PROCEEDINGS OF ELMAR-2017

59th International Symposium ELMAR-2017

18-20 September 2017, Zadar, Croatia

EDITED BY

Mario Muštra
Dijana Vitas
Branka Zovko-Cihlar

University of Zagreb
Faculty of Electrical Engineering and Computing
Department of Wireless Communications
Unska 3 / XII
10000 Zagreb
CROATIA

Elmar

59th International Symposium ELMAR-2017 is organised by:

Croatian Society Electronics in Marine - ELMAR, Zadar

University of Zagreb Faculty of Electrical Engineering and Computing, Department of Wireless Communications

ELMAR-2017 symposium General Sponsor

Ministry of Maritime Affairs, Transport and Infrastructure of the Republic of Croatia

ELMAR-2017 symposium Sponsors

Ministry of Science and Education of the Republic of Croatia

Tankerska plovidba d.d.

Town of Zadar

OiV - Transmitters and Communications Ltd.

HRT - Croatian Radiotelevision

ELMAR-2017 symposium takes place under the co-sponsorship of:

IEEE Region 8
IEEE Croatia Section
IEEE Croatia Section Chapter of the Signal Processing Society
IEEE Croatia Section Chapter of the Antennas and Propagation Society
IEEE Croatia Section Chapter of the Microwave Theory and Techniques Society
Croatian Academy of Sciences and Arts
Croatian Academy of Engineering - HATZ
University of Zagreb
University of Zagreb Faculty of Electrical Engineering and Computing
University of Zadar

ELMAR-2017 symposium is supported by:

ZADAR TOURIST BOARD
COUNTY OF ZADAR
FALKENSTEINER BORIK ZADAR CROATIA

ELMAR-2017 SYMPOSIUM COMMITTEES

General Chair

Branka Zovko-Cihlar, University of Zagreb, Croatia

Program Chair

Mislav Grgić, University of Zagreb, Croatia

ELMAR-2017 SYMPOSIUM
INTERNATIONAL PROGRAM COMMITTEE

Juraj Bartolić, Croatia
Narcis Behlilović, Bosnia and Herzegovina
David Broughton, United Kingdom
Aura Conci, Brasil
Marek Domanski, Poland
Janusz Filipiak, Poland
Borko Furht, USA
Mohammed Ghanbari, United Kingdom
Mislav Grgić, Croatia
Sonja Grgić, Croatia
Ho Yo-Sung, Korea
Bernhard Hofmann-Wellenhof, Austria
Ebroul Izquierdo, United Kingdom
Aggelos K. Katsaggelos, USA
Ana Katalinić Mucalo, Croatia
Ismail Khalil, Austria
Tomislav Kos, Croatia
Murat Kunt, Switzerland
Igor Kuzle, Croatia
Panos Liatsis, United Kingdom
Rastislav Lukac, Canada
Lidija Mandić, Croatia
Branka Medved Rogina, Croatia
Borivoj Modlic, Croatia
Marta Mrak, United Kingdom

Mario Muštra, Croatia
Zdeněk Němec, Slovak Republic
Miloš Oravec, Slovak Republic
Jarmila Pavlovičova, Slovak Republic
Fernando Pereira, Portugal
Jan Pidanič, Slovak Republic
Pavol Podhradský, Slovak Republic
Kamisetty R. Rao, USA
Darko Ratkaj, Switzerland
Fabiana Rodrigues Leta, Brasil
Gregor Rozinaj, Slovak Republic
Markus Rupp, Austria
Gerald Schaefer, United Kingdom
Mubarak Shah, USA
Shiguang Shan, China
Thomas Sikora, Germany
Karolj Skala, Croatia
Ryszard Stasinski, Poland
Luis Torres, Spain
Frantisek Vejrazka, Czech Republic
Dijana Vitas, Croatia
Stamatis Voliotis, Greece
Krzysztof Wajda, Poland
Nick Ward, United Kingdom
Branka Zovko-Cihlar, Croatia

ELMAR-2017 SYMPOSIUM
INTERNATIONAL REVIEW COMMITTEE

Winton Afrić, Croatia
Codruta Ancuti, Italy
Goran Bakalar, Croatia
Sanja Bauk, Montenegro
Alen Begović, Bosnia and Herzegovina
Narcis Behlilović, Bosnia and Herzegovina
Marko Bosiljevac, Croatia
Jelena Božek, Croatia
Miloš Brajović, Montenegro
Jasmina Čaušević, Croatia
Emil Dumić, Croatia
Juraj Fosin, Croatia
Irena Galić, Croatia
Branimir Ivšić, Croatia
Juraj Kačur, Slovakia
Ana Katalinić-Mucalo, Croatia
Jan Kufa, Czech Republic
Hrvoje Leventić, Croatia
Časlav Livada, Croatia
Sadko Mandžuka, Croatia
Marta Mrak, United Kingdom

Mario Muštra, Croatia
Zdeněk Němec, Slovakia
Miloš Oravec, Slovakia
Jarmila Pavlovičová, Slovakia
Juraj Petrović, Croatia
Jan Pidanič, Slovakia
Pavol Podhradský, Slovakia
Michal Reznicek, Czech Republic
Renata Rybárová, Slovakia
Gregor Rozinaj, Slovakia
Markus Rupp, Austria
Tomás Shejbal, Czech Republic
Mladen Sokele, Croatia
Isidora Stanković, Montenegro
Zvonimir Šipuš, Croatia
Namir Škaljo, Bosnia and Herzegovina
Dijana Vitas, Croatia
Mario Vranješ, Croatia
Josip Vuković, Croatia
Radovan Zentner, Croatia
Branka Zovko-Cihlar, Croatia

