

Spatial Mapping and Feature Analysis for Individual Finger Movements Using High Density Electromyography: Preliminary Study

Prabhav Mehra¹, Manya Dave², Ahsan Khan¹, and Raymond K. Y. Tong¹

¹ Department of Biomedical Engineering, The Chinese University of Hong Kong, Shatin, Hong Kong

² Department of Electronics, IIT Ropar, Ropar, India

Email: {prabhavmehra, kytong}@cuhk.edu.hk, 2016eeb1084@iitpr.ac.in, ahsan@link.cuhk.edu.hk

Abstract—The analysis between finger movements is an important aspect of biophysics and rehabilitation. The study aims to evaluate the distinctive muscle activities between finger movements through the help of High-Density Electromyographic (EMG) signals for increased myoelectric control of soft robotic hand. 64-channel EMG signal was recorded during individual finger isometric task for 5 healthy subjects. Raw, single differential and double differential EMG signals across the 2D array was analyzed. Spatial image of these signals for the 4 different finger movement demonstrated multiple distinctive properties, the major distinction. Feature set of six distinct features was calculated for the array of EMG signals to quantitatively differentiation between finger movements. Centroid of these feature set acquired different 3D space indicating differences in the finger movements. This indicated that HD-EMG could be used for differentiating finger movements and could be used as a method for classification algorithm for increased myoelectric finger control in future.

Index Terms—high density EMG, Electromyography (EMG), spatial analysis, myoelectric finger control

I. INTRODUCTION

Electromyography signals are the recorded electrical signals obtained from the muscle fibres discharge in form of Motor Unit Action Potentials (MUAPs).

The study of electromyographic signals has wide applications like clinical diagnosis, prosthesis, and rehabilitation devices. The classification of electromyographic signals [1] corresponding to the movement of different fingers helps to improve the feature of multi-finger control for rehabilitation establishing better mimicry of the human hand movements. It is an important study for the development of advanced rehabilitation system with better functionality and comfort. The amplitude of EMG signals for finger

movements is very small relative to that for commonly studied bicep brachii or vastus lateralis muscles, and the muscles responsible for the movement of different fingers

are quite close, so it is much more difficult to identify them.

In earlier works, feature extraction has been done for the classification of finger movements using the time-domain and/ or frequency domain features for bipolar surface EMG signals. Networks are then made to classify the signal using these complex features. However, these feature extraction techniques are more time consuming, more susceptible to error and they may not be suitable for real-time applications. Some classifiers have used Fourier transform, Wavelet transform, Auto Regressive model parameters, and Hjorth time domain parameters [2], [3] over Support Vector Machines and Extreme Learning Machines while others have used methods like Principal Component Analysis (PCA), Linear Discriminant Analysis (LDA) techniques [4]. Machine learning based techniques over these complex features have been able to classify with accuracy up to 98.0% [5], but the extraction of the features that have been used in these methods is highly computationally extensive. Moreover, these features do not provide any information about the difference in the locations of muscles that are used for different finger movements which can be used as a method for classification. Spatial firing pattern is also an important aspect of analysis for rehabilitation of subjects with neuromuscular disorder.

For the spatial domain study of electromyographic signals, electrodes need to be placed over a wide muscle area to collect signals from different zones in the muscles. High-density surface electromyography is an advanced EMG signal acquisition technique. The closely spaced electrode grid allows the recording of signals from a larger area using multiple channels, which can be analysed spatially. [6], [7] There have been very limited studies on the classification of finger movements using HD-EMG signals with the help of time domain features and frequency and spatial features.

In this work, the Spatial properties of the high-density electromyographic signals have been used to find a feature set that can be used to classify the motion of the four fingers. Some important features [1] like RMS value of intensity and centre of gravity for monopolar, single differential (bi-polar) and double differential signals that have been used for the classification of arm movements in

some earlier studies [8], [9] have been mixed with properties like activation pattern and duration of certain channels of the multi-channel electrode grid. Also, differences in the spatial maps among the activations of different channels for different fingers are observed using the heat-maps.

