

IJMSTR Editorial Board

Editor-in-Chief: Ming Yang, Southern Polytechnic State U., USA
Nikolaos Bourbakis, Wright State U., USA
Konstantina S. Nikita, National Technical U. of Athens, Greece

Associate Editors: J.J. P. Tsai, Asia U. Taiwan
John Volakis, The Ohio State U., USA

International Editorial Review Board:

Rudiger Brause, Goethe U. Frankfurt, Germany
Dimitrios Fotiadis, U. of Ioannina, Greece
Tatjana Jevremovic, U. of Utah, USA
Zhanpeng Jin, Binghamton U., USA
Lee Potter, The Ohio State U., USA

George Tsichritzis, U. of Pireas, Greece
Lefteris Tsoukalas, Purdue U., USA
Maria Virvou, U. of Pireas, Greece
Michalis Zervakis, Technical U. of Crete, Greece

IGI Editorial:

Lindsay Johnston, Managing Director
Jennifer Yoder, Production Editor
Adam Bond, Journal Development Editor

Jeff Snyder, Copy Editor
Allyson Stengel, Editorial Assistant
Henry Ulrich, Production Assistant



IGI PUBLISHING

WWW.IGI-GLOBAL.COM

INTERNATIONAL JOURNAL OF MONITORING AND SURVEILLANCE TECHNOLOGIES RESEARCH

October-December 2013, Vol. 1, No. 4

Table of Contents

SPECIAL ISSUE ON BIOMEDICAL MONITORING TECHNOLOGIES: SELECTED PAPERS FROM THE 12TH IEEE INTERNATIONAL CONFERENCE ON BIOINFORMATICS AND BIOENGINEERING (BIBE 2012) AND THE 8TH INTERNATIONAL SYMPOSIUM ON ADVANCED TOPICS IN ELECTRICAL ENGINEERING (ATEE 2013), PART 2

GUEST EDITORIAL PREFACE

- iv *Christos P. Loizou, Department of Electrical Engineering, Cyprus University of Technology, Limassol, Cyprus*
Mihaela Morega, Faculty of Electrical Engineering, University "Politehnica" of Bucharest, Bucharest, Romania
Efthymoulos C. Kyriakou, Department of Computer Science and Engineering, Frederick University, Lemesos, Cyprus
Sever Pasca, Faculty of Electronics Telecommunications and Information Technology, University "Politehnica" of Bucharest, Bucharest, Romania
Styliani Petroudi, Department of Computer Science, University of Cyprus, Nicosia, Cyprus
Panagiotis D. Bamidis, Lab of Medical Informatics, Medical School, Aristotle University of Thessaloniki, Thessaloniki, Greece
Marios S. Pattichis, Department of Electrical and Computer Engineering, The University of New Mexico, Albuquerque, NM, USA
Constantinos S. Pattichis, Department of Computer Science, University of Cyprus, Nicosia, Cyprus

RESEARCH ARTICLES

- 1 **An Improved Stimuli System for Brain-Computer Interface Applications**
Irina-Emilia Nicolae, Faculty Electronics, Telecommunications and Information Technology, University Politehnica of Bucharest, Bucharest, Romania
- 9 **Comparison of SEMG Derived Parameters and Blood Oxygen Saturation in Monitoring Neuromuscular Fatigue in Humans**
M. Tarata, Department of Medical Informatics, University of Medicine and Pharmacy of Craiova, Craiova, Romania
W. Wolf, Universität der Bundeswehr München, Neubiberg, Germany
D. Georgescu, Department of Medical Informatics, University of Medicine and Pharmacy of Craiova, Craiova, Romania
D. Alexandru, Department of Medical Informatics, University of Medicine and Pharmacy of Craiova, Craiova, Romania
M. Serbanescu, Department of Medical Informatics, University of Medicine and Pharmacy of Craiova, Craiova, Romania
- 20 **An Adaptive Magnetic Field Source for Magnetic Drug Fixation**
Alexandru Mihail Morega, University "Politehnica" of Bucharest, Bucharest, Romania & "Gheorghe Mihoc – Caius Iacob" Institute of Statistical Mathematics and Applied Mathematics of the Romanian Academy, Bucharest, Romania
Cristina Savastru, University "Politehnica" of Bucharest, Bucharest, Romania
Mihaela Morega, University "Politehnica" of Bucharest, Bucharest, Romania
- 34 **Radiation Safety of the Patients Investigated by Radiological Imaging Methods**
Lidia Dobrescu, University "Politehnica" of Bucharest, Bucharest, Romania
Silviu Stanciu, Central Military Emergency University Hospital "Dr. Carol Davila" of Bucharest, Romania
Armand Ropot, S.C. CERTSIGN S.A., Bucharest, Romania
- 48 **A Prototype MR Compatible Positioning Device for Guiding a Focused Ultrasound System for the Treatment of Abdominal and Thyroid Cancer**
Nicos Mylonas, Frederick University Cyprus, Limassol, Cyprus & City University, London, UK
Christakis Damianou, Cyprus University of Technology, Limassol, Cyprus
- 61 **Despeckle Filtering Toolbox for Medical Ultrasound Video**
Christos P. Loizou, Department of Computer Science, Intercollege, Limassol, Cyprus
Charoula Theofanous, Department of Electrical Engineering, Computer Engineering & Informatics, Cyprus University of Technology, Limassol, Cyprus
Marios Pantziaris, Cyprus Institute of Neurology and Genetics, Nicosia, Cyprus
Takis Kaspas, Department of Electrical Engineering, Computer Engineering & Informatics, Cyprus University of Technology, Limassol, Cyprus
Paul Christodoulides, Department of Electrical Engineering, Computer Engineering & Informatics, Cyprus University of Technology, Limassol, Cyprus
Andrew N. Nicolaidis, The Vascular Screening and Diagnostic Centre, Nicosia, Cyprus
Constantinos S. Pattichis, Department of Computer Science, University of Cyprus, Nicosia, Cyprus

Copyright

The International Journal of Monitoring and Surveillance Technologies Research (IJMSTR) (ISSN 2166-7241; eISSN 2166-725X), Copyright © 2013 IGI Global. All rights, including translation into other languages reserved by the publisher. No part of this journal may be reproduced or used in any form or by any means without written permission from the publisher, except for noncommercial, educational use including classroom teaching purposes. Product or company names used in this journal are for identification purposes only. Inclusion of the names of the products or companies does not indicate a claim of ownership by IGI Global of the trademark or registered trademark. The views expressed in this journal are those of the authors but not necessarily of IGI Global.

The International Journal of Monitoring and Surveillance Technologies Research is currently listed or indexed in: Cabell's Directories; INSPEC; MediaFinder; The Standard Periodical Directory; Ulrich's Periodicals Directory

Despeckle Filtering Toolbox for Medical Ultrasound Video

Christos P. Loizou, Department of Computer Science, Intercollege, Limassol, Cyprus

Charoula Theofanous, Department of Electrical Engineering, Computer Engineering & Informatics, Cyprus University of Technology, Limassol, Cyprus

Marios Pantziaris, Cyprus Institute of Neurology and Genetics, Nicosia, Cyprus

Takis Kasparis, Department of Electrical Engineering, Computer Engineering & Informatics, Cyprus University of Technology, Limassol, Cyprus

Paul Christodoulides, Department of Electrical Engineering, Computer Engineering & Informatics, Cyprus University of Technology, Limassol, Cyprus

Andrew N. Nicolaidis, The Vascular Screening and Diagnostic Centre, Nicosia, Cyprus

Constantinos S. Pattichis, Department of Computer Science, University of Cyprus, Nicosia, Cyprus

ABSTRACT

Ultrasound medical video has the potential in differentiating between normal and abnormal tissue and structure. Ultrasound imaging is used in border identification and texture characterisation of the atherosclerotic carotid plaque in the common carotid artery (CCA), the identification and measurement of the intima-media thickness (IMT) and the lumen diameter that are very important in the assessment of cardiovascular disease. However, visual perception is reduced by speckle noise affecting the quality of ultrasound B-mode imaging. Noise reduction is therefore essential for increasing the visual quality or as a pre-processing step for further automated analysis, such as the video segmentation of the IMT and the atherosclerotic carotid plaque in ultrasound video sequences. In order to facilitate this analysis, the authors have developed a video analysis software toolbox based on MATLAB® that uses video despeckling, texture analysis and image quality evaluation techniques to automate the pre-processing and complement the disease evaluation in ultrasound CCA videos. The proposed software, which is based on a graphical user interface (GUI), incorporates video normalisation, 4 different despeckle filtering techniques (DsFlsmv, DsFhmedian, DsFkuwahara and DsFsrad), 65 texture features, 11 quantitative video quality metrics and objective video quality evaluation. The software was validated on 10 ultrasound videos of the CCA, by comparing its results with quantitative visual analysis performed by two medical experts. It was shown that the filters DsFlsmv, and DsFhmedian improved video quality perception (based on the expert's assessment and the video quality metrics). It is anticipated that the system could help the physician in the assessment of cardiovascular video analysis. However, exhaustive evaluation of the despeckle filtering toolbox has to be carried out by more experts on more videos.

