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# PROCEEDING

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## **PROCEEDINGS**

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**19-21 September 2017, Yogyakarta, Indonesia**

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## TABLE OF CONTENTS

<p><b>High Performance Direct Torque Control of Induction Motor Drives: Problems and Improvements</b>            Nik Rumzi Nik Idris (UTM-PROTON Future Drive Laboratory, Universiti Teknologi Malaysia, Johor, Malaysia), Tole Sutikno (Department of Electrical Engineering, Universitas Ahmad Dahlan, Yogyakarta, Indonesia)</p>	1
<p><b>Towards Development of A Computerised System for Screening and Monitoring of Diabetic Retinopathy</b>            Hanung Adi Nugroho (Universitas Gadjah Mada, Indonesia)</p>	8
<p><b>Performance Analysis of Network Emulator Based On The Use Of Resources In Virtual Laboratory</b>            Yuri Ariyanto, Yan Watequlis Syaifudin, Budi Harijanto (State Polytechnic of Malang, Malang, East Java, Indonesia)</p>	9
<p><b>Teaching And Learning Support For Computer Architecture And Organization Courses Design On Computer Engineering and Computer Science For Undergraduate: A Review</b>            Wijaya Kurniawan, Mochammad Hannats Hanafi Ichsan (Brawijaya University, Malang, East Java, Indonesia)</p>	15
<p><b>WatsaQ: Repository of Al Hadith in Bahasa (Case Study: Hadith Bukhari)</b>            Atqia Aulia, Dewi Khairani, Rizal Broer Bahaweres, and Nashrul Hakiem (Department of Informatics, UIN Syarif Hidayatullah, Jakarta, Indonesia)</p>	21
<p><b>IoT Smart Device for e-Learning Content Sharing on Hybrid Cloud Environment</b>            Mohd. Yazid Idris, Deris Stiawan, Nik Mohd Habibullah, Abdul Hadi Fikri, Mohd Rozaini Abd Rahim, Massolehin Dasuki (Universiti Teknologi Malaysia, Johor Bahru, Malaysia)</p>	25
<p><b>Target Tracking in Mobile Robot under Uncertain Environment using Fuzzy Logic Controller</b>            Ade Silvia Handayani, Tresna Dewi, Nyayu Latifah Husni (State Polytechnic of Sriwijaya, Palembang, Indonesia), Siti Nurmaini, Irsyadi Yani (University of Sriwijaya, Palembang, Indonesia)</p>	30
<p><b>Nitrogen (N) Fertilizer Measuring Instrument On Maize-Based Plant Microcontroller</b>            Hendra Yufit Riskiawan, Taufiq Rizaldi, Dwi Putro S. Setyohadi, Tri Leksono (Information Technology Department, Politeknik Negeri Jember, Indonesia)</p>	35
<p><b>Reconfigurable Logic Embedded Architecture of Support Vector Machine Linear Kernel</b>            Jeevan Sirkunan, N. Shaikh-Husin and M. N. Marsono (Fac. of Electrical Eng., Universiti Teknologi Malaysia, Johor, Malaysia), Trias Andromeda (Diponegoro University, Semarang, Indonesia)</p>	39

<p><b>An Analysis of Concentration Region on Powerpoint Slides using Eye Tracking</b></p> <p>Fergyanto E. Gunawan, Oky Wijaya, Benfano Soewito , Sevenpri Candra Diana (Bina Nusantara University, Jakarta, Indonesia) Cosmas E. Suharyanto( Putera Batam University, Riau Archipelago, Indonesia)</p>	44
<p><b>Implementation of K-Means Clustering Method to Distribution of High School Teachers</b></p> <p>Triyanna Widiyaningtyas, Martin Indra Wisnu Prabowo, M. Ardhika Mulya Pratama (Electrical Engineering Departement, Universitas Negeri Malang, Malang, Indonesia)</p>	49
<p><b>Incremental High Throughput Network Traffic Classifier</b></p> <p>H. R. Loo, Alireza Monemi, and M. N. Marsono (Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Johor, Malaysia), Trias Andromeda ( Diponegoro University, Semarang, Indonesia)</p>	55
<p><b>Edge Detection on Objects of Medical Image with Enhancement multiple Morphological Gradient Method</b></p> <p>Jufriadif Na`am (Computer Science Faculty, Universitas Putra Indonesia YPTK, Padang, Indonesia)</p>	61
<p><b>Unified Concept-based Multimedia Information Retrieval Technique</b></p> <p>Ridwan Andi Kambau, Zainal Arifin Hasibuan (Faculty of Computer Science, University of Indonesia, Depok, West Java, Indonesia)</p>	68
<p><b>Text Modeling In Adaptive Educational Chat Room Based On Madamira Tool</b></p> <p>Jehad A. H. Hammad, Mochamad Hariadi, Mauridhi Hery Purnomo (Department of Computer Engineering, Institut Teknologi Sepuluh Nopember (ITS) Surabaya, Indonesia), Nidal A. M Jabari (Department of Computer, Technical Colleges(Arroub), Palestine)</p>	76
<p><b>Analysis of Statement Branch and Loop Coverage in Software Testing With Genetic Algorithm</b></p> <p>Rizal Broer Bahaweres<sup>1,2</sup>, Khoirunnisya Zawawi<sup>1</sup>, Dewi Khairani<sup>1</sup>, Nashrul Hakiem<sup>1</sup> (<sup>1</sup>Department of Informatics, Syarif Hidayatullah State Islamic University, Jakarta, Indonesia <sup>2</sup>Faculty of Computer Science, NRU Higher School of Economics, Moscow, Russia )</p>	82
<p><b>Combining Deep Belief Networks and Bidirectional Long Short-Term Memory Case Study: Sleep Stage Classification</b></p> <p>Intan Nurma Yulita<sup>ab</sup>, Mohamad Ivan Fanany<sup>a</sup>, Aniati Murni Arymurthy<sup>a</sup> (<sup>a</sup>Faculty of Computer Science, Universitas Indonesia, Depok, Indonesia, <sup>b</sup>Department of Computer Science, Universitas Padjadjaran, Sumedang, Indonesia)</p>	88
<p><b>Improvement of eGov &amp; mGov in Multilingual Countries with Digital Etymology using Sanskrit Grammar</b></p> <p>Arijit Das</p>	91



<p><b>EEG Based Emotion Monitoring Using Wavelet and Learning Vector Quantization</b> Esmeralda C. Djamal and Poppi Lodaya (Universitas Jenderal Achmad Yani, Bandung, Indonesia)</p>	94
<p><b>Myoelectric control systems for hand rehabilitation device: a review</b> Khairul Anam, Ahmad Adib Rosyadi, Bambang Sujanarko (University of Jember, Jember, Indonesia), Adel Al-Jumaily (School of Biomedical Engineering, University of Technology, Sydney, Australia)</p>	100
<p><b>Variance Analysis of Photoplethysmography for Blood Pressure Measurement</b> Hendrana Tjahjadi, Kalamullah Ramli (Departement of Electrical Engineering, Universitas Indonesia, Depok, Indonesia)</p>	106
<p><b>Implementation of Unbiased Stereology Method for Organ Volume Estimation using Image Processing</b> Mohammad Ammar Faiq, Balza Achmad, Ginus Partadiredja (Universitas Gadjah Mada Yogyakarta, Indonesia)</p>	110
<p><b>Ethnobotany Database: Exploring diversity medicinal plants of Dayak Tribe Borneo</b> Haeruddin<sup>1</sup>, Ummul Hairah<sup>1</sup>, Edy Budiman<sup>1</sup>, Herni Johan (Department of Computer Science and Information Technology, Universitas Mulawarman Samarinda - Indonesia, <sup>2</sup>Departement of Mutiara Mahakam Academy of Midwifery, AKBID Samarinda, Samarinda - Indonesia)</p>	116
<p><b>Automated Post-Trabeculectomy Bleb Assesment by Using Image Processing</b> Agwin Fahmi Fahanani, Hasballah Zakaria, Andika Prahasta, Elsa Gustianty, R. Maula Rifada, Astrid Chairini (Department of Biomedical Engineering, Institut Teknologi Bandung, Bandung, Indonesia)</p>	122
<p><b>Non-invasive Hemoglobin Measurement for Anemia Diagnosis</b> Raditya Artha Rochmanto , Hasballah Zakaria, Ratih Devi Alviana , Nurhalim Shahib ( <sup>1</sup>Department of Biomedical Engineering, Institut Teknologi Bandung, <sup>2</sup>Medical Faculty Padjajaran University Bandung, Indonesia Bandung, Indonesia)</p>	125
<p><b>Poincaré plot of fingertip photoplethysmogram pulse amplitude suitable to assess diabetes status</b> Bagus Haryadi<sup>1,2</sup>, Lin, Gen-Min<sup>2</sup>; Yang, Chieh-Ming<sup>2</sup>; Chu, Shiao- Chiang<sup>2</sup>; Wu, Hsien-Tsai ( Department of Electrical Engineering National Dong-Hwa University Hualien, Taiwan)</p>	130
<p><b>Certain Factor Analysis for Extra Pulmonary Tuberculosis Diagnosis</b> Ramadiani, Nur Aini, Heliza Rahmania Hatta, Fahrul Agus, Zainal Ariffin, Azainil (Mulawarman University, Samarinda, Indonesia)</p>	134

