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PROSIDING SEMINAR INTERNASIONAL
TERINDEKS SCOPUS

The 4th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI 2017)

Judul:
Myoelectric control systems for hand rehabilitation device: a review

disusun oleh:
Khairul Anam dkk

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Foreword from General Chair EECSI 2017

In the name of Allah, Most Gracious, Most Merciful

Welcome to the fourth International Conference on Electrical Engineering, Computer Science and Informatics (EECSI 2017) in Yogyakarta.

The 4th EECSI 2017 has a theme "Deep Learning High-speed Processing Technologies and Its Applications on Electrical, Electronics, Computer Science and Informatics for Humanity". This forum provides researchers, academicians, professionals, and students from various engineering fields and with cross-disciplinary working or interested in the field of Electrical Engineering, Computer Science, and Informatics to share and to show their works and findings to the world.

I would like to express my hearty gratitude to all participants for coming, sharing and presenting your experiences in this vast conference. There are more than 200 papers submitted to EECSI 2017, however only high quality selected papers are accepted to be presented in this event, so we are also thankful to all the international reviewers and steering committee for their valuable work. I would like to give a compliment to all partners in publications and sponsorships for their valuable supports.

Organizing such an prestigious conference was incredibly challenging and would have been impossible without our outstanding committee, so I would like to extend my sincere appreciation to all committees and volunteers from Universitas Ahmad Dahlan as a host and all colleagues from Universitas Gadjah Mada, Universitas Diponegoro, Universitas Sriwijaya, Universitas Islam Sultan Agung, Universitas Muhammadiyah Malang, Universitas Budi Luhur and IAES Indonesia Section for providing me with much needed support, advice, and assistance on all aspects of the conference. A special thanks for IEEE Indonesia Section for the technical co-sponsorship during the conference. We do hope that this event will encourage the collaboration among us now and in the future.

We wish you all find opportunity to get rewarding technical program, intellectual inspiration, renew friendships and forge innovation, and that everyone enjoys Yogyakarta.

Assoc. Prof. DR. Tole Sutikno
General Chair EECSI 2017

Foreword from IAES Indonesia Section

Bismillahirrohmannirrahim,
Assalamualaykum warohmatullahi wabarakatuh and Good Day,
Ladies and Gentlemen,

We would like to welcome our colleagues to attend the International Conference on Electrical Engineering, Computer Science and Informatics (EECSI 2017) in Yogyakarta – City of Culture on 19-21 September 2017.

Again, the EECSI 2017 is held in Yogyakarta "the former capital of Republic of Indonesia". In the city known as a centre of classical Javanese fine art, culture, thousand of year's old ancient temples, and authentic delicious food, I hope this event will become a great event for researchers, engineers and professionals to strengthen ties and partnerships and their findings and development to the world in the field of electrical, computer, and informatics.

Institute Advanced Engineering and Science (IAES) collaborating with Universitas Ahmad Dahlan, Universitas Diponegoro, Universitas Gajah Mada, Universitas Islam Sultan Agung , Universitas Sriwijaya, and Universiti Teknologi Malaysia as several tops universities have successfully organized the conference four times since year 2014. This year, the achievement is due to valuable contributions also from our colleagues from Universitas Muhammadiyah Malang and Universitas Budi Luhur. I would like to express my sincere gratitude and appreciation for all partners, friends, organizing committee, reviewers, keynote speakers, and participants who have made this event as a key stage to show great development to the world as today.

I would also like to extend my gratitude to Rector of Universitas Ahmad Dahlan, academia and supporting staffs from Universitas Ahmad Dahlan who become a main host and IEEE Indonesia section as a technical sponsor for EECSI 2017.

We wish you a happy conference and success in Yogyakarta.

Thank you.

Assoc.Prof. Mochammad Facta, Ph.D
IAES – Indonesia Chapter

Foreword from Rector of Universitas Ahmad Dahlan

It is our great pleasure to join and to welcome all participants of the 4th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI 2017) in Yogyakarta. I am happy to see this great work as part of collaborations among Universitas Ahmad Dahlan and Universitas Gadjah Mada, Universitas Diponegoro, Universitas Sriwijaya, Universitas Islam Sultan Agung, Universitas Muhammadiyah Malang, Universitas Budi Luhur and IAES Indonesia Section and supported well for technical co-sponshorship by IEEE Indonesia Section. On this occasion, I would like to congratulate all participants for their scientific involvement and willingness to share their findings and experiences in this conference.

I believe that this conference can play an important role to encourage and embrace cooperative, collaborative and interdisciplinary research among the engineers and scientists. I do expect that this kind of similar event will be held in the future as part of activities in education research and social responsibilities of universities, research institutions, and industries internationally.

My heartful gratitude is dedicated to Organizing Committee members and the staff of Universitas Ahmad Dahlan for their generous effort and contribution toward the success of the 4th EECSI 2017.

<u>Dr. H. Kasiyarno, M.Hum.</u>
Rector
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PARALLEL SESSION SCHEDULE