Keywords: Common Carotid Artery (CCA), Despeckling, Speckle, Texture Analysis, Ultrasound, Video

DOI: 10.4018/ijmstr.2013100106

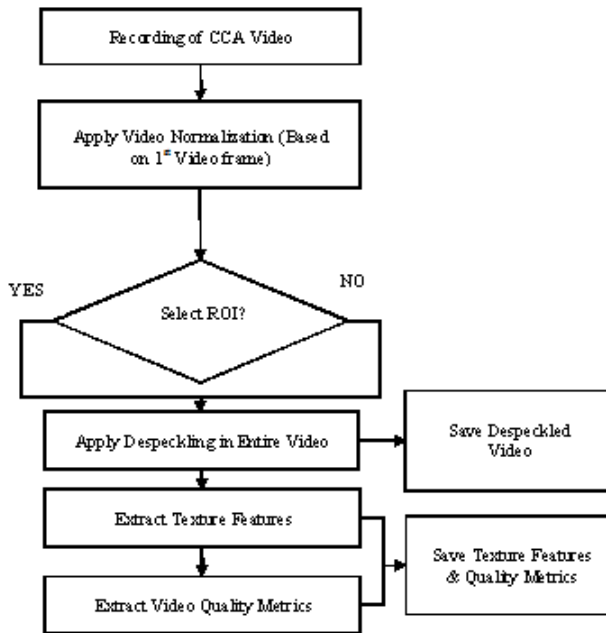
INTRODUCTION

Despite significant progress made in the last few years and the vast technological advancements in image and video processing, there are a number of factors that negatively influence the visual quality of images and videos, and hinder the automated analysis (Wang, 2004). These include video acquisition technologies, imperfect instruments, natural phenomena, transmission errors, and coding artifacts, which degrade the quality of video data by inducing noise (Loizou, 2008; Loizou, 2012b). Ultrasound imaging and video is a non-invasive powerful diagnostic tool in medicine, but it is degraded by a form of multiplicative noise (speckle), which makes the observation difficult (Loizou, 2005; Loizou, 2008). It is therefore of interest for the research community to investigate and apply new video despeckle filtering techniques that can increase the visual perception evaluation and further automate video analysis, thus improving the final diagnosis. These techniques are usually incorporated into integrated software medical image/video processing applications.

We propose in this study an integrated software toolbox (see also Figure 1 and Figure 2) for ultrasound video despeckling that can be utilized in video analysis. The present work is an extended version of a conference paper presented in the BIBE conference (Loizou, 2012b), where ultrasound video despeckling of the common carotid artery (CCA) was proposed. In order to quantitatively evaluate the proposed software system we applied different video despeckle filtering techniques and investigated their performance on 10 ultrasound videos of the CCA. The despeckling filtering techniques and the integrated software toolbox were also evaluated through visual perception, performed by two vascular experts, a cardiovascular surgeon, and a neurovascular specialist, before and after despeckle filtering. The video despeckle filtering techniques were further evaluated through a number of texture features and video quality metrics, which were extracted from the original and the despeckled videos.

There are a number of studies reported in the literature, where ultrasound image medical software systems have been introduced. An overview of these systems is given in Table 1. The systems tabulated have been grouped under freeware, and commercial. Loizou and Pattichis (2008) published a monograph on despeckle filtering that was accompanied with a despeckle filtering toolbox for ultrasound imaging of the CCA, whereas, in this paper an ultrasound video despeckle filtering toolbox is introduced. Both systems can be downloaded from <http://www.cs.ucy.ac.cy/medinfo/>. The commercial imaging systems cover the measurement of intima-media thickness (IMT), as well as the plaque texture characterization. For IMT measurement, several systems are available in the market, those that are included in the widely known commercial ultrasound machines (Esaote S.p.A, Philips Electronic Ltd) as well as the ones that can be purchased as stand-alone software systems (Segment™, Atheroedge™, Royal Perth IMT software and M'Ath®). More specifically, in Davis et al. (2010), the RF-QIMT & RF-QAS integrated patented commercial imaging software system (Esaote S.p.A, Florence, Italy) for the segmentation of the intima-media complex (IMC) was proposed and evaluated on 635 subjects. The Segment™ software used also by Phillips Electronics Ltd, was presented by Heiberg et al. (2010) and is suitable for cardiovascular image analysis. Molinari and co-workers (2011) patented the architecture of an automated strategy, which segments the lumen-intima and media adventitia borders in 2D ultrasound images. This system was classified under a class of patented AtheroEdge™ systems by Global Biomedical Technologies, Inc, CA, USA. A commercial IMT software system tool that can be used to measure the IMT and the lumen diameter in ultrasound images, and image sequences of the CCA was developed by the Royal Perth Hospital, Australia. Moreover, a software system from M'Ath® Intelligent Medical Technologies, Argenteuil, France was presented for the segmentation of the IMT from 2D ultrasound images of the CCA. Finally,

Figure 1. Flowchart analysis of despeckle filtering toolbox for ultrasound video



in Kyriakou et al., (2007), a commercialized software system for the manual delineation, and automated image normalization and texture

analysis of the atherosclerotic carotid plaque in ultrasound images of the CCA was presented.

The structure of the rest of the paper is as follows: In section 2, the theoretical concepts

Figure 2. The graphical user interface (GUI) of the proposed despeckle filtering toolbox for ultrasound video. The following components are shown: original video display, original video settings, despeckled video display, despeckled video settings (filter settings), number of frames for video despeckling, texture analysis and quality analysis.

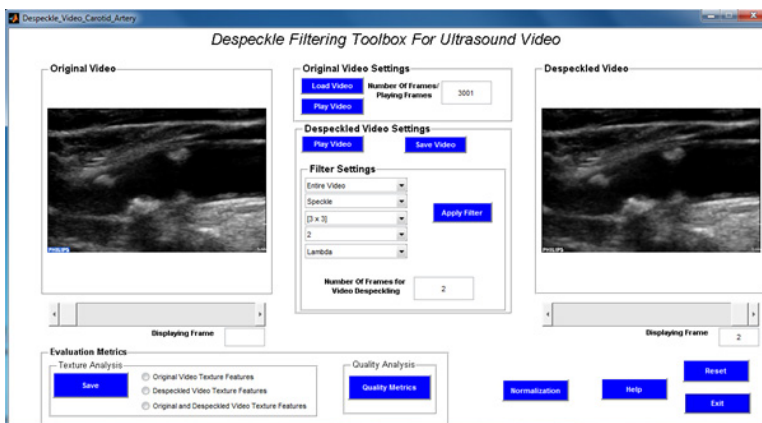


Table 1. An overview of selected ultrasound common carotid artery imaging and video analysis software systems

Principal Investigator	Year	Method	2D/3D	Software Platform	N
Freeware-Despeckling					
Loizou	2008	Despeckle Image Filtering	2D	Matlab®	440
Loizou	2012	Despeckle Video Filtering	2D	Matlab®	10
Commercial Imaging Systems-Intima Media Thickness Measurement					
Esaote S.p.A RF-QIMT&RF-QAS	2009	IMT Measurement and Quality Arterial Stiffness ⁺	2D	ART.LAB	635
Segment™, Phillips Electronics Ltd	2010	Cardiovascular Image Analysis	2D/3D	Windows/Matlab®	-
Global Biomedical Technologies AtheroEdge™	2011	IMT Measurement	2D	Matlab®	500
Royal Perth Hospital	2011	IMT Software	2D	Windows	-
M'Ath® Intelligent Medical Technologies	2012	IMT Measurement	2D	Windows	-
Commercial Imaging Systems-Plaque Segmentation and Texture Characterization					
Kyriakou	2007	Normalization and Plaque Texture Analysis	2D	Matlab®	440

N: Number of cases investigated. +: Based on the radio frequency signal.

of the proposed video despeckle filters are presented. In section 3 we provide information for the materials and methods used in this study, while in section 4 we present the results of this study. Sections 5 and 6 present a discussion in relation to previous results from other studies, and the concluding remarks respectively.