<p><b>The Improvement of Phonocardiograph Signal (PCG) Representation Through the Electronic Stethoscope</b> Sumarna, Juli Astono, Agus Purwanto, Dyah Kurniawati Agustika (Universitas Negeri Yogyakarta)</p>	141
<p><b>Neural Network on Mortality Prediction for the Patient Admitted with ADHF (Acute Decompensated Heart Failure)</b> M. Haider Abu Yazid, Shukor Talib, Muhammad Haikal Satria (Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia) Azmee Abd Ghazi (National Heart Institute (IJN), Kuala Lumpur, Malaysia)</p>	146
<p><b>Measurement Of Maximum Value Of Dental Radiograph To Predict The Bone Mineral Density</b> Sri Lestari, Mohammad Diqi (Faculty of Science and Technology, UNRIYO Yogyakarta, Indonesia), Rini Widyaningrum (Departement of Dentomaxillofacial Radiology Faculty of Dentistry, Universitas Gadjah Mada Yogyakarta, Indonesia)</p>	152
<p><b>Feature Extraction and Classification of Thorax X-Ray Image in the Assessment of Osteoporosis</b> Riandini, Mera Kartika Delimayanti (Politeknik Negeri Jakarta Kampus UI Depok West Java)</p>	156
<p><b>2D-Sigmoid Enhancement Prior to Segment MRI Glioma Tumour Pre Image-Processing</b> Setyawan Widyarto, Siti Rafidah Binti Kassim (Faculty of Communication, Visual Art and Computing, UNISEL, Kuala Selangor, Malaysia), Widya Kumala Sari (Alumni of Faculty of Medicine, Universitas Gadjah Mada Indonesia)</p>	161
<p><b>Alerting System for Sport Activity Based on ECG Signals using Proportional Integral Derivative</b> Vika Octaviani, Arief Kurniawan, Yoyon Kusnendar Suprpto, Ahmad Zaini (Institut Teknologi Sepuluh Nopember, Surabaya Indonesia)</p>	166
<p><b>Design of Automatic Switching Bio-Impedance Analysis (BIA) for Body Fat Measurement</b> Munawar A Riyadi, Achmad Ngaqib Muthouwali, Teguh Prakoso (Department of Electrical Engineering, Diponegoro University, Semarang, Indonesia)</p>	172
<p><b>Precise Wide Baseline Stereo Image Matching for Compact Digital Cameras</b> Martinus Edwin Tjahjadi, Fourry Handoko (National Institute of Technology (ITN) Malang, Malang, Indonesia)</p>	177
<p><b>Robust and Imperceptible Image Watermarking by DC Coefficients Using Singular Value Decomposition</b></p>	183

Christy Atika Sari, Eko Hari Rachmawanto, De Rosal Ignatius Moses Setiadi (Dian Nuswantoro University (UDINUS), Semarang, Indonesia)	
<b>Region of Interest Detection for Pregnancy Image Processing</b> M. Khairudin, Joko Laras B T, Dessy Irmawati (Universitas Negeri Yogyakarta, Yogyakarta, Indonesia)	188
<b>Shape Defect Detection for Product Quality Inspection and monitoring System</b> Norhashimah Mohd Saad <sup>1</sup> , Nor Nabilah Syazana Abdul Rahman <sup>1</sup> , Abdul Rahim Abdullah (Universiti Teknikal Malaysia Melaka, Durian Tunggal, Melaka), Farhan Abdul Wahab (Infineon Technologies Sdn. Bhd, Batu Berendam, Melaka)	192
<b>Toward a New Approach in Fruit Recognition using Hybrid RGBD Features and Fruit Hierarchy Property</b> Ema Rachmawati, Iping Supriana, Masayu Leylia Khodra (School of Electrical Engineering and Informatics, Institut Teknologi Bandung)	198
<b>Mobile Content Based Image Retrieval Architectures</b> Arif Rahman (Universitas Ahmad Dahlan), Edi Winarko, Moh. Edi Wibowo (Universitas Gadjah Mada, Yogyakarta, Indonesia)	204
<b>Computer Vision Based Object Tracking as a Teaching Aid for High School Physics Experiments</b> G.D. Illeperuma (The Open University of Sri Lanka, Nawala, Nugegoda, Sri Lanka), D.U.J. Sonnadara (University of Colombo, Sri Lanka)	208
<b>Texture Analysis and Fracture Identification of Lower Extremity Bones X-Ray Images</b> Rahayu Suci Prihatini, Anif Hanifa Setyaningrum, Imam Marzuki Shofi (Departement of Informatics Engineering, UIN Syarif Hidayatullah, Jakarta, Indonesia)	214
<b>Analysis of the Indonesian Vowel /e/ For Lip Synchronization Animation</b> Anung Rachman, Risanuri Hidayat, Hanung Adi Nugroho (Universitas Gadjah Mada, Yogyakarta, Indonesia)	219
<b>Anti-Cheating Presence System Based on 3WPCA- Dual Vision Face Recognition</b> Edy Winarno, Wiwien Hadikurniawati, Imam Husni Al Amin, Muji Sukur (Faculty of Information Technology, Universitas Stikubank Semarang Indonesia)	224
<b>Sketch Plus Colorization Deep Convolutional Neural Networks for Photos Generation from Sketches</b> Vinnia Kemala Putri and Mohamad Ivan Fanany (Faculty of Computer Science, Universitas Indonesia, Depok, West-Java Indonesia)	229
<b>Imperceptible Image Watermarking based on Chinese Remainder Theorem over the Edges</b> Prajanto Wahyu Adi, Yani Parti Astuti, Egia Rosi Subhiyakto (Department of	235

Informatics Engineering Universitas Dian Nuswantoro (UDINUS) Semarang, Indonesia)	
<b>Wood Texture Detection with Conjugate Gradient Neural Network Algorithm</b> Setyawan Widyarto, I Nyoman Suryasa , Otto Fajarianto (Universitas Budi Luhur, Jakarta, Indonesia), Mohd Shafry Mohd Rahim (Universiti Teknologi Malaysia, Johor Bahru, Malaysia), Khairul Annuar bin Abdullah (Universiti Selangor, Malaysia), Gigih Priyandoko, Gilang Anggit Budaya (Universiti Malaysia Pahang, Malaysia)	240
<b>Spoken Word Recognition Using MFCC and Learning Vector Quantization</b> Esmeralda C. Djamal, Neneng Nurhamidah and Ridwan Ilyas (Universitas Jenderal Achmad Yani, Bandung, Indonesia)	246
<b>A Hierarchical Description-based Video Monitoring System for Elderly</b> Mochamad Irwan Nari, Agung Wahyu Setiawan and Widyawardana Adiprawita (Institut Teknologi Bandung, Indonesia)	252
<b>Performance Measurement Based on Coloured Petri Net Simulation of Scalable Business Processes</b> Abd. Charis Fauzan, Riyanarto Sarno, Muhammad Ainul Yaqin (Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia)	257
<b>The Design a System of Retention and Control on Broiler Farms Based on The Flow of Data</b> Ahmad Sanmorino, Isabella (Universitas Indo Global Mandiri, Palembang, Indonesia)	263
<b>Empirical Investigation on Factors Related to Individual of Impact Performance Information System</b> Tri Lathif Mardi Suryanto, Nur Cahyo Wibowo (Universitas Pembangunan Nasional “Veteran” Jawa Timur), Djoko Budiyanto Setyohadi (Universitas Atma Jaya Yogyakarta, Indonesia)	267
<b>Comparative Study of Web3D Standard Format to Determine the Base Format for A Web3D Framework</b> Mursid W. Hananto, Ahmad Ashari, Khabib Mustofa (Universitas Gadjah Mada, Yogyakarta, Indonesia)	273
<b>Task-Technology Fit for Textile Cyberpreneur’s Intention to Adopt Cloud-Based M-Retail Application</b> Nik Zulkarnaen Khidzir, Wan Safra Diyana, Wan Abdul Ghani, Tan Tse Guan (Faculty of Creative Technology and Heritage, Universiti Malaysia Kelantan, Bachok, Malaysia), Mohammad Ismail (Faculty of Entrepreneurship and Business, Universiti Malaysia Kelantan, Kota Bharu, Malaysia)	279
<b>MAKASSAR SMART CITY OPERATION CENTER PRIORITY OPTIMIZATION USING FUZZY MULTI-CRITERIA DECISION-MAKING</b>	285

