

IFMBE Proceedings

Isnardo Torres · John Bustamante
Daniel A. Sierra (Eds.)

Volume 60

VII Latin American Congress on
Biomedical Engineering CLAIB 2016,
Bucaramanga, Santander,
Colombia, October 26th–28th, 2016



IFMBE Proceedings

Volume 60

Series editor

James Goh

Deputy Editors

Fatimah Ibrahim

Igor Lacković

Piotr Ładyżyński

Emilio Sacristan Rock

The International Federation for Medical and Biological Engineering, IFMBE, is a federation of national and transnational organizations representing internationally the interests of medical and biological engineering and sciences. The IFMBE is a non-profit organization fostering the creation, dissemination and application of medical and biological engineering knowledge and the management of technology for improved health and quality of life. Its activities include participation in the formulation of public policy and the dissemination of information through publications and forums. Within the field of medical, clinical, and biological engineering, IFMBE's aims are to encourage research and the application of knowledge, and to disseminate information and promote collaboration. The objectives of the IFMBE are scientific, technological, literary, and educational.

The IFMBE is a WHO accredited NGO covering the full range of biomedical and clinical engineering, healthcare, healthcare technology and management. It is representing through its 60 member societies some 120.000 professionals involved in the various issues of improved health and health care delivery.

IFMBE Officers

President: James Goh, Vice-President: Shankhar M. Krishnan

Past President: Ratko Magjarevic

Treasurer: Marc Nyssen, Secretary-General: Kang Ping LIN

More information about this series at <http://www.springer.com/series/7403>

Isnardo Torres · John Bustamante
Daniel A. Sierra (Eds.)

VII Latin American Congress on
Biomedical Engineering CLAIB 2016,
Bucaramanga, Santander, Colombia,
October 26th – 28th, 2016

Editors

Isnardo Torres
Presidente
Asociación Colombiana de Bioingeniería
y Electrónica Médica - ABIOIN
Bucaramanga
Colombia

John Bustamante
Centro de Bioingeniería
Universidad Pontificia Bolivariana - UPB
Medellín
Colombia

Daniel A. Sierra
Escuela de Ing. Eléctrica, Electrónica
Universidad Industrial de Santander
Bucaramanga
Colombia

ISSN 1680-0737 ISSN 1433-9277 (electronic)
IFMBE Proceedings
ISBN 978-981-10-4085-6 ISBN 978-981-10-4086-3 (eBook)
DOI 10.1007/978-981-10-4086-3

Library of Congress Control Number: 2017934456

© Springer Nature Singapore Pte Ltd. 2017

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

The IFMBE Proceedings is an Official Publication of the International Federation for Medical and Biological Engineering (IFMBE)

Printed on acid-free paper

This Springer imprint is published by Springer Nature

The registered company is Springer Nature Singapore Pte Ltd.

The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Contents

A System to study the Evolution of Cardiac Arrhythmias at Home	1
<i>R.I. Gonzalez-Fernandez, M.L. Mulet-Cartaya, J.D. Lopez-Cardona, A. Lopez-Reyes, O. Canto-Hernandez, E. Ledesma Valdes, V. Rodríguez-Peraza, P. Gonzalez-Acosta, and M. Gomez-Florida</i>	
Implementation of risk management activities within a quality management system. An osseous adhesive as case study	5
<i>R.M. Guerra Bretaña, M.C. Pérez Álvarez, M.S. de Almeida, and L.A. de Sena</i>	
Estimation of the optimal maintenance frequency of medical devices: A Monte Carlo simulation approach	9
<i>Antonio Miguel Cruz and William Ricardo Rodriguez Dueñas</i>	
A visual EEG epilepsy detection method based on a wavelet statistical representation and the Kullback-Leibler divergence	13
<i>A. Quintero-Rincón, M. Pereyra, Carlos D’Giano, H. Batatia, and M. Risk</i>	
First Steps For A Web-Based Platform Oriented To The Study Of The Infant Neuro-Development And Disability . . .	17
<i>Sergio D. Cano Ortiz, Zoila Gonzales Videaux, Amilcar Borrás Gonzalez, Reinhardt Langmann, Hartmut Haehnel, and Ludmila Regueiferos Diaz</i>	
How do our students learn clinical engineering? A pilot study	22
<i>Antonio Miguel Cruz, Daniel Alejandro Quiroga Torres, Ana Maria Presiga, and Nestor Flórez Luna</i>	
An Embedded Hybrid BCI Speller	26
<i>P.A. García, E.M. Spinelli, and G.M. Toccaceli</i>	
Teaching maintenance of medical devices in simulation centers: a pilot study	30
<i>Daniel Alejandro Quiroga Torres, Antonio Miguel Cruz, Ana Maria Presiga, and Nestor Flórez Luna</i>	
Biofunctionalization Process of α -SiC:H Surfaces Applied to an Interdigitated Microelectrode Array to Detect Enterotoxigenic <i>Escherichia coli</i>	34
<i>José Herrera-Celis, Claudia Reyes-Betanzo, Abdu Orduña-Díaz, Ana Pérez-Coyotl, Armando Hernández-Flores, Janet Morales-Chávez, and Arely Culebro-Gomez</i>	
Dofetilide effect on human atrial action potential under normal and atrial fibrillation conditions. In silico study	38
<i>C. Tobón, S. Pérez, J.P. Ugarte, and J. Saiz</i>	
Architecture of an emotion recognition and video games system to identify personality traits	42
<i>M. Callejas-Cuervo, L.A. Martínez-Tejada, and J.A. Botero-Fagua</i>	
Classification of Weight Status Using Anthropometric and Clinical Indicators.	46
<i>A.E. Martinez-Licon, F.M. Martinez-Licon, J.C. Romero-Macias, and L.A. del Castillo-Alfaro</i>	
How Can Biomedical Engineering and Health Science Students Learn Together?	50
<i>W.R. Rodríguez, A.M. Ríos, and A. Miguel Cruz</i>	
Effect of Light Scattering due to Multilamellar Bodies in the Human Eye	54
<i>Emilia M. Méndez-Aguilar, Ismael Kelly-Pérez, and L.R. Berriel-Valdos</i>	
Formalization of Gene Ontology relationships with factor graph towards Biological Process prediction	58
<i>F. Spetale, P. Bulacio, F. Krsticevic, S. Ponce, and E. Tapia</i>	