DAY	TIME SLOT	ROOM A	ROOM B	ROOM C	ROOM D	ROOM E
FIRST DAY - 19 SEPTEMBER 2017 (TUESDAY)	13:00 - 13:15	Performance Analysis of Network Emulator Based On The Use of Resources In Virtual Laboratory (Yuri Ariyanto)	EEG Based Emotion Monitoring Using Wavelet and Learning Vector Quantization (Esmeralda Contessa Djamal)	Precise Wide Baseline Stereo Image Matching for Compact Digital Cameras (Martinus Edwin Tjahjadi)	Performance Measurement Based on Coloured Petri Net Simulation of Scalable Business Processes (Abd. Charis Fauzan)	High Efficiency Single Phase Inverter Design (Didi Istardi)
	13:15 - 13:30	Teaching & Learning Support For COA Courses Design On CE & CS For Undergraduate (Wijaya Kurniawan)	Myoelectric control systems for hand rehabilitation device: a review (Khairul Anam)	Robust and Imperceptible Image Watermarking by DC Coefficients Using Singular Value Decomposition (Eko Rachmawanto)	The design a system of retention and control on broiler farms based on the flow of data (Ahmad Sanmorino)	Compressed Natural Gas (CNG) Technology For Fuel Power Plants (Isworo Pujotomo)
	13:30 - 13:45	WatsaQ: Repository of Al Hadith in Bahasa (Case Study: Hadith Bukhari) (Rizal Broer Bahaweres)	Variance Analysis of Photoplethysmography for Blood Pressure Measurement (Hendrana Tjahjadi)	Region of Interest Detection for Pregnancy Image Processing (Moh Khairudin)	Empirical Investigation on Factors Related to Individual of Impact Performance Information System (Tri Lathif Mardi Suryanto)	Analysis of Electric Circuit Model on Atmospheric Pressure Dielectric Barrier Discharge (DBD) Plasma (Suyadi)
	13:45 - 14:00	IoT Smart Device for e-Learning Content Sharing on Hybrid Cloud Environment (Mohd. Yazid Idris)	Implementation of Unbiased Stereology Method for Organ Volume Estimation using Image Processing (Balza Achmad)	Shape Defect Detection for Product Quality Inspection and Monitoring System (Norhashimah Mohd Saad)	Comparative Study of Web3D Standard Format to Determine the Base Format for A Web3D Framework (Mursid W Hananto)	PID Designs Using DE and PSO Algorithms for Damping Oscillations in A DC Motor Speed (Widianto Widianto)
	14:00 - 14:15	Target Tracking in Mobile Robot under Uncertain Environment using Fuzzy Logic Controller (Ade Handayani, ASH)	Ethnobotany Database: Information Management and Exploration of Medicinal Plants Borneo (Haeruddin)	Toward a New Approach in Fruit Recognition using Hybrid RGBD Features and Fruit Hierarchy Property (Ema Rachmawati)	Task-Technology Fit for Textile Cyberpreneur's Intention to Adopt Cloud-Based M-Retail Application (Nik Zulkarnaen Khidzir)	Measurement of Partial Discharge Induced Electromagnetic Wave using Loop Antenna (Umar Khayam)
	14:15 - 14:30	Nitrogen (N) Fertilizer Measuring Instrument On Maize-Based Plant Microcontroller (Hendra Riskiawan)	Automated Post-Trabeculectomy Bleb Assesment by Using Image Processing (Agwin Fahmi Fahanani)	Mobile Content Based Image Retrieval Architectures (Arif Rahman)	Makassar Smart City Operation Centre Priority Optimization Using Fuzzy MCDM (Fachrul Kurniawan)	The Effect of Coating on Leakage Current Characteristic of Coast Field Aged Ceramic Insulator (Dini Fauziah)
	14:30 - 14:45	Reconfigurable Logic Embedded Architecture of Support Vector Machine Linear Kernel (Jeevan Sirkunan)	Non-invasive Hemoglobin Measurement for Anemia Diagnosis (Raditya Artha Rochmanto)	Computer Vision Based Object Tracking as a Teaching Aid for High School Physics Experiments (Gayan Illeperuma)	Ontology-Based Sentence Extraction for Answering Why-Question (A. A. I. N. Eka Karyawati)	Renewable Energy Inclusion on Economic Power Optimization using Thunderstorm Algorithm (AN Afandi)
	14:45 - 15:00	An Analysis of Concentration Region on Powerpoint Slides using Eye Tracking (Fergyanto E Gunawan)	Poincaré plot of fingertip photoplethysmogram pulse amplitude suitable to assess diabetes status (Bagus Haryadi)	Texture Analysis and Fracture Identification of Lower Extremities Bones X-Ray Images (Rahayu Suci Prihatini)	The Ontology-Based Methodology Phases To Develop Multi-Agent System (OmMAS) (Arda Yunianta)	Optimum Phase Number for Multiphase PWM Inverters (Anwar Muqorobin)