Fachrul Kurniawan, Supeno Mardi Susiki Nugroho, Mochamad Hariadi (Institut Teknologi Sepuluh Nopember (ITS), Surabaya), Aji Prasetya Wibawa (Universitas Negeri Malang), Munir (Universitas Pendidikan Indonesia, Bandung, Indonesia)	
<b>Ontology-Based Sentence Extraction for Answering Why-Question</b> A. A. I. N. Eka Karyawati (Department of Computer Science, Faculty of Mathematics and Natural Sciences, Udayana University, Bali, Indonesia)	290
<b><i>The Ontology-Based Methodology Phases To Develop Multi-Agent System (OmMAS)</i></b> Arda Yunianta, Omar Obarukab , Norazah Yusof (King Abdulaziz University, Rabigh, Saudi Arabia), Aina Musdholifah (Gadjah Mada University, Indonesia), Nataniel Dengen, Haviluddin (Mulawarman University, Indonesia), Herlina Jayadiyanti (UPN Veteran Yogyakarta, Indonesia), Mohd Shahizan Othman (University Teknologi Malaysia, Malaysia).	296
<b>Scalability Measurement of Business Process Model Using Business Processes Similarity and Complexity</b> Muhammad Ainul Yaqin, Riyanarto Sarno, Abd. Charis Fauzan (Informatics Department, Institut Teknologi Sepuluh Nopember)	302
<b>Smartphone for Next Generation Attendance System and Human Resources Payroll System</b> Benfano Soewito, Fergyanto E. Gunawan (Binus Graduate Programs Bina Nusantara University Jakarta, Indonesia), Manik Hapsara (University of New South Wales Canberra, Australia)	309
<b>Enhancing Online Business Marketing to Expand Market Shares through IT Governance</b> Sandy Kosasi, Vedyanto, I Dewa Ayu Eka Yuliani (Information System Department STMIK Pontianak Pontianak, West Kalimantan, Indonesia)	315
<b>A Generic Framework for Information Security Policy Development</b> Wan Basri Wan Ismail, Raja Ahmad Tariqi Raja Ahmad, Setyawan Widyarto (Faculty of Communication, Visual Art and Computing University of Selangor Malaysia), Khatipah Abd Ghani (Faculty of Education and Social Science University of Selangor Malaysia )	320
<b>Modeling IT Value based on Meta-Analysis</b> Suhardi, Novianto Budi Kurniawan, Aan Subrata, Jaka Sembiring (School of Electrical Engineering and Informatics Institut Teknologi Bandung Bandung, Indonesia)	326
<b>A Combination of The Evolutionary Tree Miner and Simulated Annealing</b> Afina Lina Nurlaili, Riyanarto Sarno (Department of Informatics Institut	332

Teknologi Sepuluh Nopember Surabaya, Indonesia)	
<b>Scalable Attack Analysis of Business Process based on Decision Mining Classification</b> Dewi Rahmawati, Riyanarto Sarno (Informatics Department, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia)	337
<b>Service Computing System Engineering Life Cycle</b> Suhardi, Novianto Budi Kurniawan, Jaka Sembiring (School of Electrical Engineering and Informatics, Institut Teknologi Bandung, Bandung, Indonesia)	343
<b>High Efficiency Single Phase Inverter Design</b> Didi Istaridi (Politeknik Negeri Batam, Indonesia)	349
<b>Analysis of Electric Circuit Model on Atmospheric Pressure Dielectric Barrier Discharge (DBD) Plasma</b> Suyadi, Jatmiko E Suseno, Muhammad Nur (Diponegoro University)	352
<b>COMPRESSED NATURAL GAS (CNG) TECHNOLOGY FOR FUEL POWER PLANTS</b> Isworko Pujotomo, Retno Aita Diantari (College of Engineering – PLN Foundation for Education & Welfare PT. PLN (Persero) Jakarta, Indonesia)	352
<b>PID Designs Using DE and PSO Algorithms For Damping Oscillations in a DC Motor Speed</b> Lailis Syafaah, Widiyanto, Ilham Pakaya, Diding Suhardi, M. Irfan (Department of Electrical Engineering, The University of Muhammadiyah Malang, Indonesia)	354
<b>Measurement of Partial Discharge Induced Electromagnetic Wave using Loop Antenna</b> Umar Khayam, Fendi Imam Fatoni (School of Electrical Engineering and Informatics, Bandung Institute of Technology, Bandung, Indonesia)	359
<b>The Effect of Coating on Leakage Current Characteristic of Coast Field Aged Ceramic Insulator</b> Dini Fauziah*, Heldi Alfiadi, Rachmawati, Suwarno (School of Electrical Engineering and Informatics, Institut Teknologi Bandung, Bandung, Indonesia)	363
<b>Renewable Energy Inclusion on Economic Power Optimization using Thunderstorm Algorithm</b> A.N. Afandi (Universitas Negeri Malang, Jawa Timur, Indonesia), Goro Fujita, Nguyen Phuc Khai (Shibaura Institute of Technology, Tokyo, Japan), Yunis Sulistyorini (IKIP Budi Utomo, Malang, Indonesia), Nedim Tutkun (Duzce University, Duzce, Turkey)	369
<b>Optimum Phase Number for Multiphase PWM Inverters</b> Anwar Muqorobin, Pekik Argo Dahono and Agus Purwadi (School of Electrical Engineering and Informatics, Institute of Technology Bandung, Bandung, Indonesia)	375

<p><b>Small-Disturbance Angle Stability Enhancement using Intelligent Redox Flow Batteries</b></p> <p>Mohammad Taufik (Padjadjaran University, Sumedang, Indonesia), Dwi Lastomo (University of PGRI Adi Buana, Surabaya, Indonesia), Herlambang Setiadi (School of Information Technology &amp; Electrical Engineering, The University of Queensland Brisbane, Australia)</p>	381
<p><b>Evaluation Study of Waste Materials for Renewable Energy through 3R Model in Bogor City</b></p> <p>Didik Notosudjono, Dede Suhendi, Engkos, Bagus Dwi Ramadhon (Electrical Engineering Department, Universitas Pakuan, Bogor, Indonesia)</p>	387
<p><b>Measurement of Partial Discharge inside Metal Enclosed Power Apparatus using Internal Sensor</b></p> <p>Umar Khayam, Yushan (School of Electrical Engineering and Informatics Bandung Institute of Technology Bandung, Indonesia)</p>	391
<p><b>Design Unmanned Aerial Vehicle Integrated Camera Near Infra-Red to Observe the Plant Health</b></p> <p>Rizki Wahyu Pratama, Ferry Hadary , Redi Ratiandi Yacoub (Jurusan Teknik Elektro Fakultas Teknik Universitas Tanjungpura)</p>	397
<p><b>Single Frame Resection of Compact Digital Cameras for UAV Imagery</b></p> <p>Martinus Edwin Tjahjadi (Department of Geodesy, National Institute of Technology (ITN) Malang, Indonesia)</p>	401
<p><b>A MOVING OBJECTS DETECTION IN UNDERWATER VIDEO USING SUBTRACTION OF THE BACKGROUND MODEL</b></p> <p>M. R. Prabowo, N. Hudayani, S. Purwiyanti, S. R. Sulistiyanti, F. X. A. Setyawan (Department of Electrical Engineering, Faculty of Engineering University of Lampung, Bandar Lampung, Indonesia)</p>	406
<p><b>Fall Detection Based on Accelerometer and Gyroscope using Back Propagation</b></p> <p>Adlian Jefiza (Institut Teknologi Sepuluh Nopember, Surabaya Indonesia)</p>	410
<p><b>Honey Yield Prediction Using Tsukamoto Fuzzy Inference System</b></p> <p>Tri Hastono, Albertus Joko Santoso, Pranowo(Universitas Atma Jaya Yogyakarta, Indonesia)</p>	416
<p><b>Determining The Nutrition of Patient Based on Food Packaging Product Using Fuzzy C Means Algorithm</b></p> <p>Sri Winiarti, Sri Kusumadewi, Izzati Muhimmah, Herman Yuliansyah (Universitas Ahmad Dahlan Yogyakarta, Indonesia)</p>	422