ELMAR-2017 SYMPOSIUM
ORGANISING COMMITTEE

Mislav Grgić, Croatia
Mario Muštra, Croatia
Jelena Božek, Croatia

Dijana Vitas, Croatia
Josip Vuković, Croatia

ELMAR-2017 PROGRAM

Monday, September 18	Tuesday, September 19	Wednesday, September 20
8:30 - 16:30 **Registration**	9:00 - 11:30 **Registration**	9:00 - 11:30 **Registration**
9:00 - 9:30 **OPENING SESSION:** **Welcome Speeches**	9:00 - 11:15 **Special Session 3 and** **Session 3**	9:00 - 10:30 **Sessions 6 & 7**
9:30 - 10:00 **Welcome Cocktail**	11:15 - 11:30 **Session Break**	10:30 - 11:00 **Session break**
10:15 - 12:30 **PLENARY SESSION:** **Keynote Talks**	11:30 - 12:30 **Session 4 & 5**	11:00 - 12:30 **Sessions 8 & 9**
12:30 - 14:00 **Lunch Break**	13:00 - 20:00 **Excursion by Ship*** *Lunch on board*	12:30 - 14:00 **Lunch Break**
14:15 - 17:00 **Special Sessions 1 & 2** **and Sessions 1 & 2**		14:00 - 16:30 **Sessions 10 & 11**
17:15 - 20:00 **Guided Zadar Sightseeing**		15:45 **Closing Session**
21:00 **ELMAR-2017 Symposium** **Gala Dinner**	20:30 **Dinner**	

ELMAR-2017 PROGRAM

Monday, 18 September 2017

8:30 - 16:30 **Registration**	
HALL A	
9:00 - 09:30 **OPENING SESSION: Welcome Speeches**	
09:30 - 10:00 **WELCOME COCKTAIL** Bar at Hotel "Donat"	
HALL A	
10:15 - 12:30 **PLENARY SESSION: Keynote Talks**	
12:30 - 14:00 **Lunch Break**	

HALL A	HALL B
14:15 - 15:45 **SPECIAL SESSION 1:** **Intelligent Transport Systems**	14:15 - 15:45 **SESSION 1:** **Multimedia Communications**
16:00 - 17:00 **SPECIAL SESSION 2:** **Computer Vision for New Emerging Applications**	16:00 - 17:00 **SESSION 2:** **Wireless Communications 1**

17:15 - 20:00 **GUIDED ZADAR SIGHTSEEING** <u>Meeting Point</u>: Hotel "Funimation", Main Entrance, 17:15
21:00 **ELMAR-2017 SYMPOSIUM GALA DINNER** <u>Meeting Point</u>: Hotel "Funimation", 21:00

ELMAR-2017 PROGRAM

Tuesday, 19 September 2017

9:00 - 11:30	**Registration**	
HALL A		**HALL B**
9:00 - 11:15 **SPECIAL SESSION 3:** **Radar Systems**		9:00 - 11:15 **SESSION 3:** **Speech and Audio Processing**
11:15 - 11:30	**Session Break**	
11:30 - 12:30 **SESSION 4:** **Wireless Communications 2**		11:30 - 12:30 **SESSION 5:** **Image Processing 1**
13:00 - 20:00 **EXCURSION BY SHIP** Meeting Point: Hotel "Funimation", Main Entrance, 12:45 *Lunch will be served on board the ship*		
20:30 **DINNER**		

ELMAR-2017 PROGRAM

Wednesday, 20 September 2017

9:00 - 11:30 **Registration**	
HALL A	**HALL B**
9:00 - 10:30 **SESSION 6:** **Telecommunications**	9:00 - 10:30 **SESSION 7:** **Power Electronics and Automation**
10:30 - 11:00 **Session Break**	
11:00 - 12:30 **SESSION 8:** **Image Processing 2**	11:00 - 12:30 **SESSION 9:** **Smart Systems**
12:30 - 14:00 **Lunch Break**	
14:00 - 15:30 **SESSION 10:** **Navigation Systems**	14:00 - 15:30 **SESSION 11:** **Sea Ecology**
15:45 **CLOSING SESSION**	

Monday, 18 September 2017

8:30 - 16:30	**Registration**

9:00 - 9:30   **OPENING SESSION: Welcome Speeches**

Session Chairs: **Branka Zovko-Cihlar, Mario Muštra**

9:30 - 10:00   **WELCOME COCKTAIL**
Bar at Hotel "Donat"

10:15 - 12:30   **PLENARY SESSION: Keynote Talks**

Session Chair: **Branka Zovko-Cihlar**

Prof. Panos Liatsis, Department of Electrical Engineering, The Petroleum Institute UAE
Patient-Specific Blood Flow Modelling in the Assessment of Functional Stenosis Severity

Tigran Vržina, Transmitters & Communications Ltd., CROATIA
Impact of Transition from Analog (FM) to Digital (DAB+) Sound Broadcasting on Environmental Preservation

Prof. Peter Planinšič, University of Maribor, Faculty of Electrical Engineering and Computer Science, SLOVENIA
SAR-images Analysis and Applications

12:30 - 14:00   **Lunch Break**

14:15 - 15:45   **SPECIAL SESSION 1: Intelligent Transport Systems**

Session Chairs: **Mario Muštra, Sadko Mandžuka**

Borna Kapusta, Mladen Miletić, Edouard Ivanjko, Miroslav Vujić; CROATIA
Preemptive Traffic Light Control based on Vehicle Tracking and Queue Lengths

Daniel Pavleski, Daniela Koltovska-Nechoska, Edouard Ivanjko; MACEDONIA/ CROATIA
Evaluation of Adaptive Traffic Control System UTOPIA using Microscopic Simulation

Krešimir Vidović, Sadko Mandžuka, Davor Brčić; CROATIA
Estimation of Urban Mobility using Public Mobile Network

Emir Žunić, Almir Djedović, Dženana Đonko; BOSNIA AND HERZEGOVINA
Cluster-based analysis and time-series prediction model for reducing the number of traffic accidents

Tomislav Erdelić, Tonči Carić, Martina Ravlić; CROATIA
Predicting Waiting Times at Intersections

Pero Škorput, Hrvoje Vojvodić, Sadko Mandžuka; CROATIA
Cyber Security in Cooperative Intelligent Transportation Systems

16:00 - 17:00   **SPECIAL SESSION 2: Computer Vision for New Emerging Applications**