	15:00 - 15:30			COFFEE BREAK		
	15:30 - 15:45	Implementation of K-Means Clustering Method to Distribution of High School Teachers (Triyanna Widiyaningtyas, MT)	Certain Factor Analysis for Extra Pulmonary Tuberculosis Diagnosis (Ramadiani)	Analysis of the Indonesian Vowel /e/ For Lip Synchronization Animation (Anung Rachman)	Scalability Measurement of Business Process Model Using Business Processes Similarity and Complexity (Muhammad Ainul Yaqin)	Small-Disturbance Angle Stability Enhancement using Intelligent Redox Flow Batteries (Dwi Lastomo)
	15:45 - 16:00	Incremental High Throughput Network Traffic Classifier (Muhammad Nadzir Marsono)	The Improvement of Phonocardiograph Signal (PCG) Representation Through the Electronic Stethoscope (Dyah Agustika)	Anti-Cheating Presence System Based on 3WPCA-Dual Vision Face Recognition (Edy Winarno)	Smartphone for Next Generation Attendance System and Human Resources Payroll System (Fergyanto E Gunawan)	Evaluation Study of Waste Materials for Renewable Energy through 3R Model in Bogor City (Didik Notosudjono)
	16:00 - 16:15	Edge Detection on Objects of Medical Image with Enhancement multiple Morphological Gradient Method (Jufriadif Na`am)	Neural Network on Mortality Prediction for the Patient Admitted with ADHD (Mohamad Haider Abu Yazid)	Sketch Plus Colorization Deep Convolutional Neural Networks for Photos Generation from Sketches (Vinnia Kemala Putri)	Enhancing Online Business Marketing to Expand Market Shares through IT Governance (Sandy Kosasi)	Measurement of Partial Discharge inside Metal Enclosed Power Apparatus using Internal Sensor (Umar Khayam)
	16:15 - 16:30	Unified Concept-based Multimedia Information Retrieval Technique (Ridwan Kambau)	Measurement Of Maximum Value Of Dental Radiograph To Predict The Bone Mineral Density (Sri Lestari)	Comparison of Five Classifiers for Classification of Syllables Sound using Time-Frequency Features (Risanuri Hidayat)	A Generic Framework for Information Security Policy Development (Setyawan Widyarto)	Design Unmanned Aerial Vehicle Integrated Camera Near Infra-Red to Observe the Plant Health (Rizki Wahyu Pratama)
	16:30 - 16:45	Text Modeling In Adaptive Educational Chat Room Based On Madamira Tool (Jehad Hammad)	Feature Extraction and Classification of Thorax X-Ray Image in The Assessment of Osteoporosis (Riandini)	Imperceptible Image Watermarking based on Chinese Remainder Theorem over the Edges (Prajanto Wahyu Adi)	Designing Multi-Channel Service Desk Based onITIL Version 3 (Ahmad Sahrizal)	Single Frame Resection of Compact Digital Cameras for UAV Imagery (Martinus Edwin Tjahjadi)
	16:45 - 17:00	Analysis of Statement Branch and Loop Coverage in Software Testing With Genetic Algorithm (Rizal Broer Bahaweres)	2D-Sigmoid Enhancement Prior to Segment MRI Glioma Tumour (Widya Kumala Sari)	Wood Texture Detection with Conjugate Gradient Neural Network Algorithm (Gilang Budaya)	Modeling IT Value based on Meta-Analysis (Novianto Budi Kurniawan)	A Moving Objects Detection in Underwater Video Using Substraction of the Background Model (Nurul Hudayani)
	17:00 - 17:15	Combining Deep Belief Networks and Bidirectional Long Short Term Memory (Case Study: Sleep Stages Classification) (Intan Yulita)	Design of Automatic Switching Bio-Impedance Analysis (BIA) for Body Fat Measurement (Munawar Riyadi)	Spoken Word Recognition Using Mel-Frequency Cepstrum Coefficients and Learning Vector Quantization (Esmeralda Contessa Djamal)	A Combination of The Evolutionary Tree Miner and Simulated Annealing (Afina Nurlaili)	Fall Detection Based on Accelerometer and Gyroscope using Back Propagation (Adlian Jefiza)
	17:15 - 17:30		Alerting System for Sport Activity Based on ECG Signals using Proportional Integral Derivative (Vika Octaviani)	A Hierarchical Description-based Video Monitoring System for Elderly (Mochamad Irwan Nari)	Scalable Attack Analysis of Business Process based on Decision Mining Classification (Dewi Rahmawati)	Honey Yield Prediction Using Tsukamoto Fuzzy Inference System (Tri Hastono)