<p><b>The Successful Elements Implementing the eLearning using Cloud Services Data Centre at Private Institution of Higher Learning in Malaysia</b></p> <p>Azlinda Abdul Aziz, Setyawan Widyarto , Salyani Osman , Suziyanti Marjudi (Department of Computing, Faculty of Communication, Visual Art and Computing, UNISEL, Kuala Selangor, Malaysia)</p>	428
<p><b>Improving E-Book Learning Experience by Learning Recommendation</b></p> <p>Fergyanto E. Gunawan, Benfano Soewito (Binus Graduate Programs, Bina Nusantara University, Jakarta, Indonesia), and Sevenpri Candra (School of Business Management, Bina Nusantara University, Jakarta, Indonesia).</p>	433
<p><b>A Comparison of Cloud Execution Mechanisms: Fog, Edge and Clone Cloud Computing</b></p> <p>Tina Francis (Computer Department, BITS Pilani, Dubai Campus, DIAC Dubai, UAE) , Dr. Muthiya Madhijagan (SCOPE (School of Computer Science and Engineering) VIT University, Vellore Tamil Nadu, India)</p>	436
<p><b>Recommendation System on Knowledge Management System via OAI-PMH</b></p> <p>Nyoman Karna, Iping Supriana, Nur Maulidevi (Sekolah Teknik Elektro dan Informatika Institut Teknologi Bandung, Indonesia)</p>	438
<p><b>Development and Evaluation of Android Based Notification System to Determine Patient's Medicine for Pharmaceutical Clinic</b></p> <p>Imam Riadi, Sri Winiarti, Herman Yuliansyah (Department of Informatics Universitas Ahmad Dahlan Yogyakarta)</p>	443
<p><b>Implementation of Decision Expert (DEX) in The "SALADGARDEN" Application</b></p> <p>Anita Hidayati, Fityan Aula Juyuspan, Cindy Novianty, Muhammad Bima D S (Computer and Informatics Engineering Jakarta State Polytechnic Depok, Indonesia)</p>	448
<p><b>Optimizing Effort and Time Parameters of COCOMO II Estimation using Fuzzy Multi-Objective PSO</b></p> <p>Kholed Langsari, Riyanarto Sarno (Department of Informatics Engineering Institut Teknologi Sepuluh Nopember Surabaya, Indonesia)</p>	453
<p><b>Evaluation Of Knowledge Management System Using Technology Acceptance Model</b></p> <p>Jarot S. Suroso, Astari Retnowardhani, Abraham Fernando (Bina Nusantara University Jakarta, Indonesia)</p>	459
<p><b>Deep learning on curriculum study pattern by selective cross join in advising students' study path</b></p>	454



Tekad Matulatan (Universitas Maritim Raja Ali Haji, Tanjung Pinang, Indonesia), Muhammad Resha (Universitas Hasanuddin, Makassar, Indonesia)	
<b>Revealing Daily Human Activity Pattern using Process Mining Approach</b> Muhammad Rifqi Ma'arif (Department of Information Management, STMIK Jenderal A. Yani Yogyakarta)	469
<b>Information Technology Governance Assessment in Universitas Atma Jaya Yogyakarta using COBIT 5 Framework</b> Gabriella Sabatini, Djoko Budiyanto, Setyohadi Yohanes Sigit Purnomo W. P. (Teknik Informatika, Universitas Atma Jaya Yogyakarta, Indonesia)	474
<b>Forecasts Marine Weather On Java Sea Using Hybrid Methods: TS-ANFIS</b> Deasy Alfiah Adyanti, Ahmad Hanif Asyhar, Dian Candra Rini Novitasari, Ahmad Lubab, Moh. Hafiyusholeh (Mathematics Department Islamic State University of Sunan Ampel Surabaya, Indonesia)	479
<b>Opinion Detection of Public Sector Financial Statements Using K-Nearest Neighbors</b> Ahmad Dwi Arianto, Achmad Affandi (Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia), Supeno Mardi Susiki Nugroho (Badan Pemeriksa Keuangan Republik Indonesia, Jakarta, Indonesia)	485
<b>Encryption System based on a Structured Matrix: Vandermonde Matrix</b> Hana Ali-Pacha, Naima Hadj-Said and Adda Ali Pacha (University of Sciences and Technology of Oran, Oran M'Naouer Algeria)	489
<b>Designing Multi-Channel Service Desk Based onITIL Version 3</b> Ahmad Sahrizal (ITB, Indonesia)	489
<b>A Reactive Path Planning Approach for a Four-Wheel Robot by the Decomposition Coordination Method</b> Hala El Ouarrak, Mostafa Rachik (Faculty of Science Ben M'Sik, Sidi Othmane, Casablanca, Morocco), Ibrahim Sanou, Fatiha Akef and Mohammed Mestari (ENSET Mohammedia Av Hassan II Mohammedia, Morocco)	490
<b>Adaptive-Fuzzy-PID Controller Based Disturbance Observer for DC Motor Speed Control</b> Zulfatman Has, Ahzen Habibidin Muslim, Nur Alif Mardiyah (Department of Electrical Engineering, University of Muhammadiyah Malang, Indonesia)	496
<b>Extra Robotic Thumb and Exoskeleton Robotic Fingers for Patient with Hand Function Disability</b> Rifky Ismail, Mochammad Ariyanto and Kharisma Pambudi (Diponegoro University, Indonesia)	502
<b>Parameterized Kick Engine For R-SCUAD Robot</b> Nuryono Widodo (Universitas Ahmad Dahlan, Indonesia)	508

<p><b>Neural Network Controller Design for a Mobile Robot Navigation; a Case Study</b></p> <p>Tresna Dewi, Pola Risma, Yurni Oktarina, and M. Taufik Roseno (Politeknik Negeri Sriwijaya Palembang, Indonesia)</p>	512
<p><b>Redirection Concept of Autonomous Mobile Robot HY-SRF05 Sensor to Reduce The Number of Sensors</b></p> <p>Nuryanto, Andi Widiyanto, Auliya Burhanuddin (Engineering Faculty, Universitas Muhammadiyah Magelang, Indonesia)</p>	517
<p><b>Autonomous Navigation for an Unmanned Aerial Vehicle by the Decomposition Coordination Method</b></p> <p>Chaimaa Jihane □, Hala El Ouarrak †, and Mohamed Mestari □, Mostafa Rachik † (□Ecole Normale Suprieure d'Enseignement Technique Mohammedia, Av Hassan II Mohammedia, Morocco, †Faculty of Science Ben M'Sik, Casablanca, Morocco)</p>	521
<p><b>Design of PID Disturbance Observer for Temperature Control on Room Heating System</b></p> <p>Yoga Alif Kurnia Utama (Electronic Engineering Department, University of Widya Kartika, Surabaya, Indonesia)</p>	527
<p><b>Development of Low Cost Supernumerary Robotic Fingers as an Assistive Device</b></p> <p>Mochammad Ariyanto*, Rifky Ismail, Joga Dharma Setiawan, Zainal Arifin (Department of Mechanical Engineering, Diponegoro University, Semarang, Indonesia)</p>	533
<p><b>Design of A Microchip Optical Switching Driven by Low Direct-Current Voltage</b></p> <p>Dedi Irawan (Islamic State University of Sultan Syarif Kasim Riau, Pekanbaru, Indonesia)</p>	539
<p><b>A Web-Based Wireless Sensor System to Measure Carbon Monoxide Concentration</b></p> <p>Suryono, Ragil Saputra, Bayu Surarso, Ali Bardadi (Diponegoro University, Semarang, Indonesia)</p>	544
<p><b>Detecting the Early Drop of Attention using EEG Signal</b></p> <p>Fergyanto E. Gunawan, Krisantus Wanandi, Benfano Soewito (Binus Graduate Programs, Bina Nusantara University, Jakarta, Indonesia), Sevenpri Candra (School of Business Management, Bina Nusantara University)</p>	549
<p><b>The Design of a Smart Refrigerator Prototype</b></p> <p>Z. Ali, S. E. Esmaeili (Department of Electrical and Computer Engineering, American University of Kuwait, Salmiya, Kuwait)</p>	554
<p><b>Odor Localization using Gas Sensor for Mobile Robot</b></p>	555