Session Chairs: **Irena Galić, Časlav Livada**

Hrvoje Leventić, Danilo Babin, Lazar Velicki, Irena Galić, Vladimir Zlokolica; CROATIA/BELGIUM/SERBIA
Semi-automatic Left Atrial Appendage Segmentation from 3D CCTA Images

Krešimir Romić, Irena Galić, Tomislav Galba; CROATIA
Technology Assisting the Blind - Routing on the Staircases Using Wide-angle Camera

Časlav Livada, Miro Proleta, Krešimir Romić, Hrvoje Leventić; CROATIA
Beyond the Touch: a Web Camera based Virtual Keyboard

Monika Andonová, Jarmila Pavlovičová, Slavomír Kajan, Miloš Oravec, Veronika Kurilová; SLOVAKIA
Diabetic Retinopathy Screening Based on CNN

17:15 - 20:00   **GUIDED ZADAR SIGHTSEEING**
Meeting Point: Hotel "Funimation", Main Entrance, 17:15

21:00   **ELMAR-2017 SYMPOSIUM GALA DINNER**
Meeting Point: Hotel "Funimation", bar at the pool, 21:00

14:15 - 15:45   **SESSION 1: Multimedia Communications**

Session Chairs: **Sonja Grgić, Jarmila Pavlovičová**

Petra Dražić; CROATIA
The Propagation of Ka-Band Signals Through the Atmosphere

Srećko Kunić, Zoran Šego, Branka Zovko Cihlar; CROATIA
Analysis of Audio and Video Synchronization in TV Digital Broadcast Devices

Iiams Bajčinovci, Mario Vranješ, Danijel Babić, Branimir Kovačević; CROATIA/SERBIA
Subjective and Objective Quality Assessment of MPEG-2, H.264 and H.265 Videos

16:00 - 17:00   **SESSION 2: Wireless Communications 1**

Session Chair: **Marko Bosiljevac**

Martin Matis, Dominik Nezník, Dávid Hrabčák, Ľubomír Doboš, Ján Papaj; SLOVAKIA
Intelligent Channel Assigning in CR-MANET based on Spectrum Sensing

Dávid Hrabčák, Martin Matis, Dominik Nezník, Ľubomír Doboš, Ján Papaj; SLOVAKIA
Proposal of Simple Metrics for Evaluation of Social Ties in Mobility Models for MANET Networks

Botond Sandor Kirei, Calin Farcas, Robert Groza, Marina Dana Topa; ROMANIA
An All-Digital Frequency Locked Loop and its Linearized s-domain Model

17:15 - 20:00   **GUIDED ZADAR SIGHTSEEING**
                          Meeting Point: Hotel "Funimation", Main Entrance, 17:15

21:00   **ELMAR-2017 SYMPOSIUM GALA DINNER**
                          Meeting Point: Hotel "Funimation", bar at the pool, 21:00

Tuesday, 19 September 2017

9:00 - 12:30   **Registration**

9:00 - 11:15   **SPECIAL SESSION 3: Radar Systems**

Session Chairs: **Winton Afrić, Jan Pidanič**

Tomáš Hnilička, Tomáš Zálabský, Vitezslav Krčmar; CZECH REPUBLIC
Design of Power Hybrid Structures for a N-port Power Combiner

Mirko Jukl, Siniša Lacković, Fran Pregernik; CROATIA
Digital Simulator of Radar Targets and Clutter for Surveillance Radar System

Michal Rezniček; CZECH REPUBLIC
Doppler CW Radar Signal Processing, Implementation and Analysis

Luboš Rejfek, Ondrej Fišer, David Matousek, Ladislav Beran, Pavel Chmelar; CZECH REPUBLIC
Correction of Received Power for Doppler Measurements by FMICW Radars

Luboš Rejfek, Ondrej Fišer, David Matousek, Ladislav Beran, Pavel Chmelar; CZECH REPUBLIC
Sensitivity Analysis of PCDR35 Radar

Tomáš Zálabský, Pavel Bezousek; CZECH REPUBLIC
Phase Interferometry for Approach Radars

Tomáš Zálabský, Pavel Bezousek, Tomáš Hnilička; CZECH REPUBLIC
An Antenna Array Synthesis for Large Vertical Aperture Antenna for Secondary Surveillance Radar

11:15 - 11:30   **Session Break**

11:30 - 12:30   **SESSION 4: Wireless Communications 2**

Session Chairs: **Sonja Zentner Pilinsky**

Jan Pidanič, Vojtech Valenta, Karel Juryca; CZECH REPUBLIC
The Radio Coverage Monitoring by Low-Cost System based on SDR

Srushti Shetty, Siniša Lacković, Sonja Zentner Pilinsky; INDIA/CROATIA
4G Coverage Analysis of Main Croatian Roads

Yury V. Yukhanov, Tatiana Y. Privalova; RUSSIA
Electromagnetic Scattering of Plane H-Polarized Wave by an Antenna Array of Loaded Planar Waveguides

Andrej Galoić, Branimir Ivšić, Davor Bonefačić; CROATIA
Rectifier for Energy Harvesting Application

Dominik Barbarić, Marko Bosiljevac, Zvonimir Šipuš; CROATIA
Realization of Distributed Optical-Fiber Temperature Sensor

Sanja Bauk, Jose Angel Leon Calvo, Rudolf Mathar, Anke Schmeink; MONTENEGRO/GERMANY
V2P/I Communication for Increasing Occupational Safety at a Seaport

13:00 - 20:00   **EXCURSION BY SHIP**
<u>Meeting Point</u>: Hotel "Funimation", Main Entrance, 12:45
Lunch will be served on ship

20:30   **DINNER**

9:00 - 11:15   **SESSION 3: Speech and Audio Processing**

Session Chairs: Gregor Rozinaj, Juraj Kacur

Rustam Latypov, Ruslan Nigmatullin, Evgeni Stolov; RUSSIA
Instantaneous Frequency and Detection of Dynamics in Speech