Image/Video Despeckle Filters

In this section, the theoretical background for the following four video despeckle filtering methods is introduced: a) linear despeckle filter (DsFlsmv), b) hybrid median filter (DsFhmedian), c) nonlinear filter (DsFkuwahara), and d) speckle reducing anisotropic diffusion (DsFsradi) filtering. Further algorithmic implementation details and coding can be found in (Loizou, 2008). These filters were applied to each video frame: a) for the whole video frame, and b) for a region of interest (ROI) in each video. The number of iterations, the filtering window size and other filtering parameters that

are used for each despeckle filtering method were tuned based, on the subjective despeckled video evaluation by two medical experts (see also section 3E).

Linear Despeckle Filter (DsFlsmv)

The filters of this type utilize the first order statistics such as the variance and the mean of a pixel neighbourhood and may be described by a multiplicative noise model (Loizou, 2005; Loizou, 2006; Lee, 1980). Hence the algorithms in this class may be traced back to the following equation:

$$f_{i,j} = \bar{g} + k_{i,j}(g_{i,j} - \bar{g}) \quad (1)$$

where $f_{i,j}$, is the estimated noise-free pixel value, $g_{i,j}$, is the noisy pixel value in the moving window, \bar{g} , is the local mean value of an $N_1 \times N_2$ region surrounding and including

pixel $g_{i,j}$, $k_{i,j}$ is a weighting factor, with $k \in [0,1]$, and i, j are the pixel coordinates. The factor $k_{i,j}$, is a function of the local statistics in a moving window and is defined (Loizou, 2005; Loizou, 2006; Lee, 1980) as:

$$k_{i,j} = \frac{(1 - \bar{g}^2 \sigma^2)}{(\sigma^2 + \sigma_n^2)}. \quad (2)$$

The values σ^2 , and σ_n^2 , represent the variance in the moving window and the variance of noise in the whole video frame respectively. The noise variance may be calculated for the logarithmically compressed frame by computing the average noise variance over a number of windows with dimensions considerably larger than the filtering window (Loizou, 2005; Loizou, 2006; Lee, 1980). The moving window size for the despeckle filter DsFismv can be selected from 3x3 up to 16x16 and the number of iterations applied to each video frame from 1 to 20.

Hybrid Median Filtering (DsFhmedian)

DsFhmedian was introduced in (Nieminen, 1987) and computes the median of the outputs generated by median filtering with three different windows (cross shape window, x-shape window and normal window). A 5x5 size moving window is used with a selectable number of iterations applied to each video frame ranging from 1 to 20.

Nonlinear Filtering (DsFkuwahara)

The DsFkuwahara is an 1D filter operating in a 5x5 pixel neighborhood by searching for the most homogenous neighborhood area around each pixel (Kuwahara, 1976; Loizou, 2008). The middle pixel of the 1x5 neighborhood is then substituted with the median gray level of the 1x5 mask. The filter is iteratively applied a selectable (from 1 to 20) times on the video frame.

Speckle Reducing Anisotropic Diffusion Filtering (DsFsrad)

Speckle reducing anisotropic diffusion is described in Yongjian (2002). It is based on setting the conduction coefficient in the diffusion equation using the local frame gradient and the frame Laplacian. The DsFsrad speckle reducing anisotropic diffusion filter in Yongjian (2002) uses two seemingly different methods, namely the Lee (Lee, 1980) and the Frost diffusion filters (Frost, 1982). A more general updated function for the output image by extending the PDE versions of the despeckle filter is in Yongjian (2002):

$$f_{i,j} = g_{i,j} + \frac{1}{\eta_s} \text{div}(c_{srad}(|\nabla g|) \nabla g_{i,j}). \quad (3)$$

where η_s is the size of the filtering window. The diffusion coefficient for the speckle anisotropic diffusion, $c_{srad}(|\nabla g|)$, is given in Yongjian (2002):

$$c_{srad}^2(|\nabla g|) = \frac{\frac{1}{2} |\nabla g_{i,j}|^2 - \frac{1}{16} (\nabla^2 g_{i,j})^2}{(g_{i,j} + \frac{1}{4} \nabla^2 g_{i,j})^2}. \quad (4)$$

It is required that $c_{srad}(|\nabla g|) \geq 0$. The above instantaneous coefficient of variation combines a normalized gradient magnitude operator and a normalized Laplacian operator to act like an edge detector for speckle images. High relative gradient magnitude and low relative Laplacian indicates an edge. The DsFsrad filter utilizes speckle reducing anisotropic diffusion after (3) with the diffusion coefficient, $c_{srad}(|\nabla g|)$ in (4) (Yongjian, 2002). The coefficient of variation for the DsFsrad filter can be selected from 0.01 up to 0.1 and the number of iterations from 1 to 200.

Despeckle Filtering Toolbox For Ultrasound Video

The proposed integrated software toolbox for ultrasound video despeckling, implements procedures for loading video files of most popular standards (see also Figure 1). The video analysis usually starts with a definition of an ROI in the first video frame where despeckle filtering will be applied in a frame by frame basis for the whole video sequence. There are 65 different texture features and six video quality metrics that are extracted and evaluated by comparing the original and despeckled videos.

Figure 1 presents a flowchart analysis of the proposed integrated video despeckling software system, where the different modules of the software are outlined. In Figure 2 we present the graphical user interface (GUI) of the proposed system. The video despeckling software can be downloaded as an executable code from <http://www.cs.ucy.ac.cy/medinfo/>.

Recording and Display of Ultrasound Videos

A total of 10 B-mode longitudinal ultrasound videos of the CCA bifurcation from women and men of 40 years or older were recorded (see Figure 3 and Figure 4) representing different types of atherosclerotic plaque formation (Type I to Type IV; Loizou, 2005; Loizou, 2008) with irregular geometry typically found in this blood vessel. The videos were acquired using the ATL HDI-5000 ultrasound scanner (Advanced Technology Laboratories, Seattle, USA) (A Philips Medical Company, 2001) and were recorded digitally on a magneto optical drive, with a resolution of 576x768 pixels with 256 gray levels, and having a frame rate of 100 frames/sec. The ATL HDI-5000 ultrasound scanner is equipped with a 256-element fine pitch high-resolution 50-mm linear array, a multi-element ultrasound scan head with an extended operating frequency range of 5–12 MHz and it offers real spatial compound imaging. B-mode scan settings were adjusted at 170 dB, so that the maximum dynamic range was used with a linear post-processing curve. In order to ensure that

a linear-post-processing curve is used, these settings were pre-selected (by selecting the appropriate start-up presets from the software) and were included in the part of the start-up settings of the ultrasound scanner. The position of the probe was adjusted so that the ultrasonic beam was vertical to the artery wall. The time gain compensation (TGC) curve was adjusted (gently sloping) to produce uniform intensity of echoes on the screen, but it was vertical in the lumen of the artery where attenuation in blood was minimal so that echogenicity of the far wall was the same as that of the near wall. The overall gain was set so that the appearance of the plaque was assessed to be optimal, and slight noise appeared within the lumen. It was then decreased so that at least some areas in the lumen appeared to be free of noise (black).

All video frames were manually resolution-normalized at 16.66 pixels/mm. This was carried out to overcome the small variations in the number of pixels per mm of image depth (i.e. for deeply situated carotid arteries, image depth was increased and therefore digital image spatial resolution would have decreased) and in order to maintain uniformity in the digital image spatial resolution (Kyriakou, 2005). The videos were recorded from 6 asymptomatic subjects and from 4 symptomatic subjects at risk of atherosclerosis, who have already developed clinical symptoms, such as a stroke or a transient ischemic attack (TIA). The video despeckling methods can be performed for a selected time interval, covering the cardiac cycles of interest or under investigation.

Ultrasound Video Normalization

Brightness adjustments of ultrasound videos (see Figure 3 and Figure 4) can be carried out based on the method introduced in Elatrozy (1998), which improves image compatibility by reducing the variability introduced by different gain settings, different operators, different equipment, and facilitates ultrasound tissue comparability (Kyriakou, 2005). Algebraic (linear) scaling of the first video frame is manually performed by linearly adjusting the image so that the median gray level value of the blood

Figure 3. Examples of despeckle filtering on a video frame of a CCA video acquired from a male symptomatic subject at the age of 62 with 40% stenosis and a plaque at the far wall of the CCA, for the whole image frame in the left column, and on an ROI (including the plaque (shown in b)), in the right column for: a), b) original, c), d) DsFlsmv, e), f) DsFhmedian, g), h) DsFkuwahara, and i), j) DsFsrad. The automated plaque segmentations are shown in all examples.