DAY	TIME SLOT	ROOM A	ROOM B	ROOM C	ROOM D
SECOND DAY - 20 SEPTEMBER 2017 (WEDNESDAY)	8:00 - 8:15	Determining The Nutrition of Patient Based on Food Packaging Product Using Fuzzy C Means Algorithm (Sri Winiarti)	Autonomous navigation for an Unmanned Aerial Vehicle by the Decomposition Coordination Method (Hala El Ouarrak)	Performance of Routing Protocol in MANET with Combined Scalable Video Coding (Parma Rantelinggi)	Conceptual Framework for Public Policymaking based on System Dynamics and Big Data (Feldiansyah Nasution)
	8:15 - 8:30	The successful elements implementing the eLearning using Cloud Services Data Centre (Setyawan Widyarto)	Adaptive-Fuzzy-PID Controller Based Disturbance Observer for DC Motor Speed Control (Zulfatman Has)	Attack Scenarios and Security Analysis of MQTT Communication Protocol in IoT System (Syaiful Andy)	Discovering Process Model from Event Logs by Considering Overlapping Rules (Yutika Amelia Effendi)
	8:30 - 8:45	Improving E-Book Learning Experience by Learning Recommendation (Fergyanto E Gunawan)	Extra Robotic Thumb and Exoskeleton Robotic Fingers for Patient with Hand Function Disability (Mochammad Ariyanto)	Encoding Of Passive Surface Acoustic Wave Based Anti-Collision Radio Frequency Identification Tags (Gysberth Wattimena)	CHMM for Discovering Intentional Process Model From Event Logs By Considering Sequence of Activities (Kelly Sungkono)
	8:45 - 9:00	A Comparison on Cloud Execution Mechanisms: Fog, Edge and Clone cloud Computing (Tina Francis)	Parameterized Kick Engine For R-SCUAD Robot (Nuryono Widodo)	Compact Fractal Patch Microstrip Antenna Fed by Coplanar Waveguide for Long Term Evolution Communications (Syah Alam)	Sosio-Technical Factors of E-Government Implementation (Darmawan Napitupulu)
	9:00 - 9:15	Recommendation System on Knowledge Management System via OAI-PMH (Nyoman Karna)	Neural Network Controller Design for a Mobile Robot Navigation; a Case Study (Tresna Dewi)	Graphical Approach for RF Amplifier Specification in Radio over Fiber System: Maximum Power Issues (Teguh Prakoso)	Methodology for Constructing Form Ontology (Uung Ungkawa)
	9:15 - 9:30	Development and Evaluation of Android Based Notification System to Determine Patient's Medicine (Imam Riadi)	Redirection Concept of Autonomous Mobile Robot HY-SRF05 Sensor to Reduce The Number of Sensors (Nuryanto)	FEM Modeling of Squeeze Film Damping Effect in RF-MEMS Switches (Syed Turab Haider)	Integration Protocol Student Academic Information to Campus RFID Gate Pass System (Evizal Abdul Kadir)
	9:30 - 9:45	Implementation of Decision Expert (DEX) in The "SALADGARDEN" Application (Anita Hidayati)	A Reactive path planning approach for a Four-Wheel Robot by the Decomposition Coordination Method (Hala El Ouarrak)	The Onion Routing Performance using Shadow-plugin-TOR (Banu Yohanes)	E-learning Model for Equivalency Education Program in Indonesia (Sfenrianto Sfenrianto)
	9:45 - 10:00	Optimizing Effort and Time Parameters of COCOMO II Estimation using Fuzzy Multi-Objective PSO (Kholed Langsari)	Design of PID Disturbance Observer for Temperature Control on Room Heating System (Yoga Utama)	Position Tracking for Static Target using Burst Signals with Time Difference of Arrival Method (Alia Shaliha Amany)	Developing E-Government Maturity Framework Based On COBIT 5 (Fikri Akbarsyah Anza, FAA)
	10:00 - 10:15	BREAK			
	10:15 - 10:30	Evaluation Of Knowledge Management System Using Technology Acceptance Model (Astari Retnowardhani)	Development of Low Cost Supernumerary Robotic Fingers as an Assistive Device (Mochammad Ariyanto)	Performance Analysis for MIMO LTE on the High Altitude Platform Station (Catur Budi Waluyo)	Cooperative Learning Jigsaw Model using Clustering Algorithm Partitioning Around Medoids (PAM) (Imam MIS)
	10:30 - 10:45	Deep learning on curriculum study pattern by selective cross join in advising students' study path (Tekad Matulatan)	Design of A Microchip Optical Switching Driven by Low Direct-Current Voltage (Dedi Irawan)	SDR Design for OFDM Based Spectrum Exchange Information Using Arduino UNO and X-Bee (Arief Marwanto)	Minimizing the Estimated Solution Cost with A* Search to Support Minimal Mapping Repair (Inne Gartina Husein)
	10:45 - 11:00	Service Computing System Engineering Life Cycle (Novianto Budi Kurniawan)	Wireless Sensor System for Prediction of Carbon Monoxide Concentration using Fuzzy Time Series (Suryono Suryono)	Performance Rate for Implementation of Mobile Learning in Network (Faza Alameka)	The rule Extraction of Numerical Association Rule Mining Using Hybrid Evolutionary Algorithm (Imam Tahyudin)
	11:00 - 11:15	Revealing Daily Human Activity Pattern using Process Mining Approach (Muhammad Rifqi Maarif)	Multiplier-less Architecture for 4-tap Daubechies Wavelet Filters Using Algebraic Integers (Mohammad Rafi)	Performance Evaluation of IPv6 Jumbogram Packets Transmission using Jumbo Frames (Supriyanto Praptodiyono)	Discovering Drugs Combination Pattern Using FP-Growth Algorithm (Rini Anggrainingsih)
	11:15 - 11:30	Problem Identification Of IT Governance Using COBIT 5 Framework For Education Information System (Gabriella Sabatini)	Detecting the Early Drop of Attention using EEG Signal (Fergyanto E Gunawan)	Performance Analysis of CSI:T Routing in a Delay Tolerant Networks (Hardika Putri)	Classifiers Evaluation: Comparison of Performance Classifiers Based on Tuples Amount (Mochammad Yusa)
	11:30 - 11:45	Forecasts Marine Weather On Java Sea Using Hybrid Methods: TS-ANFIS (Deasy Adyanti)	The Design of A Smart Refrigerator Prototype (Seyed Ebrahim Esmaeili)	A Study of the Number of Wavelengths Impact in the Optical Burst Switching Core Node (Arief Marwanto)	Analysis of Driving Skills based on Deep Learning using Stacked Autoencoders (Takuya Kagawa)
	11:45 - 12:00	Opinion Detection of Public Sector Financial Statements Using K-Nearest Neighbors (Ahmad Dwi Arianto)	Odor Localization using Gas Sensor for Mobile Robot (Ade Handayani)	A Reconfigurable MIMO Antenna System for Wireless Communications (Evizal Abdul Kadir)	Prediction of Rupiah Against US Dollar by Using ARIMA (Adiba Qonita)
	12:00 - 12:15	Encryption System based on a Structured Matrix: Vandermonde Matrix (Adda Ali Pacha)	A Project-Based Approach to FPGA-Aided Teaching of Digital Systems (Fajar Suryawan)		Improvement of eGov & mGov in Multilingual Countries with Digital Etymology using Sanskrit Grammar (Arijit Das)