Juraj Kacur; SLOVAKIA
Gradual Enhancement of GMM for Speaker Identification

Tomáš Koctúr, Stanislav Ondáš, Jozef Juhár; SLOVAKIA
Speech Corpus Generation Based on N-gram Confidence Measure Classification

Marianna Rosinová, Martin Lojka, Ján Staš, Jozef Juhár; SLOVAKIA
Voice Command Recognition Using EEG Signals

Jan Staš, Daniel Hladek, Jozef Juhar; SLOVAKIA
Semantic Indexing and Document Retrieval for Personalized Language Modeling

Isidora Stanković, Cornel Ioana, Miloš Daković; MONTENEGRO/FRANCE
High-Resolution Local Polynomial Fourier Transform in Acoustic Signal Analysis

11:15 - 11:30   **Session Break**

11:30 - 12:30   **SESSION 5: Image Processing 1**

Session Chairs: Sonja Grgić, Jelena Božek

Matteo Brisinello, Ratko Grbić, Matija Pul, Tihomir Anđelić; CROATIA/SERBIA
Improving Optical Character Recognition Performance for Low Quality Images

Dzenan Lapandić, Jasmin Velagić, Haris Balta; BOSNIA AND HERZEGOVINA/ BELGIUM
Framework for Automated Reconstruction of 3D Model from Multiple 2D Aerial Images

Emina Hadrović, Dinko Osmanković, Jasmin Velagić; BOSNIA AND HERZEGOVINA
Aerial Image Mosaicing Approach Based on Feature Matching

Jozef Goga, Slavomír Kajan; SLOVAKIA
Hand Gesture Recognition Using 3D Sensors

13:00 - 20:00   **EXCURSION BY SHIP**
                    Meeting Point: Hotel "Funimation", Main Entrance, 12:45
                    Lunch will be served on ship

20:30   **DINNER**

Wednesday, 20 September 2017

9:00 - 15:30   **Registration**

9:00 - 10:30   **SESSION 6: Telecommunications**

Session Chair: Pavol Podhradský

Viktor Stoynov, Zlatka Valkova-Jarvis; BULGARIA
Aggregated Assessment of Downlink Resource Scheduling Techniques in Indoor Environments via a Comparative Factor

Alen Begović, Namir Škaljo, Narcis Behlilović; BOSNIA AND HERZEGOVINA
On Using Various Local Loop Types in Recent VDSL Applications

Yevgeniya Sulema, Gregor Rozinaj; SLOVAKIA
WebRTC-based 3D Videoconferencing System

Juraj Londák, Martin Medvecký, Pavol Podhradský; SLOVAKIA
Virtual SDN and NFV Laboratory - Architecture and Implementation

Andjela Draganić, Irena Orović, Srdjan Stanković; MONTENEGRO
Spread-Spectrum-Modulated Signal Denoising based on Median Ambiguity Function

10:30 - 11:00   **Session Break**

11:00 - 12:30   **SESSION 8: Image Processing 2**

Session Chairs: Lidija Mandić, Mario Muštra

Jozef Gerát, Dominik Sopiak, Miloš Oravec, Jarmila Pavlovičová; SLOVAKIA
Vehicle Speed Detection from Camera Stream using Image Processing Methods

Zuzana Bukovčiková, Dominik Sopiak, Miloš Oravec, Jarmila Pavlovičová; SLOVAKIA
Face Verification Using Convolutional Neural Networks with Siamese Architecture

Moustafa M. Kurdi, Alex K. Dadykin, Imad A. Elzein; BELARUS
Proposed Encryption Method of Quadcopter's Video Transmitted to Underwater Robot by Using Block Packet Cipher

Ante Poljicak, Davor Donevski, Lidija Mandic; CROATIA
Applicability of the GCR Masking in an Image Watermarking Method

12:30 - 14:00   **Lunch Break**

14:00 - 15:30   **SESSION 10: Navigation Systems**

Session Chair: Tomislav Kos

Dimitar Dichev, Hristofor Koev, Dimitar Diakov, Nikolay Panchev, Rosica Miteva, Hristiyana Nikolova; BULGARIA
Automated System for Calibrating Instruments Measuring Parameters of Moving Objects

Jelena Petrović, Mladen Viher; CROATIA
Radar GIS for Site Acceptance Testing

Benjamin Weinert, Mathias Uslar, Axel Hahn; GERMANY
System-of-Systems: How the Maritime Domain can learn from the Smart Grid

15:45   **CLOSING SESSION**

9:00 - 10:30   **SESSION 7: Power Electronics and Automation**

Session Chair: Snježana Rimac-Drlje

Michal Reznicek; CZECH REPUBLIC
Humidity Field Estimation

Andrzej Firlit, Krzysztof Kołek, Krzysztof Piątek; POLAND
Rapid Controller Development for a Dynamic Voltage Restorer

Andrzej Firlit, Krzysztof Kołek, Krzysztof Piątek; POLAND
Heterogeneous Active Power Filter Controller

Nedim Osmić, Jasmin Velagić; BOSNIA AND HERZEGOVINA
Design of a Simple Service Oriented Supervisory Control and Data Acquisition System

10:30 - 11:00   **Session Break**

11:00 - 12:30   **SESSION 9: Smart Systems**

Session Chairs: Dijana Vitas, Juraj Petrović

Tomas Krejci, Michal Mandlik; CZECH REPUBLIC
Implementation of the Communication Chain for Education

Juraj Petrović, Dijana Vitas, Predrag Pale; CROATIA
Experiences with Supervised vs. Unsupervised Online Knowledge Assessments in Formal Education

Petar Taler, Safet Hamedović, Mirta Benšić, Emmanuel Karlo Nyarko; CROATIA/BOSNIA AND HERZEGOVINA
LeArEst - The Software for Border and Area Estimation of Data Measured with Additive Error

Juha Niemi, Juha T. Tanttu; FINLAND
Automatic Bird Identification for Offshore Wind Farms: A Case Study for Deep Learning

Dušan Gleich, Peter Planinšič, Danijel Šipoš, Marko Malajner; SLOVENIA
Deep Convolutional Neural Networks for SAR Patch Categorization