Nyayu Latifah Husni, Ade Silvia Handayani (State Polytechnic of Sriwijaya, Palembang, Indonesia), Siti Nurmaini, Irsyadi Yani (University of Sriwijaya, Palembang, Indonesia)	
<b>A Project-Based Approach to FPGA-Aided Teaching of Digital Systems</b> Fajar Suryawan (Universitas Muhammadiyah Surakarta, Indonesia)	561
<b>Performance of Routing Protocol in MANET with Combined Scalable Video Coding</b> Parma Hadi Rantelinggi, Fridolin Febrianto Paiki (Universitas Papua Manokwari, Indonesia), Kalvein Rantelobo (Universitas Nusa Cendana Kupang, Indonesia)	567
<b>Attack Scenarios and Security Analysis of MQTT Communication Protocol in IoT System</b> Syaiful Andy, Budi Rahardjo, Bagus Hanindhito (Institut Teknologi Bandung, Bandung, Indonesia)	571
<b>Encoding of passive anticollision radio-frequency identification surface acoustic waves tags</b> Alexander Sorokin, Alexander Shepeta, Maurits Wattimena (Major Problem-Oriented Computer Complexes Department, State University of Aerospace Instrumentation (SUAI), St. Petersburg, Russia)	575
<b>Compact Fractal Patch Microstrip Antenna Fed by Coplanar Waveguide for Long Term Evolution Communications</b> Indra Surjati (Universitas Trisakti , Jakarta, Indonesia)	576
<b>Graphical Approach for RF Amplifier Specification in Radio over Fiber System: Maximum Power Issues</b> Teguh Prakoso, Munawar Agus Riyadi (Universitas Diponegoro, Semarang, Indonesia), Razali Ngah (Universiti Teknologi Malaysia, Johor Bahru, Malaysia)	580
<b>FEM Modeling of Squeeze Film Damping Effect in RF-MEMS Switches</b> Syed Turab Haider (Department of Electrical Engineering, National University of Sciences and Technology, Islamabad, Pakistan)	585
<b>The Onion Routing Performance using Shadow-plugin-TOR</b> Hartanto Kusuma Wardana, Liauw Frediczen Handianto, Banu Wirawan Yohanes* (Faculty of Electronic and Computer Engineering, Universitas Kristen Satya Wacana, Salatiga, Indonesia)	592
<b>Position Tracking for Static Target using Burst Signals with Time Difference of Arrival Method</b> Romi Wiryadinata, Alia Shaliha Amany, Imamul Muttakin (Department of Electrical Engineering, University of Sultan Ageng Tirtayasa, Cilegon, Indonesia)	597
<b>Performance Analysis for MIMO LTE on the High Altitude Platform Station</b> Catur Budi Waluyo, Yenni Astuti (Department of Electrical Engineering, Sekolah Tinggi Teknologi Adisutjipto, Yogyakarta, Indonesia)	603

<p><b>Software Defined Radio Design for OFDM Based Spectrum Exchange Information Using Arduino UNO and X-Bee</b></p> <p>Arief Marwanto (Univ. Islam Sultan Agung (UNISSULA) Semarang – Indonesia), Sharifah Kamilah Syed Yusof, Muhammad Haikal Satria (Universiti Teknologi Malaysia (UTM) Johor Bahru – Malaysia)</p>	608
<p><b>Performance Rate for Implementation of Mobile Learning in Network</b></p> <p>Edy Budiman, Usfandi Haryaka, Jefferson Roosevelt Watulingas (Universitas mulawarman, Samarinda – Indonesia), Faza Alameka (Universitas Ahmad Dahlan, Yogyakarta - Indonesia)</p>	613
<p><b>Performance Evaluation of IPv6 Jumbogram Packets Transmission using Jumbo Frames</b></p> <p>Supriyanto, Rian Sofhan, Rian Fahrizal (Department of Electrical Engineering, University of Sultan Ageng Tirtayasa, Indonesia), Azlan Osman (School of Computer Sciences, Universiti Sains Malaysia, Penang, Malaysia)</p>	619
<p><b>Performance Analysis of CSI:T Routing in a Delay Tolerant Networks</b></p> <p>Hardika Kusuma Putri, Leanna Vidya Yovita, and Ridha Muldina Negara (Telkom University, Bandung, Indonesia)</p>	624
<p><b>A Study of the Number of Wavelengths Impact in the Optical Burst Switching Core Node</b></p> <p>Hani A. M. Harb (Faculty of CSIT, Baha University, AL-Baha, Saudi Arabia), Waleed M. Gaballah (Al-Baha Private College of Science, AL-Baha, Saudi Arabia), Ahmed S. Samra Ahmed Abo-Taleb (Mansoura University, Egypt), Arief Marwanto (Sultan Agung Islamic Univ. Semarang, Indonesia)</p>	630
<p><b>A Reconfigurable MIMO Antenna System for Wireless Communications</b></p> <p>Evizal Abdul Kadir (Department of Information Technology, Faculty of Engineering, Universitas Islam Riau, Pekanbaru, Riau, Indonesia)</p>	634
<p><b>Conceptual Framework for Public Policymaking based on System Dynamics and Big Data</b></p> <p>Feldiansyah Bin Bakri Nasution, Nor Erne Nazira Bazin (Universiti Teknologi Malaysia (UTM) Johor Bahru, Malaysia), Hasanuddin (Faculty of Social and Politic Sciences, Riau University, Indonesia)</p>	638
<p><b>Discovering Process Model from Event Logs by Considering Overlapping Rules</b></p> <p>Yutika Amelia Effendi, Riyanarto Sarno (Department of Informatics Faculty of Information Technology, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia)</p>	645

<p><b>CHMM for Discovering Intentional Process Model From Event Logs By Considering Sequence of Activities</b></p> <p>Kelly R. Sungkono, Riyanarto Sarno ( Department of Informatics Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia)</p>	651
<p><b>Sosio-Technical Factors of E-Government Implementation</b></p> <p>Darmawan Napitupulu (LIPI, Indonesia); Dana Sensuse (Laboratory of E-Government, Indonesia); Yudho Sucahyo (University of Indonesia, Indonesia)</p>	657
<p><b>Methodology for Constructing Form Ontology</b></p> <p>U. Ungkawa, D. H. Widyantoro &amp; B. Hendradjaya (School of Electrical Engineering and Informatics, Institut Teknologi Bandung, Bandung, Indonesia)</p>	663
<p><b>Integration Protocol Student Academic Information to Campus RFID Gate Pass System</b></p> <p>Hendra Gunawan and Evizal Abdul Kadir (Department of Information Technology, Faculty of Engineering, Universitas Islam Riau, Pekanbaru, Riau, Indonesia)</p>	669
<p><b>E-Learning Model for Equivalency Education Program in Indonesia</b></p> <p>Mesra Betty Yel (Faculty of Computer Science, STIKOM CKI, Jakarta, Indonesia), Sfenrianto (Master in Information Systems Management, Bina Nusantara University, Jakarta, Indonesia)</p>	675
<p><b>Developing E-Government Maturity Framework Based on COBIT 5 and Implementing in City Level:Case Study Depok City and South Tangerang City</b></p> <p>Fikri Akbarsyah Anza (Public Administration Department, Universitas Indonesia), Dana Indra Sensuse, Arief Ramadhan (Computer Science Department, Universitas Indonesia)</p>	680
<p><b>Analysis of Driving Skills based on Deep Learning using Stacked Autoencoders</b></p> <p>Takuya Kagawa, Naiwala P. Chandrasiri (Faculty of Information Kogakuin University, Tokyo, Japan)</p>	686
<p><b>Minimizing the Estimated Solution Cost with A* Search to Support Minimal Mapping Repair</b></p> <p>Inne Gartina Husein*, Benhard Sitohang, Saiful Akbar (Institut Teknologi Bandung)</p>	690
<p><b>The rule Extraction of Numerical Association Rule Mining Using Hybrid Evolutionary Algorithm</b></p> <p>Imam Tahyudin (Kanazawa University, Japan)</p>	696
<p><b>Discovering Drugs Combination Pattern Using FP- Growth Algorithm</b></p> <p>Rini Anggrainingsih, Nach Rowi Khoirudin, Haryono Setiadi (Informatics Dept Mathematics and Natural Science, UNS Surakarta, Indonesia )</p>	702