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***Abstract*— One of the challenges of the hand rehabilitation device is to create a smooth interaction between the device and user. The smooth interaction can be achieved by considering myoelectric signal generated by human's muscle. Therefore, the so-called myoelectric control system (MCS) has been developed since the 1940s. Various MCS's has been proposed, developed, tested, and implemented in various hand rehabilitation devices for different purposes. This article presents a review of MCS in the existing hand rehabilitation devices. The MCS can be grouped into main groups, the non-pattern recognition and pattern recognition ones. In term of implementation, it can be classified as MCS for prosthetic and exoskeleton hand. Main challenges for MCS today is the robustness issue that hampers the implementation of MCS on the clinical application.**

Keywords—myoelectric control system, hand rehabilitation device

I. Introduction

A myoelectric control system (MCS) is a control system that employs myoelectric signal from human muscle activity to create a smooth interaction between the machine and user. MCS empowers a rehabilitation device with an ability to predict the user intention so that the device works together along with human as if it is part of the human body. MCS has been implemented in many rehabilitation devices including hand rehabilitation device either for replacing a lost limb or recovering a limb functionality.

The review on general myoelectric control system was conducted by Oskoei and Hu [1]. They provided a comprehensive discussion on MCS in general and did not focus on specific rehabilitation devices. Meanwhile, Heo, et al. [2] reviewed the hand exoskeleton for rehabilitation and assistive device. They provided detail discussion on the hand exoskeleton. However, the focus is much on the mechanical and electrical point of view. To the best of author's knowledge, the review of the control system of hand rehabilitation device especially based on myoelectric signal does not exist yet. In fact, the well understanding of MCS on the hand rehabilitation device is needed to develop a rehabilitation device that can work together with the user seamlessly.

This article provides a comprehensive review on the implementation of MCS on the hand rehabilitation devices. In addition, it covers two main rehabilitation devices, the prosthetic and the exoskeleton. The hand rehabilitation device considered in this thesis is a wearable robot including the prosthetic and orthotic hand devices. The prosthetic hand device is a wearable hand robot that can replace the missing hand and have the functionality of the hand replaced.

Nowadays, few dexterous and commercial prosthetic hands are available such as i-limb ultra from Touch bionic [3] and a bebionic hand from Ottobock [4]. Furthermore, a few low-cost prosthetic hands are available as well, such as prosthetic hands from Open bionics [5]. In addition, very few orthotics also available. One of the example is "hand of hope", a commercial exoskeleton hand by Rehab-robotics [6].

II. Myoelectric Control System

A. Myoelectric signal

The muscles drive the limbs to generate electrical signals called electromyography (EMG) or myoelectric signal (MES). The EMG signal is a stochastic or random signal whose amplitude can range from 0 to 1.5 mV (root mean square) or 0 to 10 mV (peak-to-peak). The energy above the electrical noise level is in the range of frequency 0 – 500 Hz. Meanwhile, in the range of 50-150 Hz, the energy of the noise is dominant [7]. The noise can come from different sources such as noises from the electronic components, motion artefacts, the inherent instability of the signal, and ambient noise. The energy under the noise level is not reasonable for analysis.

The myoelectric signal may be collected in two ways, either invasive or non-invasive. Hargrove, et al. [8] shows that the control system using surface EMG is not too much different from invasive one. For further discussion, this article considers only surface EMG. Surface EMG electrodes are located on the subject's skin. Meanwhile, Fig. 1 describes the stages in the acquisition of the EMG signal. The source of EMG or myoelectric signal is the action potential generated by each of the motor units activated during a contraction. It is called a motor unit action potential (MUAP). The populations of motor units activated are asynchronous to allow smooth movements. The electrodes pick up the conducted signals generated by all activities involved.

B. Myoelectric control system

The EMG signal can be employed in the control system of the hand rehabilitation devices either in EMG-based pattern recognition or non-pattern recognition system. The EMG-based pattern recognition (EMG-PR) or myoelectric pattern recognition (M-PR) consists of several steps from the pre-processing until the post-processing. The goal of M-PR is to recognise and classify the EMG patterns into classes or limb movements. On the other hand, the EMG-based non-pattern recognition (EMG-non-PR) system does not classify any limb movement. It may estimate human physical parameters such as the angle of the elbow or the force exerted by the hand according to the EMG signals collected. Moreover, the EMG-non-PR may use EMG signals as a threshold control system or proportional control system. The following sections will explain M-PR and EMG-non-PR in detail.

C. *Myoelectric pattern recognition (M-PR)*

This section addresses the stages of myoelectric pattern recognition (M-PR) in detail by describing each component of M-PR as presented in Fig. 1.

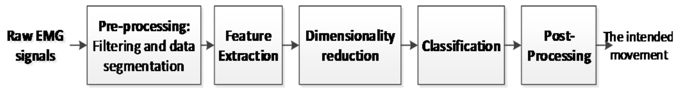

Fig. 1. Myoelectric pattern recognition system

1) *Filtering*

The aim of filtering is to reduce the unwanted noises between 20 – 500Hz. A band-pass filter with upper bandwidth cut-off of 400 Hz was applied. The power line noise 50 Hz or 60 Hz may be removed using a notch filter of 50 or 60 Hz.

2) *Data segmentation*

The classification process lasts for a certain period called a window. In this window, the system extracts valuable information from the row of myoelectric signals. This information is called a feature. The quality of features greatly determines the performance of the system [8]. The feature is extracted in a data sequence bounded in this time slot or window. Based on the data in this window, the whole stages of the recognition system are performed.

EMG signals can be segmented either as an overlapped or disjoint windowing [9]. In the overlapped windowing, the segmented data is overlapped one another depending on the window increment. On the other hand, in the disjoint segmentation, no overlapped data.

3) *Feature extraction*

The next step of the myoelectric pattern recognition is a feature extraction. The feature extraction is a process that converts patterns to features. In the case of EMG signals, it means a process that converts the pattern of EMG signals, in particular, segments to a set of features that contains salient features of the signals [10].

In general, the feature extraction in EMG signal consists of time domain and frequency domain features. Time domain features have been used widely in EMG pattern recognition system [11]. The advantages of the TD features are quick, easy implementation, low computational complexity and having good performance in low noise environment [12]. However, it has a major disadvantage in dealing with non-stationary signals such EMG signals. The examples of these features are root mean square (RMS), mean absolute value slopes (MAVS) and mean absolute value (MAV). Other features such as slope sign changes (SSC), zero crossing (ZC), and waveform length (WL) can be added. Moreover, model parameters of Hjorth time domain (HTD) and autoregressive (AR) parameters may be utilized.

Beside time domain feature, frequency domain (FD) features that are mostly obtained from power spectral density (PSD) can be employed. Other FD features are median (MDF) and mean frequency (MNF). Furthermore, time and frequency domain feature can be combined to form time-frequency domain (TFD) features. TFD features provide more accurate description of the physical phenomenon than the time domain and frequency domain features separately [13]. However, the TFD transformation needs heavy computation; somehow, it will not be reasonable for clinical application.