Ultrasound stimulation of insulin release from pancreatic beta cells	62
<i>I.M. Suarez Castellanos, B. Balteanu, Tania Singh, A. Jeremic, and V. Zderic</i>	
Lead (Pb ⁺⁺) effect on human atrial action potential under normal and atrial fibrillation conditions. In silico study . . .	66
<i>C. Tobón, D. Pachajoa, J.P. Ugarte, and J. Saiz</i>	
Acoustic spectrometer: resonant sensing platform for measuring volumetric properties of liquid samples	70
<i>S. Villa-Arango, R. Torres, P.A. Kyriacou, and R. Lucklum</i>	
Rehabilitation Equipment For Rotator Cuff Injuries Shoulder	74
<i>Hedrick ROBLES, Andrea SALAMANCA, Valentín MOLINA, and Horderlin ROBLES</i>	
An overview on biological effects of trace-element in substituted calcium phosphates	78
<i>R.M. Guerra Breña, J.R. Guerra-López, and L.A. de Sena</i>	
Trading barriers in the medical devices industry. Are these barriers hindering the development of this sector in Cuba?	82
<i>Y. Chaveco Salabarría, J.C. Rubio Romero, and R.M. Guerra Breña</i>	
A risk-based integrated management for patient safety and quality in healthcare services	86
<i>R. Roque González, R.M. Guerra Breña, Y. Chaveco Salabarría, K.F. Ortiz Jaya, and O. Vera Cabezas</i>	
CAMACUA: Low Cost Real Time Risk Alert and Location System for Healthcare Environments.	90
<i>I. Decia, A. Farías, D. Szerman, L. Grundel, D. Briatore, M. Piñeyría, A. Villar, and F. Simini</i>	
Pupillary Latency in Chromatic High speed Video-oculography	94
<i>Sánchez S. Anabel and Suaste G. Ernesto</i>	
Pressure Monitor in Endotracheal Cuff for Effective Intubation of Patients	98
<i>S. Villa-Arango, E. Mejía-Mejía, J.M. Gómez, S. Uribe, and R. Torres</i>	
Simultaneous detection of the position of eye movements and head for diagnostic purposes of the vestibular system	102
<i>G. Palomino-Roldán, E. Suaste-Gómez, and A. Castañeda-Galván</i>	
Biomedical Engineering in Latin America: A Survey of 90 Undergraduate Programs.	106
<i>J. Azpiroz-Leehan, F. Martínez-Licon, E.G. Urbina-Medal, M. Cadena M., and E. Sacristán Rock</i>	
Continuous body temperature monitoring system based on a flexible PPy/PLA wristband	110
<i>G. Rodríguez-Roldán and E. Suaste-Gómez</i>	
Fall detection system for elderly by MEMS accelerometer and SMS alert	114
<i>E. Oporto and L.A. Vilcahuaman</i>	
Plastic Casing in Medical Equipment: Evaluation of 3D Design and Molding Simulation.	118
<i>M. Gómez, Y.H. Villalta, J.E. Suen, and R.I. González</i>	
Automatic ABR detection at near-threshold intensities combining template-based approach and energy analysis	122
<i>I.M. Cabana-Pérez, E. Velarde-Reyes, A. Torres-Fortuny, E. Eimil-Suarez, and A. García-Giró</i>	
Comparative Study of Robust Methods for Motor Imagery Classification based on CSP and LDA	126
<i>Ana Julia Villar</i>	
CINARTRO: Clinical Tool to Assess Knee Kinematics by Videofluoroscopy	130
<i>Williams Olivera, Marcio Rodriguez, Dario Santos, and Franco Simini</i>	

Contents	LV
Test Bench to Validate Audio CODEC Kit as EIT Complex Voltage Measurement Circuit	134
<i>M. Arregui, E. Santos, and F. Simini</i>	
Images Digitization and Characterization of Surface and Fundus obtained through a Slit Lamp Adapted	137
<i>I. Cassi, A. Salvatelli, G. Bizai, A. Hadad, D. Ramírez Arduh, and B. Drozdowicz</i>	
Non-homogeneous multichannel electroencephalographic dynamic forward modeling of epilepsy	141
<i>P.A. Munõz-Gutiérrez and E. Giraldo</i>	
Discovery of novel dihydroorotate dehydrogenase inhibitors in trypanosomatids through a molecular docking and molecular dynamics approach	145
<i>Rodrigo Ochoa, Carlos Muskus, and Maria Luisa Serrano</i>	
Space Adventures: a serious game for childhood obesity prevention	149
<i>L.M. Parra Navarro, D.R. Paez Ardila, M.M.S. Pires, and J.L.B. Marques</i>	
Cardiac dynamic assessment through entropy proportions and probability.	153
<i>Javier Rodríguez, Leonardo Ramírez, Signed Prieto, and Catalina Correa</i>	
Automatic Detection of the Retroareolar Region in X-Ray Mammography Images	157
<i>Germán F. Torres and S. Pertuz</i>	
Improved Particle Swarm Optimization algorithm applied to rigid registration in medical images	161
<i>Ramiro Isa Jara, Francisco J. Buchelly, Gustavo J. Meschino, and Virginia L. Ballarin</i>	
Assessment of Surface Electromyography During Orofacial Praxis in Healthy Subjects	165
<i>S. Cadavid-Arboleda, L.M. Ramirez-Arbelaez, E. Perez-Giraldo, S. Restrepo-Agudelo, S. Roldan-Vasco, J.C. Suarez-Escudero, G. Cantillo-Mackenzie, C.L. Bedoya-Londono, L. Martinez-Moreno, and A. Orozco-Duque</i>	
Analyzing Multiple Accelerometer Configurations to Detect Falls and Motion	169
<i>J.D. López, C. Ocampo, A. Sucerquia, and J.F. Vargas-Bonilla</i>	
MC3C3-E1cell response to zirconium (Zr) implants with different surface characteristic by digital image processing analysis	173
<i>M.R. Katunar, A. Bouchet, J. Ballarre, and J.I. Pastore</i>	
Cost Estimate Methodology in procurement processes of ME	177
<i>V.O. Fagundes, R. Zaniboni, and R. Garcia</i>	
Evaluation of methods based on conventional videographyfor detection of gait events	181
<i>A. Arcila Cano, D. Ewins, A. Shaheen, and P. Catalfamo Formento</i>	
Brain Functional Connectivity in Parkinson’s disease – EEG resting analysis	185
<i>J. Carmona, J. Suarez, and J. Ochoa</i>	
Modeling Transient Otoacoustic Emissions in children with hearing impairment	189
<i>Y. Torné-Cabrera, L.M. Alvero, and E. Martínez-Montes</i>	
IoT Protocol Model on Healthcare Monitoring	193
<i>Edward Guillén, Jeisson Sánchez, and Leonardo Ramírez López</i>	
Force Plate Calibration and Setup for Assessments of Human Balance.	197
<i>I. Ghersi, C.F. Castro Arenas, P.D. Borsoi, and M.T. Miralles</i>	

Medical Device by Health Care Facility Interoperability in Alarm Management	201
<i>J. Loureiro and R. Garcia</i>	
Characterization Framework for Ex-combatants Based on EEG and Behavioral Features	205
<i>Andrés Quintero-Zea, Lina M. Sepúlveda-Cano, Mónica Rodríguez Calvache, Sandra Trujillo Orrego, Natalia Trujillo Orrego, and José D. López</i>	
Auditory Brainstem Responses with AEP_AUDIX System Using an Optimized Broadband Chirp Stimulus	209
<i>L.M. Alvero, J.A. Gaya, C. Miret, E. Velarde, A. Torres, E. Eimil, Y. Torne, and E. Martinez</i>	
Protein Network Related to Unfavorable Prognosis in Acute Myeloid Leukemia	213
<i>L.F. Restrepo and S. Röthlisberger</i>	
Green synthesis of silver nanoparticles using green coffee bean extract	217
<i>Lukas Cardeño Calle and Martha Elena Londoño López</i>	
Surface Electromyographic Characterization of Five Orofacial Ideomotor Praxis in 20 Healthy Individuals	221
<i>G. Cantillo-Mackenzie, L. Martinez-Moreno, C.L. Bedoya-Londoño, E. Perez-Giraldo, L.M. Ramirez-Arbelaes, S. Cadavid-Arboleda, S. Restrepo-Agudelo, S. Roldan-Vasco, A. Orozco-Duque, and J.C. Suarez-Escudero</i>	
New technique for determining age of coastal skates from Argentinian sea by digital image processing analysis: A preliminary study.	225
<i>P.A. Cristini, J.I. Pastore, S.A. Barbini, J. Ballarre, D. Sabadín, and A. Bouchet</i>	
Electrodes based on PPy polymer for electrocardiography and impedance plethysmography	229
<i>O. Teran-Jiménez, D. Hernández-Rivera, and E. Suaste-Gómez</i>	
Gesture Recognition and Machine Learning Applied to Sign Language Translation	233
<i>Luis A. Estrada Jiménez, Marco E. Benalcázar, and Nelson Sotomayor</i>	
An IoT Approach to an ECG Online Monitor System in an Android Application	237
<i>F.M. Machado, E.G. Bertogna, and M.A. Sovierzoski</i>	
Noninvasive approach to estimate ventilatory mechanics in spontaneous breathing with different PEEP and pressure support values: validation with mechanical simulation.	241
<i>I.C. Muñoz and A.M. Hernández</i>	
Characterization of silver nanoparticles for potential use as antimicrobial agent.	245
<i>J. Zapata-Giraldo, P. Mena, B. Galeano, N. Escobar, M. Mejía, I.C. Ortiz, D. Cuesta, L.E. Botero, and L.M. Hoyos-Palacio</i>	
Learning Tool for Mechanical Ventilation during Spontaneous Breathing Test on Patients Intoxicated with Pesticides	248
<i>M.B. Salazar Sánchez, A.M. Hernández Valdivieso, A.F. Botero Ospina, and C.C. Cortés Daza</i>	
A Comprehensive System for Healthcare Technology Management HTM	252
<i>L. Vilcahuaman, M. Cordova, J. Kalafatovich, and R. Rivas</i>	
Development and Evaluation of a Method for Fall Detection Based on a Wrist-Located Device	256
<i>T. de Quadros, A.E. Lazzaretti, and F.K. Schneider</i>	
Extending the horizon of biomedical engineering to help other species	260
<i>A.M. Gonzalez-Vargas</i>	
Platonic Tensegrities: dynamic aspects and characterization	264
<i>C. Castro Arenas, I. Ghersi, P.D. Borsoi, and M. Miralles</i>	