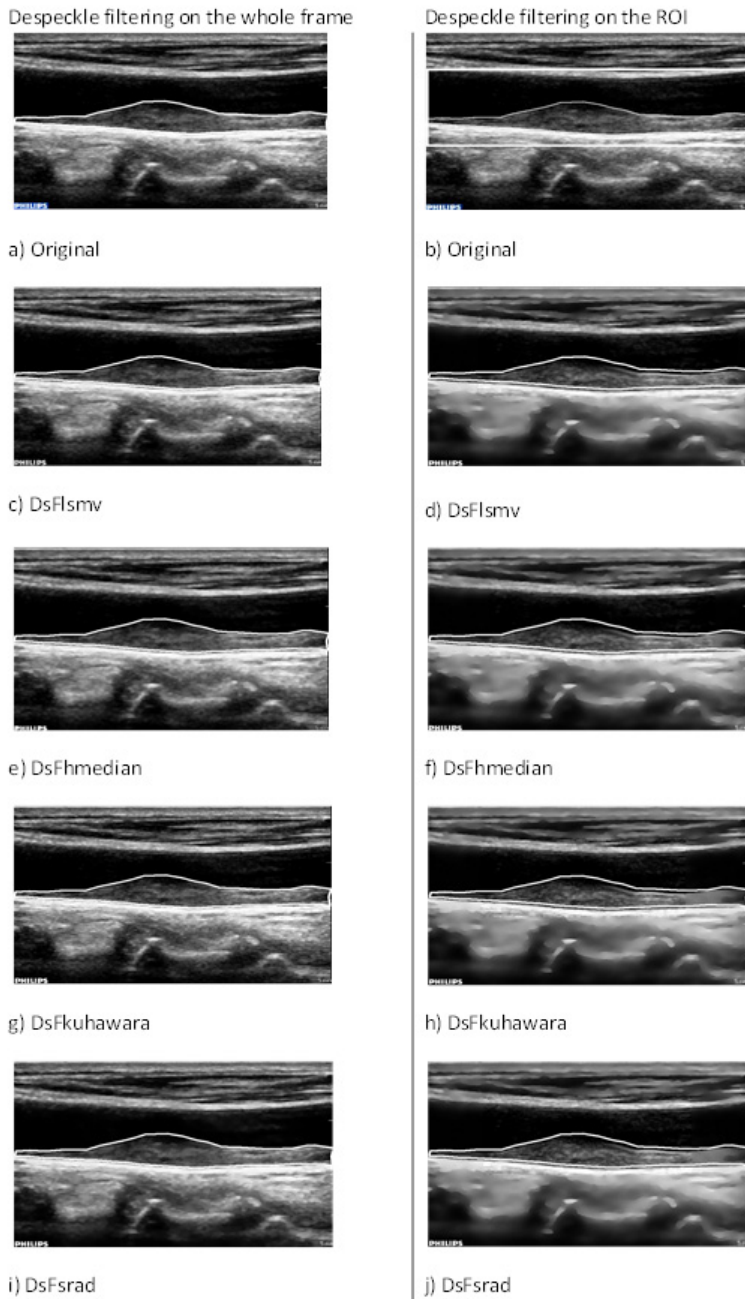
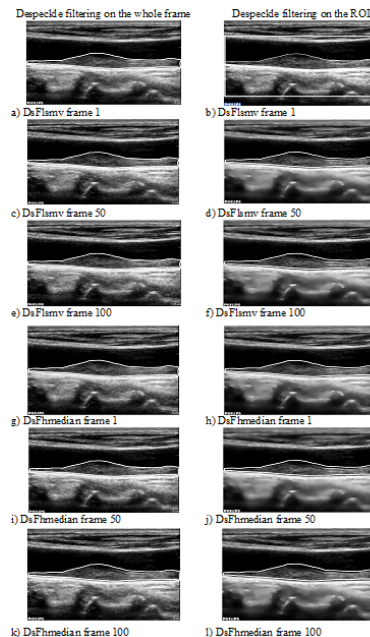


Figure 4. Examples of despeckle filtering with the filter *DsFlsmv* (a-f) and *DsFhmedian* (g-l) on a video of the CCA, acquired from a male symptomatic subject at the age of 62, with 40% stenosis and a plaque at the far wall of the CCA, on frames 1, 50 and 100 for the whole image frame in the left column, and on an ROI (shown in b)), in the right column. The automated plaque segmentations are shown in all examples.



was 0-5, and the median gray level of the adventitia (artery wall) was 180-190 (Elatrozy, 1998; Nicolaides, 2003). The scale of the gray level of the video frames ranged from 0-255. Thus the brightness of all pixels in the video frame is readjusted according to the linear scale defined by selecting the two reference regions. The subsequent frames of the video are then automatically normalized based on the selection of the first frame. The operator of the proposed software tool cannot intervene in the normalization process of subsequent frames. It is noted that a key point to maintaining a high reproducibility was to ensure that the ultrasound beam was at right angles to the adventitia, adventitia was visible adjacent to the plaque and that for image normalization a standard sample consisting of the half of the width of the brightest area of adventitia was obtained.

Despeckle Filtering

Despeckle filtering can be applied either to the whole frame or to an ROI selected by the user (see Figure 3 and Figure 4, where both are applied in the whole video). In the latter case, where the user of the system is interested only in the selected ROI, the area outside the ROI can be blurred using the *DsFsrad* filter with 100 iterations and a coefficient of variation 0.05 (or using another filter). It should be noted that the blurring is applied outside of the ROI if the user of the system is not interested to subjectively evaluate this area. The input parameters of the despeckle filters *DsFlsmv*, *DsFhmedian*, *DsFkuwahara* and *DsFsrad* can be selected by the user. These are the size of the sliding moving window and the number of iterations, as well as the coefficient of variation that is required for the *DsFsrad* filter.

Texture Feature Analysis

Texture provides useful information for the characterization of the atherosclerotic carotid plaque in both images and videos of the CCA (Christodoulou, 2003). The proposed system (see Figure 1 and Figure 2) is able to extract a total of 65 different texture features both from the original and the despeckled video frames as follows (Christodoulou, 2003):

1. Statistical Features (SF): 1) Mean, 2) Median, 3) Variance (σ^2), 4) Skewness (σ^3), and 5) Kurtosis (σ^4).
2. Spatial Gray Level Dependence Matrices (SGLDM) as proposed by (Haralick, 1973): 1) Angular second moment (ASM), 2) Contrast, 3) Correlation, 4) Sum of squares variance (SOSV), 5) Inverse difference moment (IDM), 6) Sum average (SA), 7) Sum variance (SV), 8) Sum entropy (SE), 9) Entropy, 10) Difference variance (DV), 11) Difference entropy (DE), 12), and 13) Information measures of correlation (IMC). For a chosen distance d (in this work $d=1$ was used) and for angles $\theta = 0^\circ, 45^\circ, 90^\circ$, and 135° , we computed four values for each of the above texture measures. Each feature was computed using a distance of one pixel. Then for each feature the mean values and the range of values were computed, and were used as two different feature sets.
3. Gray Level Difference Statistics (GLDS) (Weszka, 1976): 1) Homogeneity, 2) Contrast, 3) Energy, 4) Entropy, and 5) Mean. The above features were calculated for displacements $\delta=(0, 1), (1, 1), (1, 0), (1, -1)$, where $\delta \equiv (\Delta x, \Delta y)$, and their mean values were taken.
4. Neighborhood Gray Tone Difference Matrix (NGTDM) (Amadasun, 1989): 1) Coarseness, 2) Contrast, 3) Busyness, 4) Complexity, and 5) Strength.
5. Statistical Feature Matrix (SFM) (Wu, 1992): 1) Coarseness, 2) Contrast, 3) Periodicity, and 4) Roughness.
6. Laws Texture Energy Measures (LTEM) (Wu, 1992): 1) LL-texture energy from LL kernel, 2) EE-texture energy from EE-kernel, 3) SS-texture energy from SS-kernel, 4) LE-average texture energy from LE and EL kernels, 5) ES-average texture energy from ES and SE kernels, and 6) LS-average texture energy from LS and SL kernels.
7. Fractal Dimension Texture Analysis (FDTA) (Wu, 1992): The Hurst coefficients for dimensions 4, 3 and 2 were computed.
8. Fourier Power Spectrum (FPS) (Wu, 1992): 1) radial sum, and 2) angular sum.
9. Shape Parameters: 1) X-coordinate maximum length, 2) Y-coordinate maximum length, 3) area, 4) perimeter, 5) perimeter²/area, 6) eccentricity, 7) equivalence diameter, 8) major axis length, 9) minor axis length, 10) centroid, 11) convex area, and 12) orientation.