4) *Dimensionality Reduction*

The extracted features from the previous step are joined to form a set of features. However, this process increases the feature dimension. Therefore, the size should be reduced without compromising the main features. The feature reduction can be made either using feature selection (FS) or feature projection (FP) [13]. The FS selects a subset of best features that give the best performance of the system. On the other hand, the FP transforms the original feature space to a new feature space with smaller dimension. In the EMG signals cases, the feature projection is more favourable than the feature selection due to the characteristic of the EMG signals, i.e. whose variance is large [13].

The feature projection can be classified into an unsupervised and supervised method. In the unsupervised method, the feature space is projected into a new space with smaller size and without compromising the class information. Principle component analysis (PCA) [14] is an example. On the other hand, the supervised method includes the class knowledge into the projection. Linear discriminant analysis (LDA) [15] is as an instance. Inevitably, the class inclusion can enhance the accuracy of the myoelectric pattern recognition. One of the drawbacks of the LDA is a singularity problem that happens when the number of samples is smaller than the number of classes. Some methods can be used to overcome this singularity problem such as uncorrelated LDA (ULDA) [16] and orthogonal fuzzy neighbourhood discriminant analysis (OFNDA) [17].

Furthermore, the feature projection can also be grouped into linear and non-linear feature projection. PCA and LDA are examples of the linear feature projection. As for the non-linear method, the non-linear version of PCA is as an example. It is a kernel PCA that employ a kernel instead of a linear function in the process. Another example of the non-linear method is a neural-network based feature projection such as unsupervised extreme learning machine (USELM) and Autoencoder [18].

5) *Classification*

The classifier is one of the main components of the M-PR system. It classifies the features into particular classes. The predicted class will be delivered to the robot to produce a certain hand posture accordingly. In the early stage of the M-PR system, multilayer perceptron (MLP) [19] or feed-forward neural networks (FNN) was frequently used [20]. The FNNs is a powerful classifier, but the training process is time-consuming. Therefore, some researchers preferred using linear discriminant analysis (LDA) than MLP because LDA is fast and performs as accurately as FNNs. In addition to MLP and LDA, a few researchers employed hidden markov model (HMM) [21] and k-nearest neighbour (kNN) [22].

Recently, support vector machine (SVM), which is used in many applications, promises better performance than LDA, FNNs, k-nearest neighbour (kNN) as long as the SVM parameters are optimized properly [23]. However, SVM is originally developed for binary classification. The recognition system should use several SVMs to deal with multi-class classification. Recently, a new machine learning originated from the artificial neural network was proposed and called extreme learning machine (ELM) [24]. Not like FNNs, ELM omits iterative learning and does not need to tune the hidden-node parameters. Most recent classifier employed is convolutional neural network, a kind of deep learning neural network [25].

6) Post-processing

The aim of this stage is to smoothen the classification results. A majority vote is one of most common method that is employed by many researchers [26]. It makes a new result based on the output that appears most frequently from the current state and *n* previous states. This process yields a system that removes fake misclassifications.

D. Myoelectric non-pattern recognition (M-non- PR) system

The M-non-PR system has similar steps as the M-PR except in the classification stage. The M-non-PR does not have it. Instead, it has different processes, as depicted in Fig. 2.

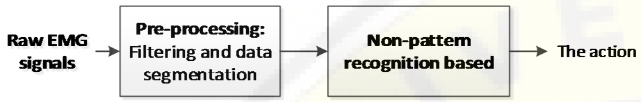

Fig. 2. The EMG-based non-pattern recognition

Among examples of EMG-based non-pattern recognition are the threshold myoelectric control, proportional myoelectric control, simultaneous and propositional myoelectric control and finite state machine (FSM) control [1].

a) The threshold myoelectric control

The threshold myoelectric control is a control system that utilizes a threshold value from the contraction level of EMG signal as a control source to activate or deactivate an action. It is also known as a binary on/off myoelectric control because the threshold value determines the on or off state of the assistive device [27]. The early stage of EMG controller in the prosthetic device employed this controller [28]. Besides, the majority of the current exoskeleton hands utilize the threshold controller instead of EMG based pattern recognition [29, 30].

b) Finite state machine

Finite state machine control consists of some states that the device should perform. The switching between states can be triggered by a timer or based on the level contraction of the EMG signals [1].

c) The proportional myoelectric control (PMC)

The PMC gives a more advanced control scheme than the threshold myoelectric control. In this control system, the control signal for the rehabilitation device is proportional to the contraction level of the EMG signal. The control system utilizes the EMG signal to estimate a specific physical parameter such as force or angle. Afterward, the control system treats those biofeedback values as the target that the device should achieve.

d) The simultaneous and proportional myoelectric control (SPMC)

The simultaneous and propositional myoelectric control is more advanced than the proportional one. This control system controls all joints proportionally and simultaneously from the EMG signal. To train the system, the amputees need a help form their healthy hand to produce target movement. The control system should estimate all physical parameters recorded from the raw EMG signal. Therefore, this control system is also known as regression based myoelectric system [31].

III. MCS ON HAND REHABILITATION DEVICES

A. EMG-based prosthetic hand

This sub-section provides a review of prosthetic hands controlled by EMG signal. The discussion is focused on the hand movement excluding the arm movements such as shoulder, elbow and wrist movements.

1) The Russian EMG controlled hand

Historically, Rieter was the first person who developed an EMG controlled hand in 1948 [32]. In 1957, B Popov, a Russian researcher, began to develop a bioelectricity controlled prosthetic hand [28]. This prosthetic is designated for the upper extremity. The electrodes were located in the stump. There are two movements: grasp and release. The EMG signals were acquired from two contradictory muscles. The hand will grasp if the exerted voltage of the flexion muscle exceeds 30-40 mV. To release or open the hand, the system will detect the opposing flexing muscle. If the recorded voltage was more than the threshold value, then the hand will open. The prosthetic hand is controlled with a threshold control system. This is a very basic myoelectric control system because it considered the one degree of freedom (DOF) only.