Contents	LVII
Wiimote-based Infrared System for Instrumental Tracking in Minimally Invasive Spine Procedures for Training	268
<i>M. Domínguez, D. Lorias, and R. Martínez</i>	
Real-Time processing of DVI signals on a FPGA as a Telemedicine modular solution	272
<i>G.F. Manotas, L.A. Rodríguez, and J.M. Velandia</i>	
Construction of arterial networks considering the Fahraeus-Lindqvist effect	277
<i>P.F. Brito, L.D.M. Meneses, B.M. Rocha, R.W. Santos, and R.A.B. Queiroz</i>	
Optical microscopy and autofluorescence recognition of <i>Toxoplasma gondii</i> and <i>Cryptosporidium parvum</i> oocysts . . .	281
<i>Alejandra Alba, Laura Baker, Graciela Juez, and Andrés Ramírez</i>	
A human gait temporal parameters calculation algorithm	285
<i>P.E. Caicedo-Rodríguez, C.F. Rengifo-Rodas, and L.E. Rodríguez-Cheu</i>	
Health Technology Management for Digital Medical Scales in Primary Healthcare	289
<i>F.S. Rosa and R. Garcia</i>	
Selective cytotoxicity of a novel compound based on Ruthenium II in a Gallbladder carcinoma cell line	293
<i>Hernán Villota, Sebastian Pizarro, Francisco Gajardo, Álvaro Delgadillo, Fabián Cortés-Mancera, and Giuliano Bernal</i>	
Apoptosis induced by a novel Ruthenium II complex in a Gallbladder carcinoma cell line	297
<i>Hernán Villota, Sebastian Pizarro, Francisco Gajardo, Álvaro Delgadillo, Fabián Cortés-Mancera, and Giuliano Bernal</i>	
Optimization of spectral analysis of electrophysiological recordings of the subthalamic nucleus in Parkinson's disease: A retrospective study	300
<i>S.E. Valderrama-Hincapié, A.M. Hernández, F. Sánchez, S. Roldán-Vasco, A.L. López-Ríos, and W.D. Hutchison</i>	
Influence of the Immune System on the Biological Dynamics of the Interstitial Fluid Pressure	304
<i>R.F. Reis, R.W. dos Santos, and M. Lobosco</i>	
Comparing Myocardium Perfusion Data Acquired by a MRI-Phantom and a Mathematical Model	308
<i>J.R. Alves, R.A.B. de Queiroz, and R.W. dos Santos</i>	
Color morphological reconstruction as a segmentation tool for microscope cell images	312
<i>J.I. Pastore, M. Brun, A. Bouchet, and V.L. Ballarin</i>	
Virtual environment as complementary tool to learning of the Imaginology dental care	316
<i>P.B. Neto, F.D.L. Abreu, and S.C.M. Rodrigues</i>	
Ergonomic and Biomechanical Evaluation of the use of Computers, Tablets and Smart Phones by Children. A Pilot Study	320
<i>Holman Ospina-Mateus, Benilda Niño-Prada, Keyla Tilbe-Ayola, and Sonia Contreras-Ortiz</i>	
Cardiovagal Reflex Blood Pressure Set Point Determination by Time Domain Analysis	325
<i>Juan Carlos Perfetto and G.A. Ruiz</i>	
Experimental Study of Apatite Layer Formation on Chitosan/Bioactive Glass Scaffolds for Bone Tissue Regeneration	329
<i>L.A. Quintero, D.O. Grajales, and D.M. Escobar</i>	

A Simple Physical Model of Human Gait Using Principles of Kinematics and BTS GAITLAB	333
<i>C.A. Collazos, H.E. Castellanos, J.A. Cardona, J.C. Lozano, A. Gutiérrez, and M.A. Riveros</i>	
Glu4Pred: A computational tool for design and testing of insulin therapies for patients with type 1 diabetes based on interval simulation	337
<i>M. García-Jaramillo, J.S. Delgado, and F. León-Vargas</i>	
Tribological properties study of lubricants for possible nanoclays reinforced biomedical applications	341
<i>J. Pardo Bernal, L. Peña Parás, and R. Tamayo Ramirez</i>	
Robotic kinematics applied to human biomechanics.	345
<i>J.F. Archila-Diaz, I.L. Argote-Pedraza, R. Bortholin, R. Rubin, J.N. Archila-Diaz, and M.L. Tronco</i>	
SAFER: A Context-Aware Ubiquitous Assistance Platform for Elderly Care.	349
<i>J.F. Bravo-Torres, H.S. Redrován-Parra, A.F. Soto-Sarango, J.A. Andrade-Padilla, E.F. Ordoñez-Morales, M. López-Nores, and Y. Blanco-Fernández</i>	
Time-course reconstruction of neural activity for multiples simultaneous sources.	353
<i>P.A. Muñoz-Gutiérrez and E. Giraldo</i>	
Biomedical IoT Device for Self-Monitoring Applications	357
<i>Tatiana Huertas and Diego Mendez</i>	
Physical and Chemical Emulation of a Cornea	361
<i>R. Jaramillo Diaz, H. Dávila Torres, A.V. Molina Mojica, and L.J. Martínez Guerrero</i>	
Development of an Equipment to Prepare Nanofibers for Tissue Engineering Since a Standpoint of the Industrial Design	365
<i>S.L. Rúa Jiménez, J.D. Villate Lagos, E.Y. Gómez-Pachón, Y. Torres Perez, and E. Muñoz Prieto</i>	
Acquisition of Lower Limb Joint Variables by an Inertial Card System	369
<i>C. Ramos, C.A. Collazos, and A. Maldonado</i>	
Analysis of the Improvement on Textural Information in Human Iris Recognition.	373
<i>Eduardo Garea Llano, Mireya S. García-Vázquez, Luis M. Zamudio-Fuentes, Juan M. Colores Vargas, and Alejandro A. Ramírez-Acosta</i>	
Evaluation of computer vision based objective measures for complementary balance function description and assessment in Multiple Sclerosis	377
<i>Germán D. Sosa, Juanita Sánchez, Xiomary Bermúdez, Angélica Ramírez, and Hugo Franco</i>	
Biomedical computational reproducible research using Madagascar	381
<i>Jorge E. Monsegny</i>	
Muscle strain field estimation using object tracking in high definition video sequences	385
<i>M.A. Zamora, H. Franco, Q. Fang, S. Shefelbine, A. Taylor, and A. Ramirez-Martinez</i>	
Design and Construction of a Wearable Wireless Electrogoniometer for Joint Angle Measurements in Sports	389
<i>Isabela M. Mercado-Aguirre and Sonia H. Contreras-Ortiz</i>	
Improve Image Quality for Minimally Invasive Surgery Simulator Using Lenses and Image Processing.	393
<i>Edgar M. Ramírez-Rodríguez, Daniel Lorias-Espinoza, and José Antonio Gutierrez-Gnecchi</i>	
Fabrication of piezoelectric PVDF/Graphene membranes by electrospinning for respiratory rate and temperature sensing	397
<i>D. Hernández-Rivera and E. Suaste-Gómez</i>	

