
DsFlsmedcd	Lee diffusion despeckle filter
DsFlsrad	Speckle reducing anisotropic diffusion
DsFnldif	Non-linear anisotropic diffusion despeckle filter
DsFncdif	Non-linear complex diffusion filtering
DsFwaveltc	Wavelet despeckle filter
CCA	Common carotid artery
IMC	Intima media complex
SRAD	Speckle reducing anisotropic diffusion
1D	One-dimensional

2D	Two-dimensional
3D	Three-dimensional
ROI	Area of interest
GUI	Graphical user interface
IMT	Intima-media thickness
IMC	Intima-media complex
IL	Intima layer
ML	Media Layer
ILT	Intima layer thickness
MLT	Media Layer thickness
NPS	No pre-processing
DS	Despeckled
NDS	Normalised despeckled
sd	Standard deviation
GVF	Gradient vector flow
CDC	Carotid diameter during contraction
CDD	Carotid diameter during distension
%CWD	Percentage of carotid wall distension
MMSE	Minimum mean-square error
MSE	Mean square error
MAE	Mean absolute error
MARE	Mean relative absolute error
RMSE	Root mean square error
kNN	The statistical k-nearest-neighbour classifier
PSNR	Peak signal-to-noise radio
SNR	Signal-to-noise radio
COV	Coefficient of Variation
ATL HDI-3000	ATL 3000 ultrasound scanner
ATL HDI-5000	ATL 5000 ultrasound scanner
SSIM	Structural similarity index
VI	Visual inspection
CNR	Contrast to-noise ratio
CPU	Central processing unit
MSE	Mean square error
ENL	Effective number of looks
ρ	Correlation coefficient
FOM	Figure of merit
OSRAD	Oriented speckle reducing anisotropic diffusion
F	FORTRAN

ROI	Area of interest
CCA	Common carotid artery images
IQR	Inter quartile range
M	Manual
MN	Manual normalised
NF	No-filtering
N	Normalised
CV%	Coefficient of variation
se	Intra-observer error
HD	Hausdorff distance
CDC	Carotid diameter during contraction
CDD	Carotid diameter during distension
%CWD	Percentage of carotid wall distension
CIMA	Carotid intima-media area
UIR	User interaction required
MAD	Mean absolute distance
BA	Bland-Altman plots
GVF	Gradient vector flow
FNF	False negative fraction
FPF	False positive fraction
TNF	True negative fraction
TPF	True positive fraction
KI	Williams or kappa index
R	Sensitivity
Sp	Specificity
P	Precision
O	Overlap
F=1-E	Effectiveness measure
AW	Adventitia-wall
PW	Plaque-wall
MAW	Media-Adventitia-wall
NS	Not significantly different
S	Significantly different
RSW	Radial strain at wall
LS	Longitudinal stain at wall
SSW	Shear stain at wall
SSP	Shear strain at plaque
RSP	Radial strain at plaque
AIC	Automatic initial contour

MPD	Mean point distance
GAE	Geometric average error
GF	Geometric filtering
GGVF	Generalised gradient vector flow
GLDS	Gray level difference statistics
HF	Maximum homogeneity
HM	Homomorphic
HVS	Human visual system
ICA	Internal carotid artery
IDM	Inverse difference moment
IDV	Intensity difference vector
LS	Linear scaling
MRI	Magnetic resonance imaging
PET	Position emission tomography
NGTDM	Neighbourhood gray tone difference matrix
ROC	Receiver operating characteristic
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
TEM	Laws texture energy measures
FDTA	Fractal dimension texture analysis
FPS	Fourier power spectrum
SOSV	Sum of square variance
SAV	Sum average
ASM	Angular second moment
Err_3, Err_4	Minkwoski metrics
Q_	Quality index
SSIN	Structural similarity index
AD	Average difference
SC	Structural content
MD	Maximum difference
kNN	k-nearest neighbour
JPEG	Joint Photographic Experts Group
VSNR	Visual signal-to-noise ratio
IFC	Information fidelity criterion
NQM	Noise quality measure
WSNR	weighted signal-to-noise ratio
HVEC	High efficiency video coding

ITU-T	International telecommunication union-telecommunication sector
VCEG	Video quality experts group
JVT	Joint video team
VCL	Video quality layer
MPEG	Motion picture experts group
NAL	Network abstract layer
FMO	Flexible macroblock ordering
JCT-VC	Joint collaborative team on video coding
SAO	Sample adaptive offset
AMVP	Advanced motion vector prediction
CABAC	Context adaptive binary arithmetic coding
CTU	Coding tree unit
GSM	Global system for mobile communication
1G	1^{st} Generation
2G	2^{nd} Generation
GPRS	General packet radio service
UMTS	Universal mobile telecommunications system
HSDPA	High speed download packet access
HSUPA	High speed uplink packet access
HSPA	High speed packet access
LTE	Long term evolution
ITU-R	International telecommunication union-radio communication sector
QoS	Quality of service
WiMax	Worldwide interoperability for Microwave access
LOS	Line-of-sight
NLOS	Non line-of-sight
HARQ	Hybrid automatic repeat request
OFDM	Orthogonal frequency division multiplexing
SOFDMA	Scalable orthogonal frequency division multiple access
DL	Downlink
UL	Uplink
MIMO	Multiple input multiple output
MAC	Medium access control
PHY	Physical
SC-FDMA	Single carrier frequency division multiple access
FDD	Frequency division duplex
TDD	Time division duplex
ARQ	Automatic repeat request
CoMP	Coordinated multipoint transmission and reception

c-VQA	Clinical video quality assessment
UEP	Unequal error protection
MOS	Mean opinion scores