2) Suzuki 's system [33]

In 1969, Suzuki and Suematsu [33] developed a more complex control system using EMG signals. They called it pattern recognition of multichannel myoelectric signals. The system classified seven kinds of hand motions using a spatial pattern collected from three EMG channels on the forearm. The system learned the pattern or the classes using the learning discrimination mechanism [33]. Compared to the Russian EMG controller, the EMG controller is more advanced. The indication is shown by involving more motions and employing a learning mechanism to learn the pattern of EMG signals. Even though it considered multi DOFs, there is no information about the clinical application.

3) Uchida's system [34]

Hiraiwa, et al. [20] employed a single channel EMG to classify five hand motions. They utilized the neural network to analyse and classify the EMG pattern to control a prosthetic hand. The work of Hiraiwa was continued and developed by Uchida, et al. [34] to deal with multichannel EMG. In their work, the electrodes were located on the forearm especially on the flexor digitorium superficialis (FDS) muscle. Five motions involved were the flexion of all fingers (A), the flexion of the index finger (B), the flexion of the middle finger (M), the flexion of the thumb (T) and relaxation of all fingers (N). Using two EMG channels, they extracted fast Fourier transform (FFT) features. The FFT of the EMG signals became the inputs of the feed-forward neural networks (FF-NN). The experimental results showed that the system able to classify five-finger movements and attain an accuracy of 67%. In the case of 2 EMG channels, they could improve the accuracy up to 86%. All experiments were conducted in the laboratory.

4) Tsenov's system [19]

Similar to Uchida, et al. [34], Tsenov, et al. [19] developed a recognition system of finger movement using multilayer perceptron (MLP). MLP classified four finger movements: thumb, pointer, middle and hand closure. The electrodes were located on two groups of muscles, planaris longus (PL) and extensor digitorum (ED). They extracted time-domain (TD) features from EMG signals and put them on the input of the MLP. In the offline experiment, they achieved an accuracy of 93% and 98% using two and four EMG channels, respectively. Meanwhile, in the online classification, the system showed a promising performance by making 30 errors of 250 tested movements. These promising results were obtained in the laboratory environment.

5) Tenore's system [35]

Tenore, et al. [35], researchers from John Hopkins University developed a pattern recognition system using EMG signals to decode individual finger movements. The movements consisted of the flexion and extension of all individual fingers and the middle, ring, little fingers as a group. There are 12 classes involved in the experiment. The work involved five able-bodied subjects and one trans radial amputee. The experiments results show that the system achieved a high level of classification accuracy (approximately 90 %).

6) Cipriani

Cipriani, et al. [22] developed EMG pattern recognition for a prosthetic hand. Different from the previous researcher who employed MLPs or ANN, they utilized k-nearest neighbour (kNN). Features were extracted from nine EMG channels using time domain features. Moreover, they were acquired from five able-bodied and amputee subjects. There are seven hand movements classified including thumb flexion (A), index finger flexion (B), thumb opposition (C) middle, ring, and little finger flexion (D), long fingers flexion (E), tri-digital grasp (F) and lateral grip/key grip (G).

The experiment involved 10 participants, five trans-radial amputees, and five able-bodied subjects. Eight bipolar EMG electrodes were placed on the right arm of participants or the residual limbs. The recognition system was implemented online and able to classify seven finger movements with the accuracy of around 79 % and 89% on the amputee subjects and non-amputee subjects, respectively.

7) Khushaba

Khushaba, et al. [23] developed a new MPR system for finger movements using support vector machine (SVM). There were six time-domain features involved, i.e. ZC, WL, SSC, HTD, SS, and AR model parameters. Then, the size of the features was reduced using LDA. The experimental results indicated that the system achieved an accuracy of approximately 92% and about 90% in the offline classification and online classification, respectively. Regarding accuracy, Khushaba *et al.*'s recognition system was promising, but the system contains a natural shortcoming of SVM in dealing with the multi-classification problem. At least, the recognition system should use *m* SVMs to deal with *m* movement classes. Inevitably, this will add to the processing time of the system.

8) Al-Timemy

The most recent study of a pattern-recognition system on finger movement classification was undertaken by Al-Timemy, et al. [11]. They investigated several schemes for the EMG pattern recognition. The developed system extracted features from six up to twelve EMG signal using AR and TD features. There were four combinations of dimensionality reductions and classifiers employed. They are PCA-LDA, PCA-SVM, orthogonal fuzzy neighbourhood discriminant analysis [17] (OFNDA)-LDA and OFNDA-SVM. Those systems classified 12 classes on six amputees. Meanwhile, it worked on and 15 classes on ten healthy subjects. The most accurate of the four combinations was the system with OFNDA-LDA. The experimental results showed that the proposed system achieved an accuracy of around 98% on the non-amputees and 90% on the amputees.

9) SPMC for MPR

The researchers realized that the existing MPRs did not consider many DOFs. SPMC is a solution that is being popular utilized nowadays. Jiang, et al. [36] employed SPMC to control 3-DOFs of the wrist. MLP was used to estimate the three joint angles of the wrist and send it to SPMC. The experimental results showed that the joint angle estimation from non-amputees was more consistent than the amputees. Other publications regarding the implementation of SPMC can be found in [37, 38].