II. METHODOLOGY

The individual finger movements were analyzed using High Density Electromyography (HD-EMG) signals during the experimental setup under which the subjects performed the respective task with 4-different fingers. Total of 5 subjects performed the designed experiment. (n = 5)

A. Experimental Protocol

The subjects were instructed to press the button isometrically as shown in Fig. 1 for duration of 5 secs with 15 repetitions. The same task was performed for each of the 4 fingers in a pattern of first index finger, then second finger, third ring and at last fourth finger. A rest interval of 5 secs was taken between successive repetitions.

During the task, flexor muscle signals were recorded using TMSi 64-channel high density EMG system and the electrode patch with interelectrode distance of 8mm. The patch was placed parallel to Flexor carpi radialis muscle and 64-channel EMG signal was recorded at 2048 Hz during the experiment. The subjects were instructed throughout the experiment to minimize other finger movements.

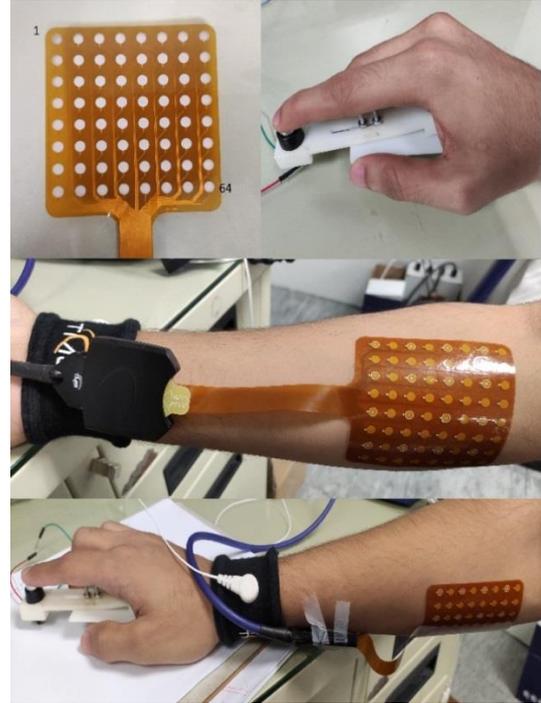


Figure 1. Experimental setup, 1A. 64-channel electrode (8×8 grid) and button setup, 1B. Electrode placement, 1C. Complete experimental setup

B. Signal Processing

The recorded signals were bandpass filtered between 5-200 Hz and 50Hz harmonic artifacts were removed using combinational notch filter.