Zoja Vulaj, Miloš Brajović, Anela Draganić, Irena Orović; MONTENEGRO
Detection of Irregular QRS Complexes using Hermite Transform and Support Vector Machine

12:30 - 14:00   **Lunch Break**

14:00 - 15:30   **SESSION 11: Sea Ecology**

Session Chair: **Irena Jurdana**

Goran Bakalar, Myriam Beatriz Baggini, Sebastian Gabriel Bakalar; USA
Protection of Adriatic Sea: Declaring New Nature Parks and New Protected Areas in Central Adriatic Region

Renato Ivče, Sanjin Valčić, Irena Jurdana; CROATIA
Assessment and Prediction Model of Ballast Water Management

Goran Bakalar, Myriam Beatriz Baggini, Sebastian Gabriel Bakalar; USA
Comparisons of Remote FCM Analysis System and Ordinary Analytical Methods for Identification of BW Content

Lorenzo Manzoli, Aldo Franco Dragoni, Andrea Bonci, Paolo Sernani, Massimiliano Pirani, Nicola Falcionelli; ITALY
A Boat-Based Flying Drone to Monitor Coastlines and Render them in Augmented Reality

15:45   **CLOSING SESSION**

Semi-automatic Left Atrial Appendage Segmentation from 3D CCTA Images

Hrvoje Leventić[1], Danilo Babin[2], Lazar Velicki[3], Irena Galić[1] and Vladimir Zlokolica[4]

[1] Faculty of Electrical Engineering, Computer Science and Information Technology, University of Osijek, Croatia

[2] imec-IPI-UGent, Faculty of Engineering and Architecture, Ghent University, Belgium

[3] Institute for Cardiovascular Diseases, Sremska Kamenica, Serbia

[4] Faculty of Technical Sciences, University of Novi Sad, Serbia

hrvoje.leventic@etfos.hr

Abstract—Left Atrial Appendage closure is a relatively novel percutaneous procedure for patients suffering from Atrial Fibrillation (AF). LAA closure has only recently been approved for clinical use and preparations for closure procedures are in most hospitals performed by manual segmentation of Coronary CT Angiography (CCTA) images. We present a novel semi-automatic LAA segmentation method using two seed points (starting and stopping points for segmentation) and manually selected threshold. The method performs the visualization of the segmented LAA and enables a doctor to select 3 points which define a plane in 3D space (the ostium) where the LAA will be occluded.

Performance of the proposed method is evaluated on 8 CCTA datasets manually segmented by a cardiovascular surgeon. Proposed method achieves an average DICE coefficient of 91.7% on evaluation datasets.

Keywords—CCTA; LAA; Left atrial appendage segmentation; Centerline detection

I. Introduction

Atrial Fibrillation (AF) is a cardiac disease associated with a high risk of stroke. Some research suggests that it is responsible for almost 20% of all strokes [1], with the vast majority of cardiac thrombii formed in left atrial appendage [2]. It is estimated that there is over 33 million people worldwide suffering from atrial fibrillation [3] and that number is expected to increase with the increasing age of population, especially in the developed countries. Common method for stroke prevention in patients with AF is anticoagulation therapy which reduces risk of stroke by $\sim 60\%$ [4], but patients who are at higher risk of stroke are also more likely to have contraindications to anticoagulation therapy [5].

Left atrial appendage closure, a relatively novel method of stroke prevention in patients with AF, has recently been shown as non-inferior to anticoagulation therapy [6]. All closure devices are available in several predefined sizes and an appropriately sized device for each patient has to be selected for the procedure. This means that to be able to choose appropriately sized device, doctors require accurate measurements of LAA. Several most important measurements are: diameter and shape of the ostium, LAA morphology, number of lobes, angle of the dominant lobe, etc. It has been shown that LAA measurements derived from CCTA images are superior to TEE derived measurements [7] when it comes to choosing the appropriate size of the device.

To the best of our knowledge, all state of the art methods measure the required LAA dimensions manually, either from 2D slices or from 3D volume by manual (interactive) segmentation. A semi-automatic method for LAA segmentation proposed in [8] requires manual selection of four fiducial points to obtain LAA bounding box, from which a pool of segmentation proposals is generated for each 2D slice. Afterwards, best 2D proposal for each slice is selected using random forest regression and all selected 2D proposals are merged into a 3D model using spatial continuity. The work proposed in [9] focuses on automatic whole heart isolation, where the focus is not on the segmentation of the LAA, but on the removal of the LAA from the segmented whole heart image for visualization of coronary arteries and bypass arteries.

Our proposed method requires a user to select two seed points and determine threshold value for segmentation. The method is robust to threshold value selection and "leaks" which can occur after thresholding when other anatomical structures (e.g. pulmonary vein) are in close proximity to LAA and their intensity values are similar.

This paper is organized in following sections: section 2 deals with the implementation details of the proposed method, section 3 shows the evaluation of the proposed method on our datasets, while section 4 is used for the discussion and gives the concluding remarks about the proposed method.

II. Proposed Method

Our proposed method performs a semi-automatic segmentation of left atrial appendage. Method requires a user to select two seed points: first inside the LAA and second inside left atrium, outside the LAA. After that user selects a threshold value and starts the segmentation. Method performs a multi step spherical region growing algorithm to segment the LAA. After the segmentation a segmented model is visualized. The user selects 3 points on the model which determine the location of LAA ostium, and algorithm cuts the model at plane determined by the 3 points.