10) Muscle synergy

The robustness issue of MPR, especially in clinical application, is the current problem of MCS. Muscle synergy was proposed to produce a robust feature to result in a robust MPR. The success of the implementation of the muscle synergy will lead to the success of SPMC. Ison and Artemiadis [39] evaluated the role of muscle synergy in the MCS. This publication has trigged other researchers implementing the muscle synergy on MCS [40] [41]. The experiments did not involve the amputee. However, the results indicate the big hope for the success of the muscle synergy on the clinical application.

B. EMG-based exoskeleton hand

This section presents a review on the current EMG-based exoskeleton hand.

1) Mulas's exoskeleton [29]

Mulas's exoskeleton is an exoskeleton hand that is designed for the hand recovery of a patient following stroke. The EMG electrodes were located on the subject's forearm. The signal was used to predict the user's intention to do a specific task or activity. The exoskeleton is composed of a glove with plastic support to guide the fingers to accomplish a natural movement and avoid getting an excessive load on the tips. It is actuated by two electric motors that are Hitec servos HS-8-5BB. One actuator is employed to move the thumb while the other were utilized to flex the four fingers simultaneously. Two springs on the dorsal side were put in to allow extension movements.

The main controller runs on the personal computer (PC) using MALTAB. The PC obtains the user's intention from the EMG signals acquired from two electrodes that capture the signals from the flexor digitorum superficialis and the Flexor flexor pollicis Longus. Then the output control from the PC was fed to the microcontroller to control the finger movements according to the intended position. In the hierarchical structure, the microcontroller behaves as a low-level controller while the PC behaves as a high-level controller. The controller utilized the threshold value of EMG to flex the fingers.

2) Wege's exoskeleton hand [42]

This exoskeleton hand was developed to support the rehabilitation process for the patient after a stroke or hand injuries. It has four degrees of freedom in each finger.

Therefore, in total, it supports up to 20 finger joints. The system is equipped with some sensors such as hall sensors, optical encoders, and force sensors. Other sensors are surface (EMG) sensors at the forearm. This exoskeleton hand employed the blind source separation to separate the information contained in the high-density surface EMG signals at the forearm into several signals related to specific finger movement. Ten electrodes were located in the forearm

3) Tong's exoskeleton [30]

This exoskeleton was designed as a hand robotic training device to help stroke patient in recovering the impaired hand function. This device is able to detect the user's intention from the user's muscles in the hand opening and closing training. The exoskeleton's structure fits the different finger lengths and aligns the virtual centre of rotation of the metacarpophalangeal (MCP) and the proximal interphalangeal (PIP).

The embedded controller is built to accompany the hand robot that drives the linear actuator and detect the user's intention by interpreting the EMG signals that are acquired from the abductor pollicis brevis (APB) and the extensor digitorum (ED. These signals were used to predict the hand closing and hand opening, respectively. The embedded controller was equipped with a wireless module to enable the therapist to configure the exoskeleton and the training module.

4) Ngeo's finger exoskeleton [43]

This finger exoskeleton is constructed of a four-bar linkage structure that is able to actuate the movement of finger joints. The Arduino Mega micro-controller was used to control the movement of the exoskeleton based on the motor command obtained from the processed EMG signals. The surface EMG from the flexor digitorum Superficialis (FDS), flexor digitorum profundus (FDP), extensor digitorium (ed) and extensor indicies (EI) muscles were acquired and processed to predict the motor intention of the continuously moving fingers.

Each surface EMG signal was converted to a muscle activation by using the so-called EMG-to-muscle activation model. The muscle activations from each muscle were fed to the artificial neural network (ANN) to predict the intended finger joint angle. The experimental result was good and promising even though it was only tested on a healthy subject. The drawback of this system is obviously working on one finger only. The complexity and density of the muscles in the forearm have not been considered yet. Another example of EMG controller for index finger was proposed by Anam, et al. [44]

IV. Discussion

Myoelectric pattern recognition (M-PR) is used in most current prosthetic hands. On the other hand, myoelectric non-pattern recognition (M-non-PR) is widely used for exoskeleton hand, instead of M-PR. Furthermore, among M-non-PR, a myoelectric threshold controller is the most controller for the exoskeleton hands. As a result, the hand or finger actions involved are very limited. Most of them are the hand opening and hand closing only. In reality, the finger movements are not limited to two of those actions only. Therefore, the exoskeleton hand should consider more finger motions instead of just two fingers. This the main issue in the M-non-PR controller.

Different from the M-non-PR, the major issue emerging in the M-PR is the big gap between success of the laboratory experiments and the clinical applications. Farina, et al. [31] found that this is due to robustness of M-PR. The robustness issue can be overcome by following ways (Ning, et al. [45]). Firstly, the M-PR should be able to handle multi-degrees of freedom by suing a simultaneous and proportional controller. Secondly, M-PR has to utilize sensors for movement feedback. Thirdly, M-PR should have adaptation mechanism on the changes of EMG signal characteristic. Finally, M-PR should integrate EMG with sensors to allow complex actions. To the best of author's knowledge, all reviewed system has not considered this gap properly.

The main metric to measure the success of the M-PR in the laboratory and clinical application is either an error or accuracy of the classification result. These measurements (error or accuracy) is used to judge the efficacy of the proposed M-PR as an attempt to reduce the gap between the laboratory experiment and clinical application. To the best of the author's knowledge, the majority of researchers have used this metric for years. Nevertheless, there is little improvement in the error metric by proposing incorrect active decisions instead of using wrong decision only, as proposed by Scheme, et al. [46]. Therefore, the error or accuracy are the primary measurement used to verify the efficacy of the M-PR.

V. Conclusion

This paper provides the review of the myoelectric control system (MCS) on the rehabilitation devices. MCS has been developed since the 1940s. This article has emerged some issues that should be considered in developing MCS for the hand rehabilitation devices. The main issue is the robustness of myoelectric signal. This issue should be addressed properly to achieve a reliable control system for hand rehabilitation device.

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