<p><b>Classifiers Evaluation: Comparison of Performance Classifiers Based on Tuples Amount</b></p> <p>Mochammad Yusa, Ema Utami (Department of Computer Science, Magister Teknik Informatika Universitas AMIKOM Yogyakarta, Indonesia)</p>	706
<p><b>Prediction of Rupiah Against US Dollar by Using ARIMA</b></p> <p>Adiba Qonita, Annas Gading Pertiwi, Triyanna Widiyaningtyas (Electrical Engineering Department, Universitas Negeri Malang, Malang, Indonesia)</p>	713
<p><b>Forming Heterogeneous Group in Cooperative Learning Process using Partitioning Around Medoids (PAM) and Equitable Distribution</b></p> <p>Imam Much Ibnu Subroto, Badieah Assegaf and Wardianto Eko Saputra (Universitas Islam Sultan Agung, Indonesia)</p>	718

# Odor Localization using Gas Sensor for Mobile Robot

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**Abstract**—This paper discusses the odor localization using Fuzzy logic algorithm. The concentrations of the source that is sensed by the gas sensors are used as the inputs of the fuzzy. The output of the Fuzzy logic is used to determine the PWM (Pulse Width Modulation) of driver motors of the robot. The path that the robot should track depends on the PWM of the right and left motors of the robot. When the concentration in the right side of the robot is higher than the middle and the left side, the fuzzy logic will give decision to the robot to move to the right. In that condition, the left motor is in the high speed condition and the right motor is in slow speed condition. Therefore, the robot will move to the right. The experiment was done in a conditioned room using a robot that is equipped with 3 gas sensors. Although the robot is still needed some improvements in accomplishing its task, the result shows that fuzzy algorithms are effective enough in performing odor localization task in mobile robot.

**Keywords**— odor localization; fuzzy logic; TGS.

## I. INTRODUCTION

The development of odor localization research has grown widely and rapidly. Most of the researches used static [1] and dynamic instruments [2], [3], [4]. In static system, the gas sensors were placed in determined spots. Some drawbacks of them occurred, such as ineffectiveness of the sensors due to the working areas of sensors that were limited by the static range between the sensors and the sources. It is contradictive with the dynamic system, i.e. the use of mobile instruments where the gas sensors are integrated to mobile robots or mobile devices. Being integrated to the mobile robots makes the gas sensors be able to reach wider areas. Although the range between the gas sensors and the sources still influence the working areas of mobile sensors, the wide areas can be achieved by mobile characteristics of the robots where gas sensors placed.

The localization of odor sources were widely investigated by researchers using simulation [5], [6], [7] or real experiments [8], [9], [10]. The effectiveness of the robots in localizing the sources depends on the methods used. Some of the previous researchers used the algorithms as follows: 1. imitated the behavior of the animals (chemotaxis and anemotaxis) [11], [12], [13]; 2. based on the flow of the fluid (fluxotaxis) [14], [15], [16]; 3. used entropy of the posterior probability field (infotaxis) [17], etc. However, most of the algorithms has drawbacks, such as low search accuracy and

efficiency due to their dependence on the wind direction [18]. Jiandong [18] tried to find another way using fuzzy logic to localize the odor. The path where the robot should go was determined by the rate change of the plume sensed by the 3 sensors mounted on it. Fuzzy logic was successful in controlling the trajectory of the robot. Even though, the validation of the fuzzy logic was done only in simulation. It was far from the real one. In this research, a real robot was developed and implemented in a real experiment. The robots were equipped with some gas sensors that have a task to supply the inputs data to the fuzzy logic algorithm.

Some other researchers also used fuzzy logic in their experiments of odor localization [19], [20], [21], [22]. Most of them used fuzzy to control the communication network. X. Cui [19] implemented fuzzy logic in swarm robots of mobile sensor networks. It is used to control nodes of the sensor network in determining the next optimal node deployment location. Siti Nurmaini in [20] proposed Fuzzy-Kohonen Networks and Particle Swarm Optimization (FKN-PSO) to localize the odor source. The result was then compared to the Fuzzy-PSO. It showed that FKN-PSO was more efficient than Fuzzy-PSO.

Other researches, such as in [21] and [22], show that the fuzzy logic were used as sensor's information processor. P. Jiang [21] used fuzzy logic to process multi inputs of the sensors (olfaction, vision, wind speed/direction, distance and position of robot). More detailed and accurate decisions of these inputs were got easily using Fuzzy logic. The outputs of the fuzzy were set up into six behaviors, including obstacles avoidance, odor source declaration, nearest distance-based visual searching, up-wind searching, path planning, chemotaxis searching, and random searching. The proposed algorithm was successful in increasing the ability of the robots in finding the plume. Siti Nurmaini in [22] was successful using fuzzy logic in finding the best target position of each swarm robots. The fuzzy logic was only activated when the gas sensors were inactive and robots moved in unknown areas. When gas sensors were active, the Fuzzy-PSO was used. Fuzzy-PSO was successful to control the trajectory and movement of the robots.

In this research, the information of odor concentration from gas sensors was used to determine the track of the robots. The high concentration indicated that it was the way of the source came from. Therefore, the fuzzy output will be

set as the position of the right and left motors of the wheels in order to determine which way the robot should take.

## II. ODOR LOCALIZATION

As mentioned in part I, odor localization has impressed many researchers nowadays [5]–[10]. Recently, a number of approaches for odor localization have been presented. Kowadlo and Russel [23], Ishida [24] and Thomas Lochmatter in his Ph.D. thesis [25] described the detail work in this research. G. Kowadlo and R.A. Russell provided the odor localization approaches in a Venn diagram [23]. They divided the odor localization approaches in 3 categories: 1. Early work, 2. Reactive Gradient Climbing, and 3. Turbulence Dominated Fluid Flow. According to G. Kowadlo and R.A. Russel, the pioneers of the first category were Larcombe and Hassal.

The idea on the sensitive robot that was developed by Larcombe and Hassal was then improved by Rozas et al (1991), Buscemi et al (1994) and Genovese et al (1992) [23]. In that research, they did not consider the real characteristics of odor dispersal but they utilized chemical gradient that was operated to move to the odor source. The diffusion was assumed as the dominant-term of odor dispersal. There were a lot of researchers discussed the localization approaches using various type of robots. Ishida in [24] stated that flying and swimming robots were also interested to analyze. For the underwater robots, there were RoboLobster that was developed by Consi et al [27], Albacore REMUS autonomous underwater vehicle (AUV) that was tested by Farrel [28] and REMUS AUV was used by Wei Li [29]. For the flying robots, there were Patrick P. Neumann [30] and G. Montes [31].

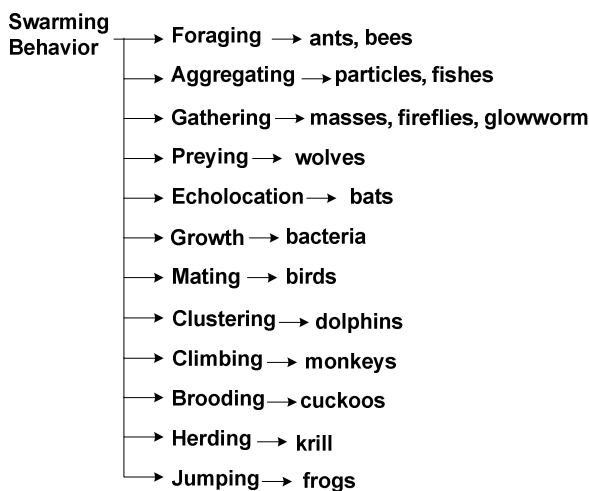


Fig. 1. Odor Localization Approaches [25], [26].

Working with odor has so many problems to consider, such as the odor characteristic, the gas sensor performance, and the experimental environment. Villarreal in [32] stated that some limitations of previous algorithms were related to the sensors processing time.