Visual Evaluation by Experts

In order to objectively evaluate the proposed system, the 10 ultrasound videos of the CCA were inspected visually after video normalization and speckle reduction filtering (see Section 3B and Section 3C) by two vascular experts, a cardiovascular surgeon, and a neurovascular specialist before and after despeckle filtering, using MATLAB® software developed by our group. For each case, the original and the normalized despeckled videos (despeckled with filters DsFismv, DsFhmedian, DsFkuwahara, DsFsrad) were presented blindly at random to the two experts. The experts were asked to assign a score in the one to ten scale corresponding to low and high subjective visual perception criteria. Ten was given to a video with the best visual perception. Therefore the maximum score for a filter is 100, if the expert assigned the score of 10 for all the 10 videos. The experts were allowed to give equal scores to more than one video in each case. For each class and for each filter the average score was computed. The two experts evaluated the area around the distal CCA, 2-3 cm before the

bifurcation and the bifurcation around the plaque borders. It should also be noted that the scoring system used in this work presupposes an a priori knowledge of the range of the quality of the videos, therefore the two experts surveyed in random order all 10 videos before proceeding to the scoring procedure.

Video Quality Metrics

Objective video quality assessment is an emerging area of active research (Varghese, 2008). This is very different than image quality assessment that has seen significant growth and success over the last 10 years. Important video quality metrics, which are also investigated in this study include: a) structural similarity index (SSI), b) visual signal-to-noise ratio (VSNR), c) information fidelity (IFC), d) noise quality measure (NQM), e) weighted signal-to-noise ratio (WSNR) and f) Peak signal-to-noise ratio (RSNR). We refer to (Merix_mux software) for algorithmic details and implementation. The above video quality metrics were calculated from the original and the despeckled video frames.

RESULTS

Examples Using the Despeckle Filtering Toolbox for Ultrasound Video

The performance of the proposed video despeckle filtering toolbox was evaluated after video normalization and despeckle filtering using visual perception evaluation, texture features, and image quality evaluation metrics. Figure 3 presents the frame 100 of the video from a symptomatic subject for the original and the despeckled frames with filters DsFlsmv, DsFhmedian, DsFkuwahara, and DsFsrad when applied to the whole frame (left column) and on an ROI selected by the user of the system (right column) respectively. The automated plaque segmentations performed by an integrated system proposed in Loizou (2007b) are also shown in the images. The filters DsFlsmv and

DsFhmedian smoothed the video frame without destroying subtle details. Figure 4 presents the application of the DsFlsmv (see Figure 4 a-f) and the DsFhmedian (see Figure 4 g-l) despeckle filters, which showed best performance (see Tables 2-4), on consecutive video frames (1, 50 and 100) of a symptomatic subject, for the cases where the filtering was applied on the whole video frame (see left column of Figure 4) and on an ROI selected by the user (see right column of Figure 4).

Texture Feature Analysis

As texture features data are not normally distributed, the Wilcoxon rank sum test (Altman, 1991), which calculates the difference between the sum of the ranks of two independent samples, may be used in order to identify if for each set of texture features a significant difference (S) or not (NS) exists between the extracted features between the original and the despeckled frames, with a confidence level of 95% ($p < 0.05$).

Table 2 presents the results of selected texture features (from the SF and SGLDM feature sets, see section 3D) that showed significance difference after despeckle filtering ($p < 0.05$). The features were extracted from the original video frame and the despeckled video frames for the whole video frame and the ROI, for all 10 videos investigated in this study. These features were the median, variance, IDM, entropy, SV, DE, coarseness, complexity and roughness. It is shown that the filters DsFlsmv and DsFhmedian comparatively preserved the features median, variance and entropy but increased coarseness. It should be noted that these findings cannot be compared with the results presented in references Loizou (2005), and Loizou (2006), as the texture features in these two studies were computed for the DsFlsmv despeckled plaque images (and not the ROIs as defined in this study).

Visual Evaluation by Experts

Table 3 presents the average results of the visual evaluation of the original and despeckled videos made by the two experts, a cardiovascular

Table 2. Texture features (mean±sd), that showed significant difference (using the Mann-Whitney U-test) after despeckle filtering, for all 10 videos of the *cea* extracted from the original and the despeckled videos from the whole video and the roi (-/-).

Features	original	DsFlsmv	DsFhmedian	DsFkuwahara	DsFsrad
Statistical Features					
Median	43±14 / 23±17	43±14 / 28±18	43±14 / 26±12	42±14 / 26±17	43±14 / 26±14
Variance	54±7 / 58±8	53±6 / 58±9	54±6 / 58±8	55±8 / 59±9	54±6 / 62±8
Spatial Gray Level Dependence Matrix					
IDM	0.27±0.07 / 0.29±0.14	0.29±0.07 / 0.075±0.08	0.39±0.05 / 0.078±0.08	0.41±0.07 / 0.083±0.088	0.38±0.06 / 0.034±0.038
Entropy	7.8±0.5 / 7.0±0.96	7.7±0.4 / 6.7±0.9	7.5±0.4 / 6.6±0.9	7.5±0.6 / 6.6±1.1	7.4±0.5 / 7.01±0.8
Sum Average	0.27±0.09 / 0.91±0.71	0.42±0.16 / 0.38±0.2	0.37±0.16 / 0.53±0.44	0.38±0.17 / 0.39±0.19	0.26±0.11 / 0.52±0.37
Sum Variance	104±37.66 / 205±199	109±52 / 57±28	90±27 / 112±115	135±42 / 117±46	105±53 / 95±83
DE	0.74±0.15 / 0.9±0.2	0.74±0.12 / 0.77±0.15	0.69±0.12 / 0.74±0.13	0.7±0.11 / 0.72±0.1	0.61±0.09 / 0.56±0.16
Neighborhood Gray Level Matrix (NGLM)					
Coarseness	38±7 / 61±11	93±13 / 110±22	52±10 / 84±21	37±4 / 55±12	54±22 / 33±18
Complexity (x1000)	74.33±12.81 / 44.16±14.8	49.4±6.5 / 29.5±9.5	59.5±7.4 / 36.7±13.1	68.6±12.1 / 69.6±21.8	62.7±11.3 / 67.9±19.1
Statistical Features Matrix (SFM)					
Roughness	2.21±0.014 / 2.16±0.02	2.14±0.012 / 2.11±0.01	2.11±0.013 / 2.11±0.02	2.15±0.01 / 2.13±0.01	2.18±0.03 / 2.28±0.09

IQR: Inter-quartile range, SOV: Sum of squares variance, ASM: Angular second moment, IDM: Inverse difference moment, DE: Difference entropy

surgeon and a neurovascular specialist. The evaluation was performed on both the whole despeckle video frame as well as to the ROI, where both methods gave similar visual evaluation scorings. We present the overall average percentage (%) score assigned by both experts for each filter and the filter ranking. It is shown in Table 3 that marginally the best video despeckle filter is the DsFlsmv with a score of 74%, followed by the filter DsFhmedian and DsFkuwahara with scores of 73% and 71% respectively. The filter DsFsrad gave poorer performance with an average score of 56%.

Video Quality Metrics

Table 4 tabulates selected video quality metrics between the original and the despeckled videos for the whole frame filtering and when the filtering was applied on an ROI. It is clearly shown that the despeckle filter DsFlsmv performs better in terms of quality evaluation for the metrics WSNR, VSNR, SSI, IFC and NQM, when applied on the whole frame. Moreover, all the investigated evaluation metrics gave better results when the DsFlsmv was applied only on the ROI, followed by the DsFhmedian.

Table 4. Video quality metrics (mean±sd) for all 10 videos of the *cca* extracted between the original and the despeckled videos from the whole video and the *roi* (-/-)

Metrics	DsFlsmv	DsFhmedian	DsFkuwahara	DsFsrاد
PSNR	39.6±2.1 / 42.9±1.6	38.9±1.1 / 40.1±4.5	29.1±1.1 / 29.9±1.2	43.9±4.3 / 34.9±6.9
WSNR	34.8±1.8 / 38±0.91	33.1±1.1 / 35±5.4	18.8±0.9 / 20.6±1.3	39.1±5.2 / 25±8
VSNR	36±3.77 / 41±3.0	30±1.86 / 38±5.3	15±1.1 / 24.7±2.3	37±5.7 / 32±10
SSI	0.98±0.01 / 0.98±0.05	0.97±0.001 / 0.96±0.06	0.77±0.025 / 0.84±0.03	0.96±0.025 / 0.88±0.08
IFC	7.2±0.93 / 6.2±0.98	6.1±0.6 / 4.6±1.3	1.9±0.08 / 1.4±0.21	6.6±2.3 / 3.7±2.1
NQM	35.3±1.9 / 29±1.9	34±1.4 / 26.7±5.1	17.7±1.1 / 14.2±1.3	34.8±4.9 / 24.1±6.7

PSNR: Peak signal-to-noise ratio, WSNR: Weighted signal-to-noise ratio, VSNR: Visual signal-to-noise ratio, SSI: Structural similarity index, IFC: Information fidelity criterion, NQM: Noise quality measure

DISCUSSION

In this work we present an integrated software system for despeckling ultrasound videos. The integrated software system was evaluated by medical experts and also used in a number of other studies performed by our group (as also presented in Table 1) with very promising results. Our effort was to achieve multiplicative noise reduction in order to increase visual perception by the experts but also to make the videos suitable for further analysis such as video segmentation and coding.