The segmentation method consists of four steps: centerline detection, initial spherical segmentation based on detected centerline, additional iterative decreasing radii segmentation and addition of isolated components. Every step of this method is performed in 3D space.
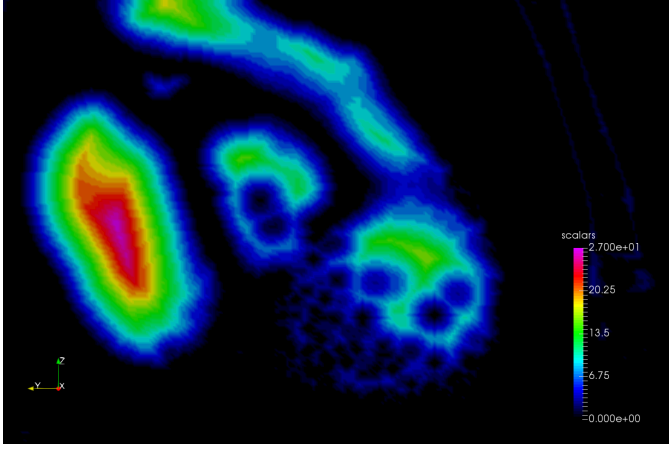
Figure 1. One slice from Euclidian transform image. Color of each voxel shows the distance to the nearest background voxel.

Figure 2. One slice from thresholded image from a dataset. Slice shows LAA (red) and left pulmonary vein (white).

All calculations are performed on thresholded image. First three segmentation steps are guided by the largest radius of a sphere at each voxel. For that reason Euclidian distance transform is calculated on the entire image. For each voxel of the thresholded image we calculate the largest radius of the sphere centered in that voxel. The largest radius is calculated by increasing the radius of the sphere until the sphere first touches a background voxel of the image. For each voxel of thresholded image the radius is saved to the Euclidian transform image. An ilustration of one slice of Euclidian transform image is visible in Fig. 1.

Calculation of Euclidian transfrom image is the most computationally expensive step of the whole method. For our datasets computation of such image lasts around 5 minutes on average PC (Intel i5, 8GB RAM). After the image is generated, all other segmentation steps are performed in 10-20 seconds, depending on the dataset. Reason for this is that after the distance transform image is calculated, for all other operations where finding a maximum sphere radius at a certain voxel is necessary, radius values are simply looked up from the distance transform image.

A. Leaks

Main problem with using any region growing algorithm to segment LAA based on thresholded image is that LAA varies wildly in its shape, size, location and direction. Often LAA

is close to other anatomical structures, e.g. pulmonary veins, other arteries. Because of the movement of the heart while acquiring CT images and thin walls of LAA and neighboring anatomical structures, after thresholding it is possible that LAA "touches" some other anatomical structure other than left atrium. Example of this can be seen in Fig. 2. where it is evident that after thresholding LAA and left pulmonary vein are connected. Our proposed method is robust to such leaks, as expained in following sections.

B. Centerline detection

Starting from first seed point (starting point) centerline detection works iteratively until voxel in current iteration reaches inside of the sphere determined by radius at second seed point (ending point). All voxels in starting seed point's 26-neighborhood are added to the list. In each iteration the method finds the voxel with maximum radius in the list, removes it from the list, adds all voxels of it's 26-neighborhood to the list and marks it as a part of the centerline. This ensures that voxels added to the centerline are always in the center of LAA, while the direction in which the centerline grows will be towards the region with larger radius values, which is the atrium. That way centerline detection will be robust to leaks, because leaks are never as big as the width of the LAA.

All possible candidates for the next centerline voxel (all 26-neighbors of any voxel added to centerline) are kept in a list and the centerline voxel in next iteration is always the one with the maximum radius in the list. This ensures that even if the centerline starts to move in the wrong direction, after adding all maximum radius voxels in that part of the LAA it will always move back towards the left atrium, so the centerline will always eventually enter the left atrium, where the centerline detection will stop after entering the sphere determined by the ending seed point.

C. Initial segmentation based on detected centerline

Initial segmentation is performed after centerline detection. Methods iterates through every voxel of detected centerline and adds its sphere to segmentation. Figure 3. shows the detected centerline and initial segmentation. It is evident from the figure that the thickness of LAA is not continually increasing from the seed point to the end of centerline, but contains bodges along its length. That is why centerline is wider in those parts, and with it the inital segmentation is also wider. Centerline "picks up" voxels with larger radius in those wider parts and continues in the general direction of left atrium.

D. Additional iterative decreasing radii segmentation

After the initial segmentation the method performs an additional segmentation step. For each voxel at the edge of segmentation algorithm determines whether the sphere in that voxel will be added to the segmentation. Each iteration goes through all edge voxels and if at least one sphere was added to the segmentation the algorithm will continue to the next

TABLE I. DICE COEFFICIENTS

Dataset	DICE Coefficient
1	0.94667
2	0.94239
3	0.90811
4	0.91817
5	0.92975
6	0.92250
7	0.93307
8	0.83837

Figure 3. Segmented LAA showing: final segmentation (white), initial segmentation (green) and detected centerlines (orange).

iteration. If no spheres were added in an iteration, algorithm stops.

For each voxel a sphere to be added to the segmentation is the sphere centered in that voxel where the sphere radius is the shortest distance to any background voxel of thresholded image. Let the currently observed voxel be $\mathbf{V}_{current}$, let the radius of the sphere in $\mathbf{V}_{current}$ be $r\left(\mathbf{V}_{current}\right)$, and let the sphere in $\mathbf{V}_{current}$ be $S_{current}$. Algorithm finds the voxel in the unsegmented part of $S_{current}$ with the maximum radius. Let that voxel be $\mathbf{V}_{rmax}$. Sphere $S_{current}$ will be added to the segmentation only if the $r\left(\mathbf{V}_{rmax}\right) \leq r\left(\mathbf{V}_{current}\right)$.

Figure 4. shows the spheres added to the segmentation in each iteration. It should be noted that Fig. 4. shows only five iterations of additional segmentation (iteration one being the initial segmentation from previous step), while in reality for this dataset segmentation ran for 14 iterations. That is the reason why the tip of the LAA in Fig. 3. is longer that in Fig. 4.