TABLE I. RECENT ODOR LOCALIZATION RESEARCH USING FUZZY

Year	Methods/Algorithm	References
2014	Fuzzy	[33]
2015	Fuzzy Fuzzy control based	[18] [21][22]
2016	Fuzzy-PSO	[34]
2017	Fuzzy-Kohonen	[20]

Sometimes, they need a long time to be ready for a second measurement (1 minute). Some strategies even required more time since they need to cover the whole area several times (more than 20 minutes) [32]. Also, the odor source was not always reached due to multiple local maxima placed near the odor source. This happens because vapors of odor source are volatile and tend to homogenize the whole area, but in the case of constant gas leaks, maximum concentration is always at the exit of the odor source [32].

This research only focused on fuzzy algorithm. Fuzzy logic is very useful in many areas of odor localization application. As mentioned in Sub chapter I, it can be used as the network controller and input sensors information processor. In this research, the information from the TGS sensors was collected and processed using fuzzy algorithm. After fuzzification, fuzzy inferring, and defuzzification process, the PWM of the robots can be controlled in such a way so that it can reach the odor source as the final target of the robot. Some Fuzzy and their combination methods/algorithms used by the researchers of localization using fuzzy algorithm in recent years can be seen in Table I.

## III. EXPERIMENTAL SETUP

### A. Robot Design

The robot in this research equipped with 5 distance sensors, 3 gas sensors (TGS 2600), and 4 Omni wheels. In order to collect the experimental data, communication between robot and computer was established using X-bee. For controlling all of the components in the robot platforms, Arduino Mega was used as the embedded controller. Fuzzy controller was designed using C/C++ language.

The robot consisted of 3 layers with diameter 15 cm. Three TGS 2600 gas sensors that were used in research were placed in position  $-90^\circ$ ,  $0^\circ$ , and  $90^\circ$  of the front side of the robot. The value of  $0^\circ$  indicated gas sensor that was placed in the middle front of the robot, while  $90^\circ$  and  $-90^\circ$  showed the position of the gas sensor in the right and left position with each angle  $90^\circ$  from the middle front sensor. The robot also consisted some other components, such as DC DC converter, motors, LCD, battery, etc. The detailed arrangements of the robot are as follows: 1. The top layer of the robots was placed TGS Sensors, LCD and Xbee communication module, 2. In the middle layer, 5 distance sensors and Arduino Mega were mounted, 3. At last, in the bottom of the layer, 4 DC motors, 2 drivers, 1 DC-DC converter, and 1 battery 12 volt were placed. The physical form of robot can be seen in Fig. 2. The block diagram of the robot is represented in Fig. 3. The communication



between the robot and the computer was established using X-bee modules.

The experiment was conducted in indoor environment of a corridor 90 cm x 500 cm room. To get an accurate data, the room was conditioned so that there was only little disturbance of wind (airflow of the wind was kept as little as possible). The room was maintained in closed conditioned. The temperature was kept between 27°C - 30°C and the humidity was in the range of 65% - 75%.

**B. Fuzzy Logic Algorithm as Controller**

The fuzzy logic was first introduced by Zadeh [35]. It is logical system that is intended to be a logic for approximate reasoning [35]. It is famous with its linguistic rules based knowledge. The rules consist of the inputs and the outputs condition. Using these rules, the robot will have an ability to decide what actions that it should take. The rules are established based on the expert knowledge, an observation of the human operators, and trough the experimental analysis, especially for the range of its membership functions.

In this research, each of gas sensors provides the inputs of the fuzzy logic. They were related to the concentration of the source around the robot that they detected. The amount of the concentration detected was the input parameters. They were then arranged into an input membership functions (MFs). From these input MFs, some rules related to the outputs action or decision taken, as the response to the inputs, were generated. These rules allowed the robot to interact with its surroundings, in this case to find a correct way to the source. By having fuzzy logic as the robot's decision maker, the robot would run to the right track in order to get closer to the source and at the end find where the source was. The fuzzy logic helped the robot to find a correct movement to the right, the left, or forward by deciding an output based on the rules generated before. The output of the fuzzy logic was related to the PWMs of the right and the left motors of the robots.



Fig. 2. Odor Localization Robot

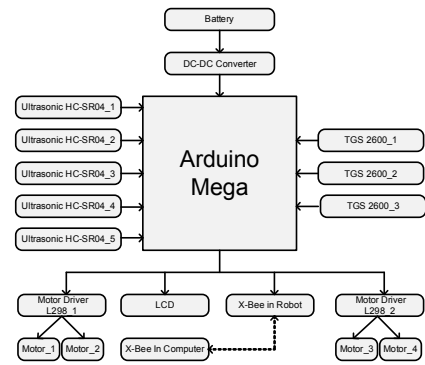


Fig. 3. Block Diagram of Odor Localization Robot

When the concentration in the right side of the robot was higher than the middle and the left side, the fuzzy logic will give decision to the robot to move to the right. In that condition, the left motor was in the high speed condition and the right motor was in slow speed condition. Therefore, the robot will move to the right.

The fuzzy logic controller system in this research was set up using some steps, i.e. Fuzzification, rule base and inference, and the defuzzification (see the flowchart Fig. 4).

**Step 1. Fuzzification**

In this step, the member of the fuzzy logic was determined (See Table II). Based on the linguistic variable shown in Table II, the fuzzy set was then set up using the membership variables, i.e. Low, Medium, and High. The membership function equation can be seen in equation (1) - (3), while the input membership function graph can be seen in Fig 5. The fuzzification process was set using the crisp inputs based on the equation (1) - (3).

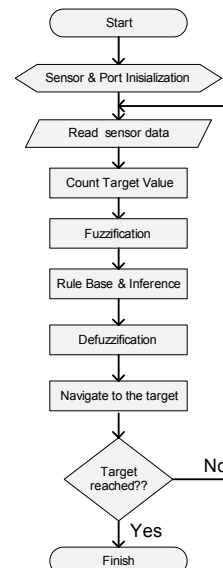


Fig. 4. Flowchart of Fuzzy algorithm

TABLE II. GAS SENSOR INPUT

Gas Concentration (ADC)	Linguistic Variable	Symbol
0-449	Low	L
50-849	Medium	M
450-900	High	H

$$\mu_{low}(x_i) = \begin{cases} 1 & \text{for } a \leq x < b \\ \frac{c-x}{c-b} & \text{for } b \leq x < c \\ 0 & \text{for } x \geq c \end{cases} \quad (1)$$

$$\mu_{medium}(x_i) = \begin{cases} 0 & \text{for } x < b \text{ and } x > d \\ \frac{x-b}{c-b} & \text{for } b \leq x < c \\ \frac{d-x}{d-c} & \text{for } c \leq x \leq d \end{cases} \quad (2)$$

$$\mu_{high}(x_i) = \begin{cases} 1 & \text{for } d < x \leq e \\ \frac{x-c}{d-c} & \text{for } c \leq x < d \\ 0 & \text{for } x < c \end{cases} \quad (3)$$

**Step 2. Rule Based and Inference**

In this step, some rules that related to the robot intelligence were generated. These rules will determine the basic rules value in controlling robot motion. 27 rules of the fuzzy logic algorithm are presented in Table III.

**Step 3. Defuzzification**

Defuzzification in this research used Sugeno method. This method is simple and suitable for this research. The implication function that was used in this research was Max-Min operation to certain membership function.

TABLE III. GAS SENSOR INPUT

S1	S2	S3	M1	M2	Condition	
L	L	L	S	S	Go forward slowly	
		M	M	S	Turn right slowly	
		H	F	S	Turn right fast	
	M	M	L	M	M	Go forward moderately
			M	M	S	Turn right slowly
			H	F	S	Turn right fast
	H	H	L	F	F	Go forward fast
			M	F	F	Go forward fast
			H	F	S	Turn right fast
M	L	L	S	M	Turn left slowly	
		M	S	M	Turn left slowly	
		H	S	F	Turn left fast	
	M	M	L	S	M	Turn left slowly
			M	M	M	Go forward moderately
			H	F	M	Turn right moderately
	H	H	L	M	M	Go forward moderately
			M	M	M	Go forward moderately
			H	F	M	Turn right moderately
H	L	L	S	F	Turn left fast	
		M	S	F	Turn left fast	
		H	S	F	Turn left fast	
	M	M	L	S	F	Turn left fast
			M	M	F	Turn left moderately
			H	M	F	Turn left fast
	H	H	L	S	F	Turn left fast
			M	M	F	Turn left fast
			H	F	F	Go forward fast