Contents	LIX
Educative ECG Platform for Undergraduate Courses in BME	401
<i>Armando S. Hernández-Delgado, Arturo Vega-González, and Juan M. Gomez-González</i>	
Biomechanical analysis of a cranial Patient Specific Implant on the interface with the bone using the Finite Element Method	405
<i>J.M. Díaz, O.A. González-Estrada, and C.I. López</i>	
Numerical simulation and fitting of tumor growth kinetics models using Python	409
<i>E.E. Ramirez Torres, L.E. Bergues Cabrales, R.E. Rivero Labrada, and J. Lambert Cause</i>	
A Low-Cost Methodology for Biomechanical Analysis of Martial Arts Using Videography and Accelerometers	413
<i>J.G. Vejar-Robles, A. Vega-Gonzalez, and R.P. Duarte-Zamorano</i>	
Identifying the needs in the integration of disciplines in the hospital infrastructure management in Colombia	417
<i>M. Madroñal Ortiz, B. Galeano Upegui, N. Escobar Mora, L. Cruz Parra, and I. Rios Cuartas</i>	
Approximations of Pupillary Shape in High-Definition Video-Oculography Registers	421
<i>R. Mora-Martínez and E. Suaste-Gómez</i>	
Motion Artifacts Recognition in Electrocardiographic Signals through Artificial Neural Networks and Support Vector Machines for Personalized Health Monitoring	425
<i>F.A. Castaño and A.M. Hernández</i>	
Thermographic comparative study between an acupuncture point and sham acupuncture for cervical pain	429
<i>D.V.Q. Moreira and P. Nohama</i>	
Iterative joint dynamic brain mapping and neural activity modeling from electroencephalographic signals	433
<i>E. Giraldo, P.A. Munõz-Gutiérrez, and G. Castellanos-Dominguez</i>	
Autoregressive Models of Electrocardiographic Signal Contaminated with Motion Artifacts: Benchmark for Biomedical Signal Processing Studies	437
<i>F.A. Castaño and A.M. Hernández</i>	
Feature selection for KNN classifier to improve accurate detection of subthalamic nucleus during deep brain stimulation surgery in Parkinson's patients	441
<i>L. Schiaffino, A. Rosado Muñoz, J. Francés Villora, M. Bataller, A. Gutiérrez, I. Martínez Torres, V. Teruel-Martí, and J. Guerrero Martínez</i>	
Ensemble Kalman filter for state estimation of brain activity by considering a large scale nonlinear dynamical model	445
<i>P.A. Munõz-Gutiérrez and E. Giraldo</i>	
A CT-based and mechanobiologic model for the simulation of rotation of tibia deformities during patient's immobilization treatment	449
<i>R.A. González-Carbonell, A. Ortiz-Prado, V.H. Jacobo-Armendáriz, Y.A. Cisneros-Hidalgo, and L. Morales-Acosta</i>	
A Comparison between Solar Radiation and Skin Cancer in South Brazil.	453
<i>P. Bertemes-Filho and F. Imai</i>	
Inhibition of Erythrocyte Hemolysis induced by H ₂ O ₂ with <i>Mangifera indica</i> L. extract	457
<i>E. Pareja, Y. Salazar, S.S. Arango, M.E. Maldonado, J.G. Zuluaga, and S. Restrepo</i>	
DelphiCare 4.0: Web Biotelemetry System	461
<i>R.J. Díaz, R. Villalpando, J.C. Hinojo, G.E. Ramírez, and L.A. Retana</i>	

Cardiorespiratory Interaction Using Nonlinear Data Processing Techniques in Patients Undergoing Test Tube T.	465
<i>J.I. Trapero, C.J. Arizmendi, C.A. Forero, S.K. Lopez, and B.F. Giraldo</i>	
Incidence and risks associated with nasal injury in newborns undergoing non-invasive ventilation through the binasal prong.	469
<i>D.F. Camillo, F.S. Barros, T.D. Costa, and P. Nohama</i>	
Study of Medical Device Purchasing Cycles through Temporal Series Analysis	473
<i>J.C. Guerrero, J.H. García, and A.M. Hernández</i>	
Creation of the Biomedical Systems Engineering undergraduate program, School of Engineering, UNAM.	477
<i>J.M. Dorador-Gonzalez, L. Báez-Rivas, L. Gonzalez-Gonzalez, and M. Guillen-Mandujano</i>	
Analysis of the respiratory flow signal for the diagnosis of patients with chronic heart failure using artificial intelligence techniques	481
<i>J.C. Rodríguez, C.J. Arizmendi, C.A. Forero, S.K. Lopez, and B.F. Giraldo</i>	
Sudden Cardiac Death Prediction Based On a Nonlinear Estimation	485
<i>R. Urda Benitez and A. Orozco Duque</i>	
Mechanical Characterization of a Breast Phantom	489
<i>D.A. Triana, K.L. Cristiano, J.C. Gutiérrez, and D.A. Miranda</i>	
Theoretical study of the interaction between carbon nanotubes and the linoleic acid, an atherogenic polyunsaturated fatty acid	492
<i>Ana M. Torres, John Bustamante, Andrés M. Garay-Tapia, and Tapas Kar</i>	
VCG and ECG indexes for classification of patients with Myocardial Infarction	496
<i>R. Correa, P.D. Arini, L.S. Correa, and E. Laciari</i>	
Incorporation of Current Density Map Method in the Epilepsy Surgery Protocol.	500
<i>A.R. García, J.P. Graffigna, and R. Otoya</i>	
Signal modes for design-oriented analysis of active sEMG spatial filter electrodes.	504
<i>F.N. Guerrero, P.A. García, and E.M. Spinelli</i>	
An Age-based Multiscale Mathematical Model of the Hepatitis C Virus Life-cycle During Infection and Therapy: Including Translation and Replication	508
<i>B.M. Quintela, J.M. Conway, J.M. Hyman, R.F. Reis, R.W. dos Santos, M. Lobosco, and A.S. Perelson</i>	
Vibrotactile System for the Replication of Textures.	512
<i>M. Santís, D. Jaramillo, and V.Z. Pérez</i>	
Nonlinear estimators of human movement in biomechanical signals: Comparison between Extended Kalman Filter and Unscented Kalman Filter	516
<i>M. Callejas Cuervo, M.A. Vélez Guerrero, and A.C. Alarcón-Aldana</i>	
Voice Controlled Prosthetic Hand with Predefined Grasps and Movements.	520
<i>Juan Pablo Ángel-López and Nelson Arzola de la Peña</i>	
ICA and SVM Clustering Applied to Remove Ocular Artifacts from Electroencephalography	524
<i>J. Pena-Rodriguez, D.A. Sierra, and C.A. Conde-Cotes</i>	
Diaphragmatic pacemaker prototype with wireless communication.	528
<i>Jorge Reynolds, Jose Forero, and Maria Arango</i>	