E. Addition of isolated components

At this point in segmentation the majority of LAA is already segmented, but in some datasets there can be parts of LAA that have not been added. For example, if the LAA has a narrow and then a wider part and that part was not added to initial segmentation (e.g. it's near the tip of LAA), additional segmentation step will not enter that part because at least one voxel in the wider part will have radius larger than voxels in narrow part of the LAA and that part of LAA will not be added to the segmentation. This problem is solved by two operations. First we apply morphological dilation with spherical structuring element of radius 2 to the segmentation. The purpose of this is to make sure that the segmented voxels of the LAA are as close to the background as possible, so there is no contact between unsegmented parts of the LAA.

After that method performs isolated components labeling with segmented LAA as label 1 and all other isolated components with their own labels. Now all isolated components which are touching the LAA are either parts of the LAA or they are other parts of the heart. Since all other parts of the heart are connected, they are all one big isolated component and volume of that component will be significantly larger than LAA. Afterwards, we add to segmentation any isolated component touching the LAA whose volume is smaller than the currently segmented part of LAA.
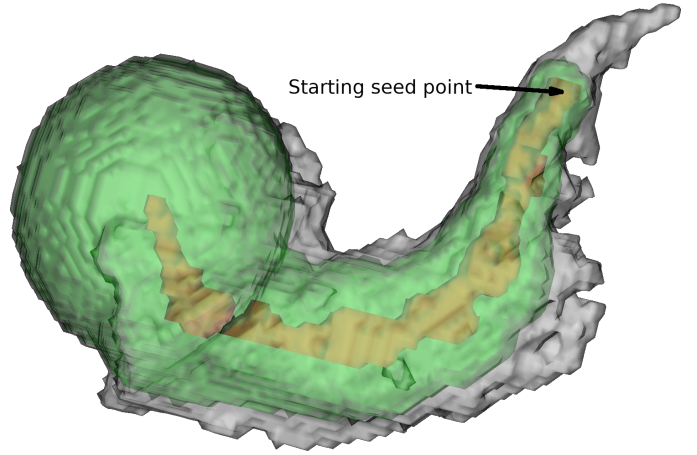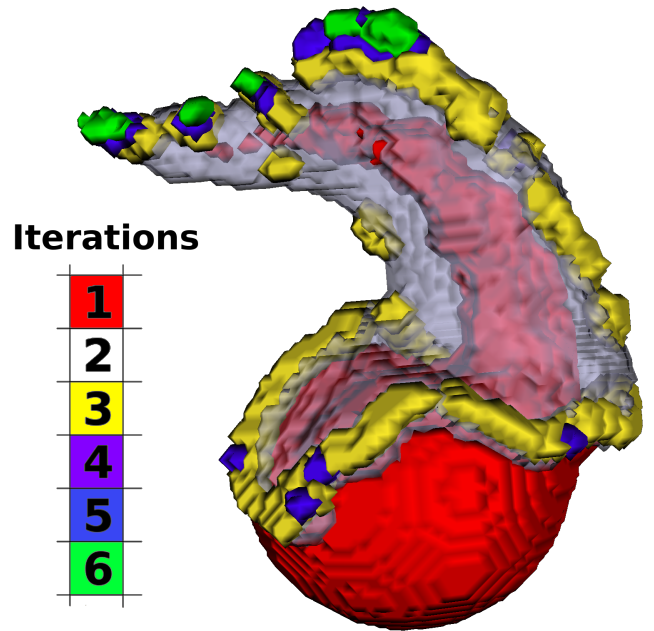

Figure 4. Iterations of the additional decreasing radii segmentation.

III. RESULTS

The segmentation results are evaluated on 8 CCTA datasets manually segmented by cardiovascular surgeon using ITK-SNAP software [10]. All DICE coefficient are calculated after the points of the cutting plane are selected. Figure 5. shows 6 of 8 resulting segmentations. White color shows segmentation by our method, while red color shows ground truth. Since our method is threshold based, it is evident that our method segments a bit larger area than ground truth, but in all datasets it retains the shape. Blue plane in images shows the location of cutting plane on each dataset. Red, green and blue spheres in images are points which define the cutting plane, which are selected by user after the segmentation is performed. Both models (ground truth and result from our segmentation) are
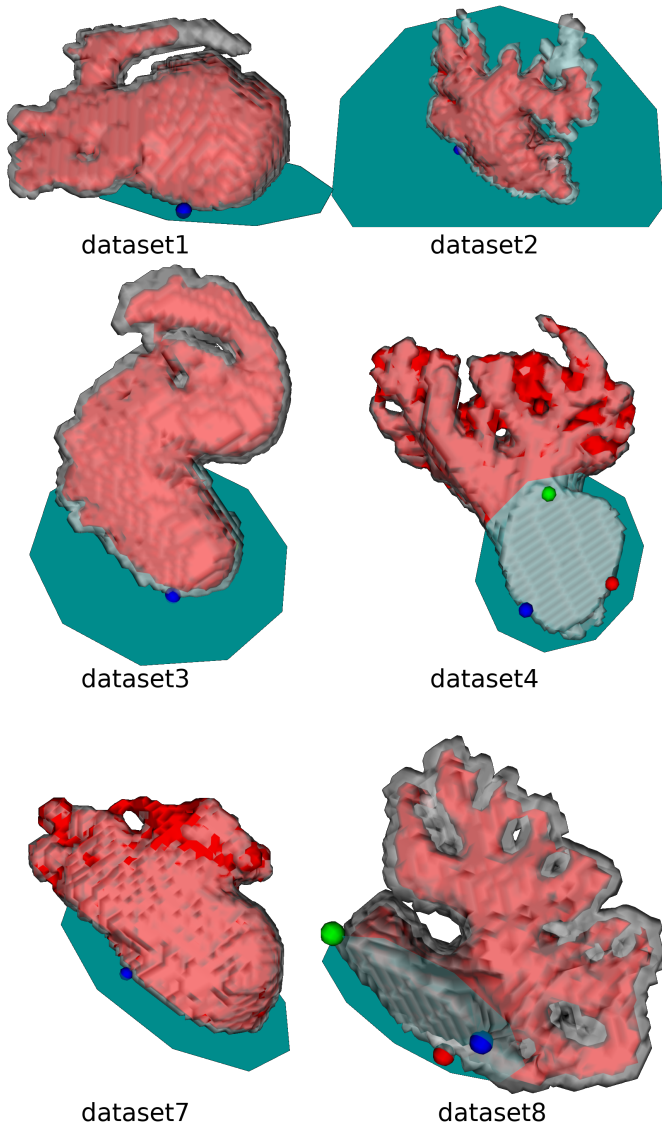
Figure 5. Segmentation results after cutting.

cardiovascular surgeon and it achieves a DICE coefficient of 91.7% on evaluation datasets.