The proposed system can also apply ultrasound video normalization, as documented in a few recent studies performed by our group (Loizou, 2012a; Loizou, 2012b; Loizou, 2012c), where ultrasound video normalization was carried out as also described in this study. It was shown in Loizou (2012b) that ultrasound

video normalization before despeckle filtering improved the video quality based on the visual evaluation by the experts. In (Loizou, 2012c), video despeckle filtering was applied prior to the segmentation of the intima media complex of the carotid artery from ultrasound videos, whereas normalization was also applied in (Loizou, 2010), for the generation of the M-mode image from ultrasound videos of the CCA.

While there are a number of commercial software packages proposed in the literature for denoising and/or analyzing ultrasound images (see also Table 1), we found no other studies in the literature for despeckle filtering in ultrasound videos of the CCA. A number of studies have investigated additive noise filtering in natural video sequences (Chan, 2005; Dabov, 2007; Maggioni, 2012; Rusanovsky, 2006; Zlokolica, 2002; Zlokolica, 2008). The usefulness of these methods in ultrasound video

Table 3. Percentage scoring of the original and despeckle videos by the experts (Loizou, 2012b)

Experts	original	DsFlsmv	DsFhmedian	DsFkuwahara	DsFsrاد
Average %	37	74	73	71	56

denoising on multiplicative noise still remains to be investigated. The DsFlsmv filter was found to perform better than other despeckle filters in two different studies presented by our group (Loizou, 2005; Loizou 2006). Loizou et al. (2007b) proposed a software system based in MATLAB® for the segmentation of the atherosclerotic carotid plaque, which was applied in 80 ultrasound images of the CCA. The system was evaluated based on visual perception by two medical experts and quantitative measures extracted from the images, where it was shown that the best despeckle filtering method was the DsFlsmv. An IMT MATLAB® based segmentation system was also proposed in (Loizou, 2007a), which was evaluated in 100 ultrasound images of the CCA. The DsFlsmv filter was used prior to the segmentation of the IMT (Loizou, 2007a; Loizou, 2009) and also prior to the segmentation of the atherosclerotic carotid plaque in ultrasound images (Loizou, 2007). The same system was later (Loizou, 2009) further developed in order to be able to segment the media and the intima layers of the CCA, where the DsFlsmv filter was used to despeckle the image prior to segmentation.

Limitations of the Video Despeckling Method

There are some limitations in the proposed methodology which are summarized below. MATLAB® is not the most computationally efficient environment. However, most of the implemented algorithms, programmed in MATLAB® are fast enough, in particular in segmenting and manually defining structures, as well as if the users can effectively define ROI and crop images to reduce the image dimensions using the available tools in the software. Therefore, computation speed is not a limiting factor for our software tool as the filtering can be applied in an ROI.

Another issue is that some automatic algorithms use many user-configurable parameters, such as the size of the moving window, the number of iterations and the coefficient of variation with the user trying to choose

the best parameter values. We have chosen in this application default values to be used as initial values for the parameters based on our experience. However, in many scenarios these parameters may still need to be changed by the user to achieve optimal results.

Validation of the final results is one of the most challenging tasks in medical image analysis applications. Results are usually compared with the “gold standard”, such as the optical perception evaluation by specialists, as also performed in this study. It is true that, such comparisons are often affected by other issues, such as, for example, inter- and intra-observer variability (Loizou, 2008; Loizou, 2007a; Loizou, 2007b; Loizou, 2012a; Loizou, 2009). However, it is relatively safe to view about such automated methods as “second readers” intended to aid the user as this has been shown in many Computed Aided Design (CAD) applications to be a useful approach.

An average processing time is about 3 seconds per frame (on an Intel Core i5-3470 processor with 3.2 GHz and 1GByte of RAM) for the video despeckling. It should be noted that the processing time of the proposed method could be further reduced by applying despeckle filtering only on key frames of the videos. Furthermore, software optimization methods (i.e. the MATLAB® software optimization toolbox) could be investigated for increasing the performance of the proposed video despeckling software system.

CONCLUSION

In this paper, a freeware despeckle filtering toolbox for ultrasound video has been presented that can be downloaded from (<http://www.cs.ucy.ac.cy/medinfo/>). The toolbox proposed in this study is based on the following four despeckle fitters, DsFlsmv, DsFhmedian, DsFkuwahara and DsFsrad. The toolbox also supports quantitative evaluation metrics between the original and the despeckled videos, as well as qualitative evaluation by the experts. Additional features of the toolbox include the computing of texture

features over selected ROIs on the original and despeckled videos. The system was evaluated on atherosclerotic carotid plaque ultrasound videos, where it was shown that the filters Ds-Flsmv, and DsFhmedian improved video quality perception (based on the expert's assessment and the quantitative video quality metrics). It is anticipated that the system could help the physician in the assessment of cardiovascular video analysis. However, exhaustive evaluation of the despeckle filtering toolbox has to be carried out by more experts on more videos.

REFERENCES

- A Philips Medical System Company. (2001). *Comparison of image clarity, SonoCT real-time compound imaging versus conventional 2D ultrasound imaging*. ATL Ultrasound, Report.
- Altman, D. G. (Ed.). (1991). *Practical statistics for medical research*. London: Chapman & Hall.
- Amadasun, M., & King, R. (1989). Textural features corresponding to textural properties. *IEEE Transactions on Systems, Man, and Cybernetics*, 19(5), 1264–1274. doi:10.1109/21.44046
- Chan, T. W., Au, O. C., Chong, T. S., & Chau, W. S. (2005). A novel content-adaptive video denoising filter. *Proc. IEEE Vision, Imag. & Sign. Proces.*, 2(2), 649-652.
- Christodoulou, C. I., Pattichis, C. S., Pantziaris, M., & Nicolaides, A. N. (2003). Texture-based classification of atherosclerotic carotid plaques. *IEEE Transactions on Medical Imaging*, 22(7), 902–912. doi:10.1109/TMI.2003.815066 PMID:12906244
- Dabov, K., Foi, A., & Egiazarian, K. (2007). Video denoising by sparse 3D transform-domain collaborative filtering. In *Proc. of the 15th Eur. Sign. Proc. Conf.* (pp. 1-5).
- Davis, P. H., Dawson, J. D., Biecha, M. B., Mastbergen, R. K., & Sonka, M. (2010). Measurement of aortic intimal-media thickness in adolescents and young adults. *Ultr. Med. Biol.*, 36(4), 560–565. doi:10.1016/j.ultrasmedbio.2010.01.002
- Elatrozy, T., Nicolaides, A., Tegos, T., Zarka, A., Griffin, M., & Sabetai, M. (1998). The effect of B-mode ultrasonic image standardization of the echodensity of symptomatic and asymptomatic carotid bifurcation plaque. *International Angiology*, 17(3), 179–186. PMID:9821032
- Frost, V. S., Stiles, J. A., Shanmungan, K. S., & Holtzman, J. C. (1982). A model for radar images and its application for adaptive digital filtering of multiplicative noise. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 4(2), 157–165. doi:10.1109/TPAMI.1982.4767223 PMID:21869022
- Gastouniotti, A., Golemati, S., Stoitsis, J., & Nikita, K. S. (2011). Comparison of Kalman-filter-based approaches for block matching in arterial wall motion analysis from B-mode ultrasound. *Measurement Science & Technology*, 22, 1–9. doi:10.1088/0957-0233/22/11/114008
- Haralick, R. M., Shanmugam, K., & Dinstein, I. (1973). Texture features for image classification. *IEEE Trans. Systems, Man, & Cybernetics, SMC*, 3, 610–621. doi:10.1109/TSMC.1973.4309314
- Heiberg, E., Sjøgren, J., Ugander, M., Carlsson, M., Engblom, H., & Arheden, K. (2010). Design and validation of a segment-free available software for cardiovascular image analysis. *BMC Medical Imaging*, 10(1), 1–13. doi:10.1186/1471-2342-10-1 PMID:20064248
- Kuwahara, M., Hachimura, K., Eiho, S., & Kinoshita, M. (1976). Digital processing of biomedical images. In M. Onoe (Ed.), *Preston, K., & M* (pp. 187–203). Plenum. Pub. Corp.
- Kyriakou, E., Pattichis, M. S., Christodoulou, C., Pattichis, C. S., Kakkos, S., Griffin, M., & Nicolaides, A. N. (2005). Ultrasound imaging in the analysis of carotid plaque morphology for the assessment of stroke. In J. S. Suri, C. Yuan, D. L. Wilson, & S. Laxminarayan (Eds.), *Plaque imaging: Pixel to molecular level* (pp. 241–275). IOS Press.
- Kyriakou, E. C., Pattichis, C. S., Karaolis, M. A., Loizou, C. P., Pattichis, M. S., Kakkos, S., & Nicolaides, A. N. (2007). An integrated system for assessing stroke risk. *IEEE Engineering in Medicine and Biology Magazine*, 26(5), 43–50. doi:10.1109/EMB.2007.901794 PMID:17941322
- Lee, J. S. (1980). Digital image enhancement and noise filtering by using local statistics. *IEEE Transactions on Pattern Analysis and Machine Intelligence, PAMI-2*(2), 165–168. doi:10.1109/TPAMI.1980.4766994 PMID:21868887