Contents	LXI
Three Dimensional Reconstruction and Airflow Simulation in a Realistic Model of the Human Respiratory Airways	533
<i>A.E. Ruiz and J.K. Aristizábal</i>	
Heart Models in 3D Print.	537
<i>Jorge Reynolds and Nasdly Diaz</i>	
Nonlinear measures characterize atrial fibrillatory dynamics generated using fractional diffusion	541
<i>J.P. Ugarte, S.I. Duque, A. Orozco-Duque, C. Tobón, J. Bustamante, and H. Andrade-Caicedo</i>	
Construction of arterial networks considering a power law with exponent dependent on bifurcation level.	545
<i>L.D.M. Meneses, P.F. Brito, B.M. Rocha, R.W. Santos, and R.A.B. Queiroz</i>	
Leveraging Wireless Communications and Biomedical Devices to Support Prehospital Trauma Care in Cuenca, Ecuador.	549
<i>R.D. Contreras-Chacón, J.F. Bravo-Torres, and M.K. Huerta</i>	
Electronic Stethoscope with Wireless Communication to a Smart-phone, Including a Signal Filtering and Segmentation Algorithm of Digital Phonocardiography Signals.	553
<i>Jorge Reynolds, José Forero, Juan Botero, Vivian Leguizamón, Luis Ramírez, and Carlos Lozano</i>	
Permanent Magnets to Enable Highly-Targeted Drug Delivery Applications: A Computational and Experimental Study	557
<i>M. Mercado-M, A.M. Hernandez, and J.C. Cruz</i>	
Analysis of the stability control of motors used in biomechanical prostheses.	561
<i>C. Alvarez Picaza, M.I. Pisarello, and J.E. Monzón</i>	
Atrial fibrillation detection through heart rate variability using a machine learning approach and Poincare plot features	565
<i>J.P. Sepulveda-Suescun, J. Murillo-Escobar, R.D. Urda-Benitez, D.A. Orrego-Metaute, and A. Orozco-Duque</i>	
Mathematical Modeling of Human Eye Affected by Increased Intraocular Pressure as a tool for the Prevention of Glaucoma.	569
<i>Eduardo Pinos-Vélez, Rocío Alvarez-Cardenas, Sebastian Torres-Ríos, Carlos Luis Chacón, William Ipanaqué-Alama, and Luis Serpa-Andrade</i>	
Model Fitting and Simulation of the Respiratory Control System under Incremental Exercise and Altitude in Healthy Subjects	573
<i>C.A. Sarmiento, A.M. Hernández, and L.Y. Serna</i>	
Supporting Diabetic Patients with a Remote Patient Monitoring Systems	577
<i>S. Zulj, G. Seketa, D. Dzaja, F. Sklebar, S. Drobnjak, L. Celic, and R. Magjarevic</i>	
Climbing/Descending Stairs Detection Using Inertial Sensors and Implementing PCA and a SVM Classifier	581
<i>R. Alvarez, E. Pulido, and D.A. Sierra</i>	
Assessment protocol of wrist flexion and extension to support processes in occupational health using Myo Armband	585
<i>V. Montoya-Leal, A. Orozco-Duque, J.P. Ugarte, M.A. Portela, J.C. Franco, and V.Z. Perez</i>	
<i>In vitro</i> study of proliferation and cellularisation on electrospun membranes for vascular prosthesis.	589
<i>Y. Montoya, R.A. Valencia, I.C. Ortiz, L.M. Hoyos, and J. Bustamante</i>	

Height Difference Effects Between the Standard and the Equipment Under Test in Calibration Process for Sphygmomanometers in Colombia	593
<i>M.A. Castro-Leal and M.A. Castro-Cortés</i>	
Parametric Modeling of Kinetic-Kinematic Polycentric Mechanical Knee	597
<i>A.M. Cárdenas, J. Uribe, and A.M. Hernández</i>	
Usability Evaluation for a Vital Signs Monitor Prototype	601
<i>L.E. Arenas, P.J. Bedoya, L. Correa, J.G. Barreneche, and A.M. Hernández</i>	
New insights into the scoring of respiratory events based on alternative sensors: A comparative effectiveness study	605
<i>C.R. Dell'Aquila, L.S. Correa, R. Correa, G.E. Cañadas, and E. Laciár</i>	
Prediction of Critical Air Quality Events Using Support Vector Machines and Particle Swarm Optimization.	609
<i>J.C. Zapata-Hernandez, Y.K. Rojas-Idarraga, D.A. Orrego, and J. Murillo-Escobar</i>	
SIRUMED [®] , software for wheelchair selection. A preliminary report.	613
<i>J. Letechipia and A. Arredondo</i>	
Upper-Limb Kinematics During Feeding and Drinking	617
<i>Sergio Parra-Sánchez, Juan Manuel Gómez-González, A. Irais Quintero-Ortega, Laura E. Castellano, Birzabith Mendoza-Novelo, José Jorge Delgado-García, Mayra Cuéllar-Cruz, and Arturo Vega-González</i>	
The Output Circuit of a Biphasic Constant Current Electrical Stimulator	621
<i>R.R. Nogueira, D.C. Souza, J.C. Palma, G.N. Nogueira-Neto, and P. Nohama</i>	
Facial Movements Detection Using Neural Networks and Mpeg-7 Descriptors Applied to Alternative and Augmentative Communication Systems	626
<i>Alexandre Felippeto Henzen and Percy Nohama</i>	
Main Effects of Energy Drinks on Mood, Reaction Time and Brain Regions	630
<i>C. Martínez-Torres, M. Calvillo, C. Romero-Rebollar, D. Martínez-Cancino, M. Flores-Leal, and L. Jiménez-Angeles</i>	
Design of a Validation Protocol for Medical Technology According to Current Standards	634
<i>J. Acevedo, N. Saldarriaga, J.S. Orozco, and J.H. García</i>	
Analysis of a Nurse Call System Implementation using a Wireless Sensors Network	638
<i>R.A. Zapatán, E.E. Armijos, L. Serpa-Andrade, and Eduardo Pinos</i>	
Multichannel Planar Microelectrode Platform for Recording Extracellular Field Potentials	642
<i>J.C. Franco, M.A. Portela, and H. Andrade-Caicedo</i>	
Modeling and simulation of ciprofloxacin pharmacokinetics: electric circuits approach.	646
<i>J.D. Otálvaro, A.F. Zuluaga, and A.M. Hernández</i>	
Gait Kinematics of Load Carriage in Healthy College Students.	650
<i>Fátima G. Tapia-Rodríguez, Daniela M. Castro, Favia P. Aviles H., J. Daniel Moreno-González, L. Fernando Andrade-Heredia, and Arturo Vega-González</i>	
An approach to emotion recognition in single-channel EEG signals using Stationary Wavelet Transform	654
<i>A. Gómez, L. Quintero, N. López, J. Castro, L. Villa, and G. Mejía</i>	
Processing of thermal images oriented to the automatic analysis of hand thermoregulation	658
<i>N. Zapata-Osorio, S. Orrego-Serna, L. Ramirez-Arbelaez, A. Castro-Ospina, and H. Fandiño-Toro</i>	