**Explanation of Table III:**

**Inputs: (S1-S3: Gas sensors)**

S1: Left S2: Middle; S3: Right

L : Low; M : Medium; H : High

**Outputs: (M1-M2: Motors)**

M1: Left; M2: Right

S : Slow; M : Medium; F : Fast

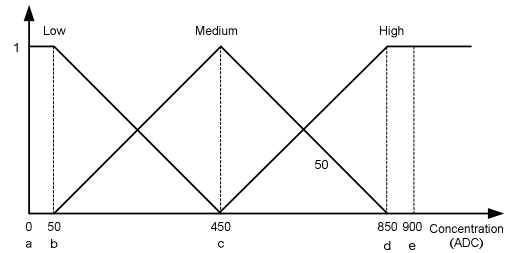


Fig. 5. Input membership function

TABLE IV. GAS SENSOR OUTPUT

PWM Motor	Linguistic Variable	Symbol
50	Slow	S
150	Medium	M
250	High	F

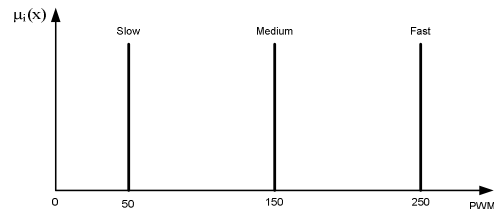


Fig. 6. Output membership function

This step produced fuzzy output value that was suitable to certain rules. The output membership function can be seen in Table IV. The Fuzzy output in this step is in a singleton form with the range 0 until 250 that was mapped into 3 linguistic variables: Slow, Medium, and Fast. The outputs related to the PWM of each of motors where the PWM value 50 indicated slow motion, 150 presented medium, and 250 showed fast one.

**IV. RESULT AND DISCUSSION**

*A. Simulation*

At first, the implementation of fuzzy in the system was simulated using Matlab. There were 3 inputs in fuzzy, namely: S1, S2, and S3 (gas sensors), while the outputs of the fuzzy in simulation were M1 and M2 that represented left and right motor. The inputs and outputs of fuzzy logic were determined in the Sugeno fuzzy logic. The range of each inputs and output membership function was referred to Fig. 5 and Fig. 6 while the fuzzy rules that manage the inputs and output of the fuzzy were set up as shown in Table III above. The defuzzification process follows the Sugeno method. One of the simulation results can be seen in Fig. 7. In this example, all the inputs were set into High condition,

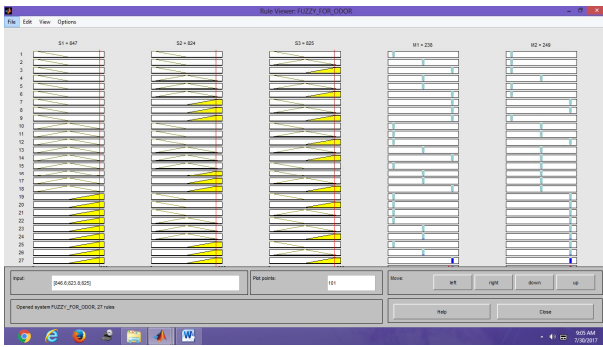


Fig. 7. Simulation using Matlab.

with the concentration value 847, 824, and 825 for S1, S2, and S3. The output value of left and right motors was in the high speed condition with PWM 238 and 249. This example is the implementation of the rule number 27 where the robot will go forward fast based on this rule.

**B. Real Experiment**

The experiment that was conducted in corridor of 90 cm x 500 cm was done in various starting positions. The range of the robots of the source was varied in order to analyze the effectiveness of the constructed fuzzy algorithms. Fig. 8 shows the experimental path of the robot in finding the gas source with starting point A, B, and C. The position A, B, and C were represented by Yellow, Red, and Green on the picture in Fig. 8. The position B is the position that is parallel to the source, while A and C represented the left and right position of the robot to the source. The real experimental condition is shown in Fig. 9.

In the research as shown in Fig. 9, the robot starts its searching in various distances not only at 200 cm, but also 300 cm, 400 cm, and 500 cm. At first, the robot just went to straight forward, some times, it changed its wheel position due to the input from the sensor reading. From the data shown in Fig. 10, it is known that it needed at least 38 second to reach the odor source in 200 cm distance away.

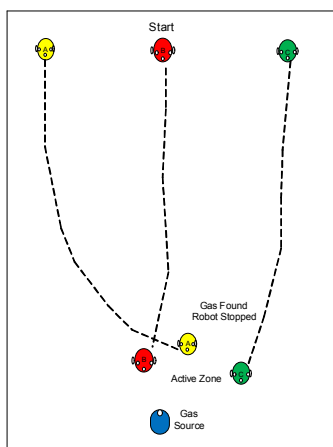


Fig. 8. The robot path in tracking the odor source.

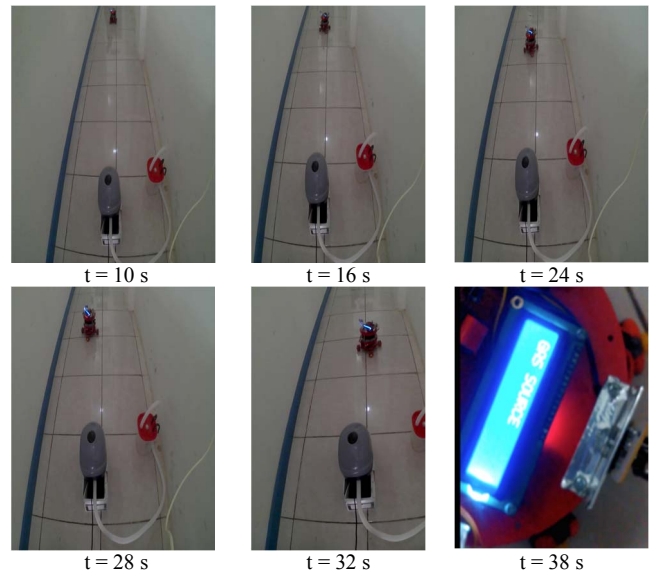


Fig. 9. Real experimental condition using B position as starting point with distance 200 m.

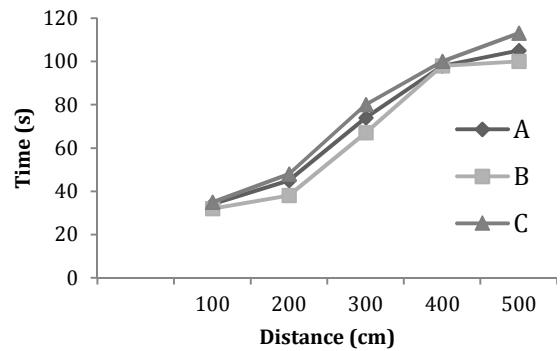


Fig. 10. Duration time needed by the robot in localizing the source

When the odor has found, the robot will stop and send the information "gas source" indication and the position to the receiver.

At the first time of its track, the robot only went forward. It is in accordance with the rules that have been set up before. For a distance of a robot that was far from the source, it usually smells a low concentration of the source. When S1, S2, and S3, were in the same condition, Low, Low, and Low, the robots will moved forward slowly. Each of the rules would be fired interchangeably based on the inputs that the robots sensed.

**V. CONCLUSION**

The experimental results show that the proposed fuzzy algorithm was able to be applied in real situation. It has capability to localize the odor using simple algorithm. However, it can only be applied in scalable and conditioned room. The longest experimental distance between robot and source is only 500 cm. It is far from the real world condition. It needs more experiments and researches. In doing the odor source localization, there are a lot of

parameters that should be considered. The disturbances of the odor such as wind flow, temperature, and humidity affect the sensors reading. In addition, the range of the Fuzzy Membership functions should also be taken into accounts. Some analyses and observation to experimental fuzzy membership functions should be done in order to get best tuning. In this experiments, there are still some drawbacks. The robot sometimes stops in the position that is not so closed to the source. It is due to the robot is lacking the steering angle that has not been covered by the fuzzy in this experiment yet. In our future work, to enhance the performance of the robots, it is needed to add some gas sensors to get more precise input data, take into account the steering angle to the output of the fuzzy and set up a collaboration between fuzzy and other algorithms to accomplish the odor localization task.

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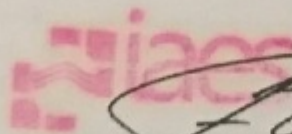
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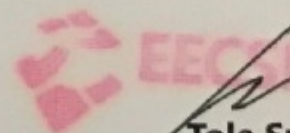
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