- Loizou, C. P. (2012). *Ultrasound image analysis of the carotid artery, applications in ultrasound filtering, segmentation and texture analysis*. Germany: Saarbruecken, Lambert Academic Publishing GmbH & Co. KG.
- Loizou, C. P., Kasparis, T., Christodoulides, P., Theofanous, C., Pantziaris, M., Kyriakou, E., & Pattichis, C. S. (2012, November 11-13). Despeckle filtering in ultrasound video of the common carotid artery. In *Proceedings of the 12th Int. Conf. Bioinf. & Bioeng. Proc. (BIBE)*, Larnaca, Cyprus.
- Loizou, C. P., Kasparis, T., Papakyriakou, P., Christodoulou, L., Pantziaris, M., & Pattichis, C. S. (2012, November 11-13). Video segmentation of the common carotid artery intima-media complex. In *Proceedings of the 12th Int. Conf. Bioinf. & Bioeng. Proc. (BIBE)*, Larnaca, Cyprus.
- Loizou, C. P., Pantziaris, M., Pattichis, C. S., & Kyriakou, E. (2010, March 3-5). M-mode state-based identification in ultrasound videos of the common carotid artery. In *Proc. Of the 4th Int. Symp. on Commun. Contr. and Sign. Proces. (ISCCSP)*, Limassol, Cyprus.
- Loizou, C. P., & Pattichis, C. S. (2008). *Despeckle filtering algorithms and software for ultrasound imaging. Synthesis Lectures on Algorithms and Software for Engineering*. San Rafael, CA: Morgan & Claypool Publishers.
- Loizou, C. P., Pattichis, C. S., Christodoulou, C. I., Istepanian, R. S. H., Pantziaris, M., & Nicolaiades, A. N. (2005). Comparative evaluation of despeckle filtering in ultrasound imaging of the carotid artery. *IEEE Trans. Ultras. Ferroel. Freq. Contr.*, 52(2), 1653–1669. doi:10.1109/TUFFC.2005.1561621 PMID:16382618
- Loizou, C. P., Pattichis, C. S., Nicolaides, A. N., & Pantziaris, M. (2009). Manual and automated media and intima thickness measurements of the common carotid artery. *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, 56(5), 983–994. doi:10.1109/TUFFC.2009.1130 PMID:19473916
- Loizou, C. P., Pattichis, C. S., Pantziaris, M., & Nicolaides, A. N. (2007). An integrated system for the segmentation of atherosclerotic carotid plaque. *IEEE Transactions on Information Technology in Biomedicine*, 11(6), 661–667. doi:10.1109/TITB.2006.890019 PMID:18046941
- Loizou, C. P., Pattichis, C. S., Pantziaris, M., Tyllis, T., & Nicolaides, A. (2007). Snakes based segmentation of the common carotid artery intima media. *Medical & Biological Engineering & Computing*, 45(1), 35–49. doi:10.1007/s11517-006-0140-3 PMID:17203319
- Loizou, C. P., Pattichis, C. S., Pantziaris, M., Tyllis, T., & Nicolaides, A. N. (2006). Quality evaluation of ultrasound imaging in the carotid artery based on normalization and speckle reduction filtering. *Medical & Biological Engineering & Computing*, 44(5), 414–426. doi:10.1007/s11517-006-0045-1 PMID:16937183
- Loizou, C. P., Pattichis, C. S., Petroudi, S., Pantziaris, M., Kasparis, T., & Nicolaides, A. N. (2012, August 28-September 1). Segmentation of atherosclerotic carotid plaque in ultrasound video. In *Proceedings of the 34th Ann. Int. Conf. IEEE Eng. Med. Biol., EMBC*, San Diego, CA.
- Maggioni, M., Boracchi, G., Foi, A., & Engiazarian, K. (2012). Video denoising, deblocking and enhancement through separable 4-D nonlocal spatiotemporal transforms. *IEEE Transactions on Image Processing*, 21(9), 3952–3966. doi:10.1109/TIP.2012.2199324 PMID:22614644
- Metrix mux objective video quality assessment software*. Retrieved from http://foulard.ece.cornell.edu/gaubatz/metrix_mux/
- Molinari, F., Meiburger, K. M., & Suri, J. (2011). Automated high-performance cIMT measurement techniques using patented AtheroEdge™: A screening and home monitoring system. In *Proceedings of the 33rd An. Int. Conf. IEEE EMBS*, Boston, MA (pp. 6651-6654).
- Nicolaides, A. N., Sabetai, M., Kakkos, S. K., Dhanjil, S., Tegos, T., & Stevens, J. M. (2003). The asymptomatic carotid stenosis and risk of stroke study. *International Angiology*, 22(3), 263–272. PMID:14612853
- Nieminen, A., Heinonen, P., & Neuvo, Y. (1987). A new class of detail-preserving filters for image processing. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 9, 74–90. doi:10.1109/TPAMI.1987.4767873 PMID:21869378
- Rusanovskyy, D., Dabov, K., & Egiazarian, K. (2006). Moving-window varying size 3D transform-based video denoising. In *Proc. Int. Workshop on Video Proc. & Quality Metrics* (pp. 1-4).
- Stott, W., Ryan, A., Jacobs, I. J., Menon, U., Bessant, C., & Jones, C. (2008). OSPACS: Ultrasound image management system. *Biologie Medicale*, 3(11), 1–5.

- Strzelecki, M., Szczypinski, P., Materka, A., & Klepaczko, A. (2013). A software tool for automatic classification and segmentation of 2D/3D medical images. *Nucl. Instr. & Method. In Phys. Research.*, 702, 137-140.
- Szczypiński, P. M., Strzelecki, M., Materka, A., & Klepaczko, A. (2008). MaZda-A software package for image texture analysis. *Computer Methods and Programs in Biomedicine*, 94(1), 66–76. doi:10.1016/j.cmpb.2008.08.005 PMID:18922598
- Tian, J., Xue, J., Dai, Y., Chien, J., & Zheng, J. (2008). A novel software platform for medical image processing and analyzing. *IEEE Transactions on Information Technology in Biomedicine*, 12(6), 800–812. doi:10.1109/TITB.2008.926395 PMID:19000961
- Varghese, G., & Wang, Z. (2008). Video denoising using a spatiotemporal statistical model of wavelet coefficients. In *Proceedings of the IEEE Int. Conf. on Acoustic, Speech & Sign. Proc.* (pp. 1257-1260).
- Wang, Z., Bovik, A., Sheikh, H., & Simoncelli, E. (2004). Image quality assessment: From error measurement to structural similarity. *IEEE Transactions on Image Processing*, 13(4), 600–612. doi:10.1109/TIP.2003.819861 PMID:15376593
- Weszka, J. S., Dyer, C. R., & Rosenfield, A. (1976). A comparative study of texture measures for terrain classification. *IEEE Trans. Syst., Man, Cybern.*, SMC(6), 269–285.
- Wu, C. M., Chen, Y. C., & Hsieh, K.-S. (1992). Texture features for classification of ultrasonic images. *IEEE Transactions on Medical Imaging*, 11, 141–152. doi:10.1109/42.141636 PMID:18218367
- Yongjian, Y., & Acton, S. T. (2002). Speckle reducing anisotropic diffusion. *IEEE Transactions on Image Processing*, 11(11), 1260–1270. doi:10.1109/TIP.2002.804276 PMID:18249696
- Zlokolica, V., Philips, W., & Ville, van de. (2002). Robust non-linear filtering for video processing. *IEEE Proc. Vision, Imag. & Sign. Proces.*, 2(2), 571-574.
- Zlokolica, V., Pizurica, A., & Philips, W. (2008). Recursive temporal denoising and motion estimation of video. *Int. Conf. on Image Processing*, 3(3), 1465-1468.