Assessment of Ankle Movements Through a Game-Based Sphere: Proof of Concept.	662
<i>Alan Meana, David Negrete-Rojas, Rafael A. Nava-Gomez, Jose A. Ruiz-Diaz, Arturo Vega-Gonzalez, and Juan M. Gomez-Gonzalez</i>	
Analysis of the alignment angles and flexion angle in women with patellofemoral pain syndrome.	666
<i>N.F. Diaz-Martinez, J.D. Pulgarin-Giraldo, L.E. Vinasco-Isaza, and W. Agredo</i>	
Managing Heterogeneous Medical Data: Learning from Experiences in Telemedicine	670
<i>J.C. Vanegas-Serna, J.J. Perez, and H. Andrade-Caicedo</i>	
Fibrosis evaluation of animal liver tissue by thermal conduction	674
<i>N. Alemán-García, A. Pérez-García, J. Sánchez-Melecio, F. Silva-Aguilera, E. Gutiérrez-Herrera, M.R. Ortiz-Posadas, J. Hernández-Ruiz, D. Kershenobich, and C. Sánchez-Pérez</i>	
Clinical Evaluation of Inductive Spectrometer to detect Breast Cancer	678
<i>C.A. González-Díaz, M.C. Uscanga-Carmona, L.M. Lozano-Trenado, J.L. Ortíz, J.A. González, and C.I. Guerrero-Robles</i>	
Kinematic Soccer Kick Analysis Using a Motion Capture System.	682
<i>Juan Pablo Ángel-López, Belarmino Segura-Giraldo, Luz Dary Rodríguez-Sotelo, and Karol Bibiana García-Solano</i>	
Measurement of the strength of upper limbs in cervical injury users to design a propulsion wheelchair mechanism.	686
<i>Norma Araceli Coral Hernández, Cuicilahuac Osornio Correa, María del Carmen Mercado Chaparro, Ana María Vásquez Gallego, Jorge Letechipia Moreno, and Andrés Torres Velásquez</i>	
Knee Joint Angle Monitoring System Based on Inertial Measurement Units for Human Gait Analysis.	690
<i>J.J. Castañeda, A.F. Ruiz-Olaya, C.N. Lara-Herrera, and F.Z. Roldán</i>	
Case Study: Audiometry and ECR profile time convergence.	694
<i>A.K. Quintana, Ma. P. Granados, and J.M. Cornejo</i>	
Computer models for ions under electric and magnetic fields: random walks and relocation of calcium in dendrites depends on timing and population type.	698
<i>J.F. Gomez-Molina, M. Corredor, A.A. Restrepo-Velasquez, and U.M. Ricoy</i>	
Structural and functional genomics analysis of methyltransferase genes and networks associate to understand antibiotic resistance inside the pangenome of <i>Pseudomonas aeruginosa</i>	702
<i>Diana Carolina Castaño, Jeanneth Mosquera-Redón, and Mauricio Corredor</i>	
Brief description on offered courses on Biomedical Engineering undergraduate programs in Mexico	706
<i>A.C. Pliego-Carrillo and E.G. Del Hierro-Gutierrez</i>	
Motor Imagery BCI System with Visual Feedback: Design and Preliminary Evaluation	709
<i>L.C. Carrere and C.B. Tabernig</i>	
Linear and non-linear methods for analysis Center Pressure and its application in Diabetic Peripheral Neuropathy: A systematic review	713
<i>D. Toloza and M. Zequera</i>	
Optimal design of a mechanism for children foot guiding.	717
<i>P.A. Niño Suarez, F. Calderon-Romero, M.B. Calva-Yañez, E.A. Portilla-Flores, and O.A. Aviles-Sánchez</i>	

Thematic profile of the e-health field, based on mainstream scientific production	721
<i>P. Romero, Y. Piedra, and M. Nyssen</i>	
Thermoregulation of the hand: assessment with infrared thermography.	725
<i>L.C. Ospina-Restrepo, L.M. Herrera-Velasquez, C.J. Barrera-Causil, H.A. Fandiño-Toro, and L.M. Ramirez-Arbelaez</i>	
Exhaled Breath analysis of smokers and nonsmokers using sensors based ultrapure Organically Modified Gold Nanoparticles	729
<i>O.E. Gualdrón, T.G. Welearegay, A.L. Jaimes, J.M. Cáceres, C.M. Durán, R. Ionescu, M. Maestre, and G. Pugliese</i>	
Synthesis and characterization of nanofibroin hydrogels from Colombian silkworm <i>Bombyx Mori</i> L.	732
<i>A. Zuluaga-Velez, R. Buitrago-Sierra, J.F. Santa, F.A. Tabares-Villa, E. Aguilar, and J.C. Sepúlveda-Arias</i>	
Human-Computer Interaction for Image Guided Surgery Systems using Physiological Signals: Application to Deep Brain Stimulation Surgery.	737
<i>D.A. Jimenez, J.B. Padilla, R. Arango, and H.F. Garcia</i>	
Programs in Biomedical Engineering Education: How to Improve it	741
<i>G. Avendaño and A. Rienzo</i>	
Video Tracking Analysis System for Forelimb Akinesia test in the Rat Parkinson model	745
<i>M.P. Bonaccorso Marinelli, M.J. Ledesma, F.E. Nieto Grimalt, and R.J. Cabrera</i>	
Rat spinal cord transection injury progression: an MRI study	749
<i>M. Flores-Leal, A. Morales-Guadarrama, H. Salgado-Ceballos, and E. Sacristán-Rock</i>	
Mobile Application: Assistance in Mathematics Basic Operations in Children with Learning Disabilities	753
<i>F.D.L. Abreu, F.P. Silva, P.B. Neto, M.A.S. Bissaco, and S.C.M. Rodrigues</i>	
Dispersive Raman Analysis of Sacha Inchi Ozonated Oil.	757
<i>H.C. Carvalho, D.A.B. Palacios, C.J. Lima, M.S. Melo, L. Silveira Jr, and R.A. Zângaro</i>	
Design of Chassis and Adjustable Elements to Support Posture for Pediatric Wheelchair	761
<i>Y. Torres-Pérez and C. Caballero-Reyes</i>	
Prosthetic Alignment and Biomechanical Parameters in Transtibial Amputees due Landmines.	765
<i>L.A. Luengas, G. Sanchez, and K. Novoa</i>	
Author Index	769

Color morphological reconstruction as a segmentation tool for microscope cell images

J.I. Pastore¹², M. Brun¹², A. Bouchet¹² and V.L. Ballarin²³

¹ ICYTE, CONICET - UNMDP, Universidad Nacional de Mar del Plata, Argentina.

² Department of Mathematics, School of Engineering, UNMDP, Argentina

³ Department of Electronics, School of Engineering, UNMDP, Argentina

Abstract— There are numerous segmentation methods for gray level microscope cell images, however in some situations the texture features and roughness are not as relevant as the color for the segmentation task. For example, for detection of histological analysis, the relative sizes of nucleus and cytoplasm, as well as their shapes, are the relevant features, while other characteristics such as texture and roughness have no value in the diagnosis.

In this context, geodesic reconstruction is one of the image operators, of mathematical morphology, that facilitates image segmentation of individual objects. This operator uses markers to highlight, in the image, objects of interest, in order to separate them from the rest of the scene.

This paper presents a new segmentation method, for microscope cell images, based on mathematical morphology color reconstruction, where the markers can be obtained automatically or semi-automatically. Automatically, when you want to detect those cells that were not removed at the generation of the markers. Semiautomatically when the expert manually selects one pixel for each cell of interest.

Keywords—Mathematical morphology, color, segmentation, reconstructions, cells.

I. INTRODUCTION

Modern technological development has enabled a huge advance in the histological knowledge. Currently, the use of segmentation algorithms aids the detection and treatment of different lesions. Thus, lots of researchers devote their efforts to develop more powerful algorithms that support diagnostics issued by medical specialists [1]. However, they are still insufficient achievements in this regard. This paper proposes a new segmentation method, for microscope cell images, based on mathematical morphology color reconstruction, where the markers can be obtained automatically or semi-automatically.

The automatic segmentation of cells microscopic images can be considered to be one of the major hurdles for a robust analysis. Automatic or semiautomatic segmentation techniques attempt to improve sensitivity and specificity by detecting, segmenting and classifying the cells and later obtain the cytoplasm or nuclei shape. To solve this problem, in this work, color mathematical morphology reconstruction

technique was developed based on a new local defined ordering [2]. The marker image can be obtained automatically or semi-automatically. Automatically, when you want to detect those cells that were not removed at the generation of the markers. Semiautomatically when the expert manually selects one pixel for each cell of interest. In the first case, the marker image is obtained performing successive dilations with a structuring element which size is related to the size of the nucleus of the cell that wants to be removed. In that way we obtained the image mask automatically. Also the expert can also select by clicking a particular cell to segment it.

Experimental results show that the proposed color morphological reconstruction can be efficiently used in the segmentation of cells.