In future we will modify the method to automatically detect the optimal threshold for segmentation and to automatically determine the right criteria for stopping the centerline detection step. These modifications will make the method "single-click" method, where the user will only have to set a single seed point and our method will preform all other segmentation and visualization steps automatically.

cut by that plane and overlap (DICE coefficient) is calculated.

Our method achieves a 91.7% DICE coefficient compared to ground truth. Lowest score of all datasets is 83.4% on dataset 8, but shape of LAA is still properly determined. Table I shows dice coefficients achieved on each of the 8 datasets.

IV. CONCLUSION

In this paper we proposed a novel semi-automatic LAA segmentation method using two seed points (starting and stopping points for segmentation) and manually selected threshold. Method performs LAA centerline detection directed by seed points. Afterwards, multi step spherical region growing based on detected centerline is performed to fully segment the LAA. After segmentation the LAA is visualized and user can select three points defining the ostium of LAA. Proposed method is evaluated on 8 CCTA datasets manually segmented by a

REFERENCES

[1] L. P. Budge, K. M. Shaffer, J. R. Moorman, D. E. Lake, J. D. Ferguson, and J. M. Mangrum, "Analysis of in vivo left atrial appendage morphology in patients with atrial fibrillation: A direct comparison of transesophageal echocardiography, planar cardiac CT, and segmented three-dimensional cardiac CT," *Journal of Interventional Cardiac Electrophysiology*, vol. 23, no. 2, pp. 87–93, Nov. 2008, +.

[2] M. E. Goldman, L. A. Pearce, R. G. Hart, M. Zabalgoitia, R. W. Asinger, R. Safford, J. L. Halperin, S. P. i. A. F. Investigators, and others, "Pathophysiologic correlates of thromboembolism in nonvalvular atrial fibrillation: I. Reduced flow velocity in the left atrial appendage (The Stroke Prevention in Atrial Fibrillation [SPAF-III] study)," *Journal of the American Society of Echocardiography*, vol. 12, no. 12, pp. 1080–1087, 1999.

[3] S. S. Chugh, R. Havmoeller, K. Narayanan, D. Singh, M. Rienstra, E. J. Benjamin, R. F. Gillum, Y.-H. Kim, J. H. McAnulty, Z.-J. Zheng, M. H. Forouzanfar, M. Naghavi, G. A. Mensah, M. Ezzati, and C. J. L. Murray, "Worldwide Epidemiology of Atrial Fibrillation: A Global Burden of Disease 2010 Study," *Circulation*, p. CIRCULATIONAHA.113.005119, Dec. 2013.

[4] R. G. Hart, O. Benavente, R. McBride, and L. A. Pearce, "Antithrombotic Therapy To Prevent Stroke in Patients with Atrial FibrillationA Meta-Analysis," *Annals of internal medicine*, vol. 131, no. 7, pp. 492–501, 1999.

[5] S. H. Ostermayer, M. Reisman, P. H. Kramer, R. V. Matthews, W. A. Gray, P. C. Block, H. Omran, A. L. Bartorelli, P. Della Bella, C. Di Mario, C. Pappone, P. N. Casale, J. W. Moses, A. Poppas, D. O. Williams, B. Meier, A. Skanes, P. S. Teirstein, M. D. Lesh, T. Nakai, Y. Bayard, K. Billinger, T. Trepels, U. Krumsdorf, and H. Sievert, "Percutaneous Left Atrial Appendage Transcatheter Occlusion (PLAATO System) to Prevent Stroke in High-Risk Patients With Non-Rheumatic Atrial FibrillationResults From the International Multi-Center Feasibility Trials," *Journal of the American College of Cardiology*, vol. 46, no. 1, pp. 9–14, Jul. 2005.

[6] V. Y. Reddy, D. Holmes, S. K. Doshi, P. Neuzil, and S. Kar, "Safety of Percutaneous Left Atrial Appendage Closure: Results From the Watchman Left Atrial Appendage System for Embolic Protection in Patients With AF (PROTECT AF) Clinical Trial and the Continued Access Registry," *Circulation*, vol. 123, no. 4, pp. 417–424, Feb. 2011.

[7] J. Saw, P. Fahmy, R. Spencer, R. Prakash, P. Mclaughlin, S. Nicolaou, and M. Tsang, "Comparing Measurements of CT Angiography, TEE, and Fluoroscopy of the Left Atrial Appendage for Percutaneous Closure," *Journal of Cardiovascular Electrophysiology*, vol. 27, no. 4, pp. 414–422, Apr. 2016.

[8] L. Wang, J. Feng, C. Jin, J. Lu, and J. Zhou, "Left Atrial Appendage Segmentation Based on Ranking 2-D Segmentation Proposals," in *Statistical Atlases and Computational Models of the Heart. Imaging and Modelling Challenges.* Springer, Cham, Oct. 2016, pp. 21–29.

[9] H. Zhong, Y. Zheng, G. Funka-Lea, and F. Vega-Higuera, "Segmentation and removal of pulmonary arteries, veins and left atrial appendage for visualizing coronary and bypass arteries," in *Computer Vision and Pattern Recognition Workshops (CVPRW), 2012 IEEE Computer Society Conference On.* IEEE, 2012, pp. 24–30.

[10] P. A. Yushkevich, J. Piven, H. C. Hazlett, R. G. Smith, S. Ho, J. C. Gee, and G. Gerig, "User-guided 3D active contour segmentation of anatomical structures: Significantly improved efficiency and reliability," *NeuroImage*, vol. 31, no. 3, pp. 1116–1128, Jul. 2006.