Christos P Loizou received the B.Sc. degree in electrical engineering and the Dipl.-Ing. (M.Sc.) degree in computer science and telecommunications from the University of Kaiserslautern, Kaiserslautern, Germany, in 1986 and 1990, respectively, and the Ph.D. degree in ultrasound image analysis of the carotid artery from the Department of Computer Science, Kingston University, London, U.K., in 2005. From 1996 to 2000, he was a Lecturer in the Department of Computer Science, Higher Technical Institute, Nicosia, Cyprus. Since 2000, he has been an Assistant Professor in the Department of Computer Science, Intercollege, Limassol, Cyprus. He was a Supervisor of a number of Ph.D. and B.Sc. students in computer image analysis and telemedicine. He is also an Associate Researcher at the Institute of Neurology and Genetics, Nicosia, Cyprus and at the Cyprus University of Technology, Limassol, Cyprus. He is the author or coauthor of the book Despeckle Filtering Algorithms and Software for Ultrasound Imaging, one more book, 12 chapters in books, 23 referred journals, and 52 conference papers in image and video analysis. His research interests include medical imaging and processing, motion and video analysis, signal and image processing, pattern recognition, biosignal analysis, in ultrasound, magnetic resonance, and optical coherence tomography imaging and computer applications in medicine. Dr. Loizou is a Senior Member of the Institution of Electrical Engineers, serves as a reviewer, in many IEEE Transaction journals and as a chair and co-chair, in many IEEE conferences.

Charoula Theofanous is a candidate for the MSc program on Electrical Engineering and Information Technologies at the Cyprus University of Technology, expected to graduate with an MSc Degree. She received her BSc degree from the same university in electrical engineering. She has performed research on image and video despeckling

Marios Pantziaris received the M.D. degree in neurology from the Aristotelion University, Thessaloniki, Greece, in 1995. Currently, he is working with Cyprus Institute of Neurology and Genetics, Nicosia, Cyprus, as a Senior Neurologist in the Neurological Department and is the Head of the Neurovascular Department. He has been trained in Carotid Duplex–Doppler ultrasonography at St. Mary’s Hospital, London, in 1995. In 1999, he was a visiting doctor in acute stroke treatment at Massachusetts General Hospital, Harvard University, Boston. He has considerable experience in carotids–transcranial ultrasound, has participated in many research projects, and has several publications to his name. He is also the Head of the Multiple Sclerosis (MS) Clinic where he is running research projects towards the aetiology and therapy of MS.

Takis Kasparis is a Professor and chair at the Department of Electrical Engineering and Information Technologies (EEIT) of the Cyprus University of Technology. He received the diploma in Electrical Engineering from the National Technical University of Athens, Greece, the MS Degree from City College of New York and the PhD degree from the City University of New York, both in Electrical Engineering. He has taught at City College and New York Institute of Technology before joining the University of Central Florida in Orlando (UCF), where he held the positions of Assistant, Associate Professor and Professor. While at UCF he has received several awards in recognition of excellence in teaching, including the prestigious Joseph M. Biedenbach Outstanding Engineering Educator Award from the Institute of Electrical and Electronic Engineers (IEEE). His research interests include Digital Signal Processing with applications to Remote Sensing, Biomedical, Communications, Audio Processing, Power Electronics as well as Digital Image Processing, Computer Vision and Electronic Circuits.

Paul Christodoulides is an Assistant Lecturer in the Faculty of Engineering and Technology of the Cyprus University of Technology. He studied Mathematics at the University of Bath, U.K. He continued his studies to obtain a M.S. degree in Applied Mathematics at Worcester Polytechnic Institute, USA and a Ph.D. in Applied Mathematics at the Université de Nice–Sophia Antipolis, France. He then worked as a Research Fellow at Monash University, Australia and as a Lecturer/Assistant Professor at Frederick Institute of Technology and the Higher Technical Institute, Cyprus, prior to joining CUT. His research interests lie mainly in Fluid Dynamics, and in particular, in the study of nonlinear and dispersive waves, in the study of fluid impact on structures, in microfluidics, as well as in problems of heat transfer and in applications of dynamical systems.

Andrew N. Nicolaides Professor Andrew Nicolaides is a graduate of the Pancyprrian Gymnasium (Nicosia) and Guy's Hospital Medical School (London University 1962), and a fellow of the Royal College of Surgeons England, and the Royal College of Surgeons Edinburgh (1967). His higher surgical training was in Oxford University, Kings College Hospital Medical School, London, UK and St Mary's Hospital Medical School, London, UK. He was awarded the Jacksonian prize by the Royal College of Surgeons England in 1972 for his work on the prevention of venous thromboembolism and obtained the degree of M.S. (Master of Surgery) in 1976. He was the Professor of Vascular Surgery at the Imperial College School of Medicine (St Mary's Hospital) and Consultant Vascular Surgeon at St Mary's Hospital from 1983–2000 and Medical Director of the Cyprus Institute of Neurology and Genetics, Nicosia, Cyprus, from 2001-2004. His research group is known internationally in several areas which include noninvasive vascular screening and diagnostic investigation, early detection and prevention of cardiovascular and venous disease. His research is now directed towards the genetic risk factors for cardiovascular disease, identification of individuals at risk and the development of effective methods of prevention, especially stroke. He is Past-President of the International Union of Angiology and Past-President of the Section of Measurement in Medicine of the Royal Society of Medicine. He has received many awards and honorary memberships from many scientific societies. He is Editor-in-Chief of International Angiology and is on the Editorial Board of many vascular journals. He is Professor Emeritus at Imperial College, London, UK and an examiner for MS and PhD degrees for London University. He is a "Special Scientist" at the University of Cyprus, Nicosia, Cyprus and Medical Director of the Vascular Screening and Diagnostic Centre in London. He has trained over 200 vascular surgeons who are practicing all over the world; ten of them are holding prestigious Chairs as professors in vascular surgery. He was made Archon Megas Referendarios, an Honour bestowed by the Patriarch of Constantinople in 1994. He is co-author of over 400 original papers and editor of 14 books.

Constantinos Pattichis (S'88–M'88–SM'99) is currently Professor with the Department of Computer Science of the University of Cyprus. His research interests include ehealth and mhealth, medical imaging, biosignal analysis, life sciences informatics, and intelligent systems. He has been involved in numerous projects in these areas funded by EU, the National Research Foundation of Cyprus, the INTERREG and other bodies, like the GRANATUM, LINKED2SAFETY, MEDUCATOR, LONG LASTING MEMORIES, INTRAMEDNET, INTERMED, FUTURE HEALTH, AMBULANCE, EMGENCY, ACSRS, TELEGYN, HEALTHNET, IASIS, IPPOKRATIS, and other with a total funding managed more than 6 million Euros. He has published 74 refereed journal and 186 conference papers, and 27 chapters in books in these areas. He is Co-Editor of the books M-Health: Emerging Mobile Health Systems, and of the Ultrasound and Carotid Bifurcation Atherosclerosis, published by Springer in 2006, and 2012 respectively. He is co-author of the monograph Despeckle Filtering Algorithms and Software for Ultrasound Imaging, published by Morgan & Claypool Publishers in 2008. He was Guest Co-Editor of the Special Issues on Atherosclerotic Cardiovascular Health Informatics, Emerging Health Telematics Applications in Europe, Emerging Technologies in Biomedicine, Computational Intelligence in Medical Systems, and Citizen Centered e-Health Systems in a Global Health-care Environment, and, of the IEEE Trans. on Information Technology in Biomedicine. He was General Co-Chairman of the IEEE 12th International Conference on BioInformatics and BioEngineering (BIBE2012), IEEE Information Technology in Biomedicine (ITAB09), Medical and Biological Engineering and Computing Conference (MEDICON'98), IEEE Region 8 Mediterranean Conference on Information Technology and Electrotechnology (MELECON'2000), and Program Co-Chair of ITAB06, and the 4th International Symposium on Communications, Control and Signal Processing (ISCCSP 2010). Moreover, he serves as Distinguished Lecturer of the IEEE EMBS, an Associate Editor of the IEEE Journal of Biomedical and Health Informatics, and on the Editorial Board of the Journal of Biomedical Signal Processing and Control. He served as an Associate Editor of the IEEE Trans. on Information Technology in Biomedicine (2000-2012), and of the IEEE Trans. on Neural Networks (2005-2007). He served as Chairperson of the Cyprus Association of Medical Physics and Biomedical Engineering (96-98), and the IEEE Cyprus Section (98-00). He is a Fellow of IET, and Senior Member of IEEE.