II. MATHEMATICAL MORPHOLOGY IN COLOR SPACE

Mathematical Morphology (MM) has a strong theoretical basis supported on concepts of geometry, algebra, topology and set theory. The principal idea of this theory is to compare the objects of interest with a set of predefined and known geometry, called "structuring element". The use of different shapes and sizes for the structuring element (SE) allows testing and quantifying how the structuring element "is, or is not contained" in the image [3-4].

The MM has been studied and successfully applied in biomedical image segmentation. The process of segmenting an image consists in generating a partitioning of the image set in groups of pixels. Its objective is to simplify or change the representation of an image in a more meaningful one to facilitate the analysis. The segmentation is used either to locate objects of interest or to determine the boundaries within an image [5].

The MM had been introduced as a processing technique for binary images, which were regarded as sets; therefore, its elementary operations are based on the set theory [3-4]. However, the extension to sets of grayscale images, using the umbra concept [3], introduced a generalization of the basic morphological operations. The grayscale morphology is based on the lattice theory, which implies a partial ordering of the data within the grayscale images. Therefore

erosion and dilation, the fundamental operations of MM, are defined within a complete lattice as the operations which distribute over the infimum and the supremum [6].

The erosion and the dilation of an image f , using a flat SE g , are defined as follows [6]:

$$\varepsilon_B^{\leq_3}(f) = \inf_{s \in B}^{\leq_3} \{f \circ \tau_s\} \quad (1)$$

$$\delta_B^{\leq_3}(f) = \sup_{s \in B}^{\leq_3} \{f \circ \tau_{-s}\} \quad (2)$$

It can be noticed that the basic morphological operations involve finding an infimum and a supremum for the points within a local region, given by the SE positioning. For a general account on mathematical morphology the interested reader should refer to the two pioneer books by Serra [3-4]. Fundamental references to works which have studied the theory of vector morphology theory are [7-11].

While the extension from binary to grayscale images is a natural one, the extension to color or multivariate images is not straightforward, because of the vectorial nature of the data and the difficulty in finding a suitable ordering for it.

A color can be represented by different algebraic structures. The color spaces provide a way to specify order and manipulate colors. These representations correspond to a subset of a three-dimensional coordinate system in which each color is represented by a point univocally. A color image can be modeled as a function $f: \Omega \subset \mathbb{R}^2 \rightarrow \mathfrak{I} \subset \mathbb{R}^3$ where \mathfrak{I} represents a color space. As mentioned above, the definition of morphological operators needs a complete lattice structure to spatial structures [6], i.e., the possibility of defining an ordering relationship among the points to be processed.

Being $\mathfrak{I} \subset \mathbb{R}^3$ a color space and \leq_3 a proposed order that gives to \mathfrak{I} a structure of complete lattice. The space of functions $f: \Omega \subset \mathbb{R}^2 \rightarrow \mathfrak{I} \subset \mathbb{R}^3$ with the order \leq defined as: $f, g: \Omega \subset \mathbb{R}^2 \rightarrow \mathfrak{I} \subset \mathbb{R}^3$, $f \leq g$ if and only if $f(x) \leq_3 g(x) \forall x \in \Omega$, has a lattice structure (Serra, 1982; Talbot et al., 1998). Indeed, $\forall f, g: \Omega \subset \mathbb{R}^2 \rightarrow \mathfrak{I} \subset \mathbb{R}^3$, $\exists \inf(f, g), \sup(f, g): \Omega \subset \mathbb{R}^2 \rightarrow \mathfrak{I} \subset \mathbb{R}^3$ defined by:

$$\left. \begin{aligned} \inf(f, g)(x) &= \inf_{(\leq_3)}(f(x), g(x)) \\ \sup(f, g)(x) &= \sup_{(\leq_3)}(f(x), g(x)) \end{aligned} \right\} \forall x \in \Omega$$

This allows defining the basic operations of erosion and dilation for a color image $f: D_f \subset \mathbb{R}^2 \rightarrow \mathfrak{I} \subset \mathbb{R}^3$ by a SE B following Eq.1 and Eq.2.

A central aspect of the MM is the construction of any operator as a combination of basic operators: erosion, dilation and the operations supreme and infimum. The formal definition of this decomposition is given by a formal

language called Morphological Language [7-8]. Particularly, the reconstruction operator, which is a very useful tool provided by mathematical morphology, is employed not only in binary images but also in grey levels. Besides, it can be applied to different stages of image processing such as filtering, segmentation or features extraction. In general, it is introduced as part of a set of operators called geodesic operators [12-13]; and it basically consists in extracting the connected components of an image from a marker image.

A. Geodesic morphological operators

The geodesic reconstruction is one of the operators of mathematical morphology that facilitates image segmentation. This operator allows, by using markers, highlighting an image objects of interest, in order to remove them from the rest of the scene. That means geodesic operators are useful when you want to process a subset of the space analyzed. The geodesic reconstruction operator employs successive dilations (erosions) to a marker image whose result is delimited by a mask image [12-13].

The definitions of geodesic erosion and dilation are closely related to the geodesic distance [14].

The *geodesic erosion* of an image f (called mark), by an structuring element b , conditioned to g (called mask), $g \leq f$, is defined as:

$$\varepsilon_{b,g}^{(1)}(f) = \varepsilon_b(f) \vee g \quad (3)$$

being \vee the supremum.

First, the mark image f is eroded. Then the supremum between the eroded image and the mask is calculated. The visual effect of this type of erosion is that the mask retains the marker so that it does not disappear (the contraction of the marker is limited). In this case the geodesic erosion is greater than or equal to the mask, it is also an increasing and anti-extensive operation.

The geodesic erosion of size n , with $n \geq 1$, of an image f , by an structuring element b , conditioned to g , is defined as the iteration of geodesic erosions of increasing size, i.e.:

$$\varepsilon_{b,g}^{(n)}(f) = \underbrace{\varepsilon_{b,g}^{(1)}(\varepsilon_{b,g}^{(1)}(\dots\varepsilon_{b,g}^{(1)}(f)))}_{n\text{-times}} \quad (4)$$

The *geodesic dilation* of an image f (mark), by a structuring element b , conditioned to g (mask), $f \leq g$, is defined as:

$$\delta_{b,g}^{(1)}(f) = \delta_b(f) \wedge g \quad (5)$$

being \wedge the infimum.

The mask acts as the limit of the marker image dilated therefore $\delta_{b,g}^{(1)}(f) \leq f$. The geodesic dilation, like classical dilating, is a growing and extensive operator.

The *geodesic dilation* of size n , $n \geq 1$, of an image f , by an structuring element b , conditioned to g , like the geodesic erosion, is defined as the iteration of geodesic dilations of increasing size, i.e.:

$$\delta_{b,g}^{(n)} = \delta_{b,g}^{(1)}(\underbrace{\delta_{b,g}^{(1)}(\dots\dots\delta_{b,g}^{(1)}(f))}_{n\text{-times}}) \quad (6)$$

The geodesic erosion and dilation have the particularity that they allow, when iterated until stability, the definition of powerful algorithms of morphological reconstruction. Both the geodesic erosion and dilation converge in a finite number of iterations [15].

Reconstruction by dilation of a mark image f from a mask image g , both with the same domain $f \leq g$, is define as the geodesic dilation of f conditioned to g until stability and it denotes $\rho_g(f)$.

The *gray level reconstruction* $\rho_g(f)$ of an image g with respect a marker image f , $f < g$, is obtained iterating successively geodesic dilations in gray levels, by a structuring element b , until new changes do not occur. That means:

$$\rho_g(f) = \bigvee_{n \geq 1} \delta_{b,g}^{(n)}(f) \quad (7)$$

As g acts like constraint, $\rho_g(f) \leq g$, so at the end of the geodesic dilation produces no change in the image. Reconstruction by dilation is an anti-extensive operation.

Each geodesic dilation of the reconstruction is performed from the geodesic dilation of the previous iteration. Thus the marker can progressively reducing its intensity in the spread under the mask

Similarly the dual reconstruction $\rho_g^*(f)$ with respect to an image g is defined $g \leq f$, as:

$$\rho_{b,g}^*(f) = \bigwedge_{n \geq 1} \varepsilon_{b,g}^{(n)}(f) \quad (8)$$

The idea is to iterate several times to spread the minimum (maximum) value of each component till the entire component is homogenized. That minimum (maximum) represents the gray level of the reconstruction of the object, so that the reconstruction of an image in gray levels will not be perfectly reconstructed, as it happens in the binary case.

B. Proposed Method

The proposed method to segment the cells can be summarized in the following four steps:

Step 1: First we define a total order in the RGB color space. In order to define the morphological operators involved in the segmentation, we use the previously defined order in [16]. This order have three stages: The order between two colors is defined first observing the average intensities, if it matches we take the distance to the color of the central element of the structural element and finally if there is a new match we used the order predefined in the decision window.

Step 2: we define the geodetic operators in the complete lattice generated by the former order.

Step 3: the marker image is determined.

Step 4: the dual reconstruction is applied using the marker image of the previous step.

Figure 1 show the proposed color morphological reconstruction applied to a synthetic image. The marker image was obtained performing a dilation with a structuring element. The size of the structuring element is related to the size of the object that wants to be removed by reconstruction. In that way we obtained the marker image automatically.

III. RESULTS

As an example of application, we applied the proposed color segmentation method to cell images from different sources.

Figure 2 shows an example of an image of avian erythrocyte [17], or red blood cells, which also show their nuclei.

We also tried our segmentation approach on these images, first with manual selection of cells, and then with automatic marker detection, with an structuring element of size 11. Figures 2 and 3 show the respective results.

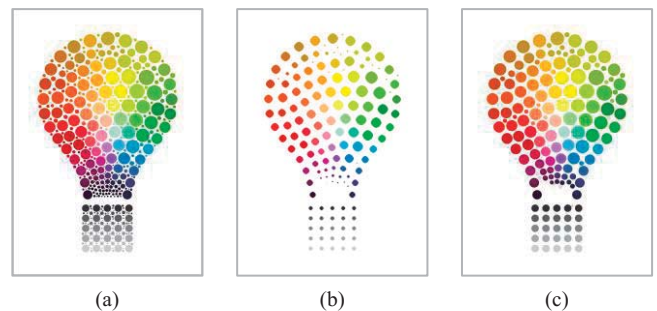


Figure. 1: Result of the propose method. (a) Original image. (b) Marker image. (c) Result of the dual reconstruction.

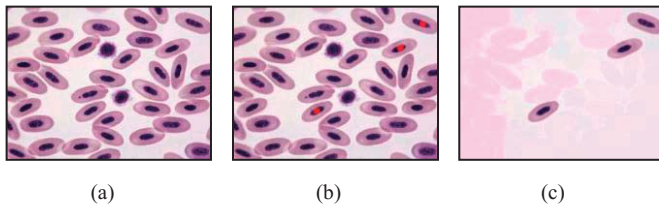


Figure 2. Avian erythrocyte sample. b) Manually selected markers in red. c) Segmented image, where we can see the three selected cells.

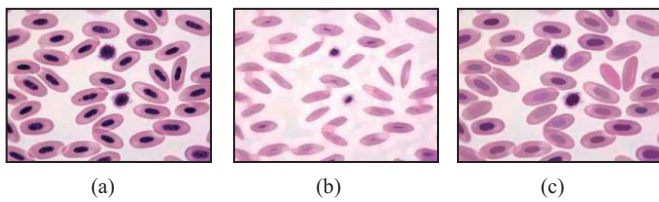


Figure 3. Avian erythrocyte sample b) Automatic selection of markers. c) Reconstructed image.

We can see that in all cases we obtain a good recovery of the marked cells. In the last case, because of the overlap between cells, the reconstructed image contains additional cell regions. This issue is not present on the previous examples, where the cells were shaped in a more consistent shape.

We also applied the proposed segmentation method to frog red blood cells, called also erythrocytes and also to nasal mucosa in allergic rhinitis obtained from a nasal cytology. Both cases were successfully segmented.

IV. CONCLUSIONS

We proposed here a new method for color image segmentation based on color reconstruction, for application on segmentation of cells images. The algorithm works directly on color images, avoiding the need to convert them to gray scale images, with the loss of information that it produces, and the final results are the full selected cells, reconstructed from original markers. Another advantage of this approach is that, because of the use of the new color image operators, no false colors are created in the process, and the resulting image contains exactly the same color present in the original image. As we can see in the result, the algorithm can perform properly in different situations, where cell nucleous are well defined, with option to select the cells manually, or using an automatic marker algorithm.

REFERENCES

1. Glasbey C. and Horgan G. (1995). *Image Analysis for the Biological Sciences*. Chichester, England.
2. Pastore J., Bouchet A., Brun M. and Ballarin V. (2015). *New Windows based Color Morphological Operators for Biomedical Image Processing.. XIX Congreso Argentino de Bioingeniería*. San Miguel de Tucumán, Tucumán, Argentina. ISBN: 978-987-23950-7-0.
3. Serra J.: *Image analysis and mathematical morphology*, Vol. I. Academic Press, London, 1982.
4. Serra J.: *Image analysis and mathematical morphology*, Vol. II. Academic Press, London, 1988.
5. González R. and Woods R.: *Digital Image Processing*. Addison-Wesely Publishing Company, 1996.
6. Angulo J. Morphological colour operators in totally ordered lattices based on distances: Application to image filtering enhancement and analysis. *Computer vision and image understanding*, 2007, 107(1-2):56-73.
7. Banon, G. J. F. and Barrera, J.: 1993, "Decomposition of mappings between complete lattices by Mathematical Morphology". *Signal Processing* Vol. 30, pp. 299–327.
8. Banon, G. J. F. and Barrera, J.: 1993, "A decomposition theorem in Mathematical Morphology". *Proceedings of the International Workshop on Mathematical Morphology and its Application to Signal Processing*, Barcelona, Spain, pp. 234–238.
9. Goutsias J., H.J.A.M. Heijmans H.J.A.M., Sivakumar K., *Morphological operators for image sequences*, *Computer Vision and Image Understanding* 62 (3) (1995) 326–346.
10. Serra J., *Anamorphoses and Function Lattices (Multivalued Morphology)*, in: Dougherty (Ed.) *Mathematical Morphology in Image Processing*, MarcelDekker, 1992, pp. 483–523.
11. Talbot H., Evans C., Jones R.. *Complete ordering and multivariate mathematical morphology: algorithms and applications*, in: *Proceedings of the International Symposium on Mathematical Morphology (ISMM'98)*, Kluwer, 1998, pp. 27– 34.
12. Lantuéjoul, C. and Beucher, S. (1981). "On the use of the geodesic metric in image analysis", *J. Microsc.*, 121, 39-49.
13. Lantuéjoul, C. and F. Maisonneuve (1984). "Geodesic methods in Quantitative image Analysis", *Pattern Recognition*, 2, 177-187.
14. Pastore J, Moler E & Ballarin V. "Segmentation of brain magnetic resonance images through morphological operators and geodesic distance", *Digital Signal Processing*, Vol. 15, pp 153-60, 2005.
15. Vincent L.. "Morphological Grayscale Reconstruction in Image Analysis: Applications and efficient Algorithms", *IEEE Transactions On Image Processing*, vol 2, 1993. 176-201.
16. Pastore J., Bouchet A., Brun M. and Ballarin V. *New Windows based Color Morphological Operators for Biomedical Image Processing*. *Journal of Physics: Conference Series*. ISSN 1742-6596 (On-Line). ISSN 1742-6588 (Print). doi:10.1088/1742-6596/705/1/012023. 04/2016.
17. <http://veterinaryonline.blogspot.com.ar/2013/01/erythrocyte-in-animals-erythrocyte.html>.