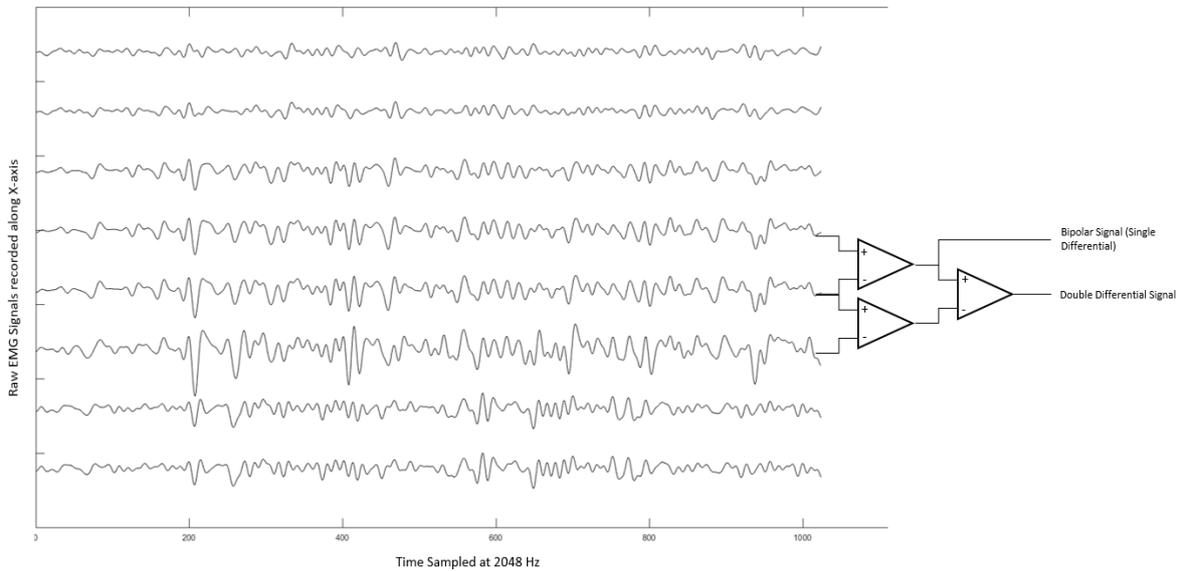


Figure 2. Differential signal extraction protocol using raw EMG signals from electrode array (8 electrode) parallel to muscles (along X-axis)

The 15 repetitions of activated signal for 5 seconds were detected by passing the mean envelope of the 64-channel EMG through the threshold. Using the detected raw EMG signal, single differential and double differential signal along the direction parallel to the muscle was determined as shown in Fig. 2.

Spatial imaging for raw EMG, single differential and double differential signal was mapped for the 64 channels by calculation root mean square amplitude of the signal during activated region, the RMS values thus calculated were averaged over 15 repetitions.

C. Feature Extraction

The features sets extracted for examining the difference between the finger movements is an extension of features suggested by Jordanic M *et al.* [3], feature set of six features were calculated instead of just three as suggested earlier. The features extracted is as following.

- 1) Intensity (averaged RMS amplitude) of raw EMG signals.
- 2) Center of gravity of spatial image of 64-channel raw EMG signal.
- 3) Intensity (averaged RMS amplitude) of Single Differential/bipolar EMG signal
- 4) Center of gravity of spatial image of single differential EMG signal.
- 5) Intensity (averaged RMS amplitude) of Double Differential EMG signal
- 6) Center of gravity of spatial image of Double differential EMG signal.

Further analysis of the spatial map of all the 3 signals (Raw, Signal and Differential) for 4-different finger movements was undertaken. The spatial map of the signals was analyzed with the aim to recognize the distinct spatial activation pattern of the muscle during distinct finger movements. In spatial map, X axis is defined as direction parallel to the muscle while Y axis is the one perpendicular. This is the 2D coordinate system of EMG electrode array.

III. RESULTS

A. Spatial Mapping

Spatial imaging of the acquired data was undertaken upon raw, single differential and double differential EMG signals. Spatial map indicated distinctive space over the EMG 2D array for different finger movements. Fig. 3 raw signal spatial map is the average of normalized intensity over 5 subjects for 64 channels while Fig. 4 is the average

of normalized map of single differential signal of the collected EMG.

The showcased spatial images for all 4 movements indicate distinct properties specially in the left half of the map. In raw spatial map, ring finger demonstrates heavy muscle activity intensities in the top left region whereas fourth finger doesn't show much activity in the left half (between electrode coordinates of 1,1 to 8,4) of the space. Index finger showed higher activity in lower diagonal half where the diagonal is between coordinate 1,8 to 4,1. whereas second finger EMG intensity was spread throughout the left half. As for the single differential spatial map, ring finger demonstrated higher intensities in the left half as compared to all other finger movements, similar to raw signals fourth finger showed very little activity in the left half and ring finger still had significant activity in the top left part of map. First and the second finger showed much more spread of intensity across the patch though the second finger had significant difference between intensity level in the right half as compared to left half, but for index finger the intensities were comparable between left and the right half.

B. Feature Analysis

All the six features for individual finger movements were calculated and the average values across all the subjects and is listed in Table I. The features extracted were divided into two categories i.e. Center of gravity and Intensity. Center of gravity was acquired by calculating X, Y coordinates for the spatial map and then projecting that onto the grid number for the signal arrays whereas intensity is the average root mean square value of the amplitude for the signal array.

Fig. 5 is the projection of the centroid of the two feature categories onto 3D space and it clearly indicates that the features acquire completely different space in the 3D geometry, demonstrating distinctive characteristics among the finger movements.

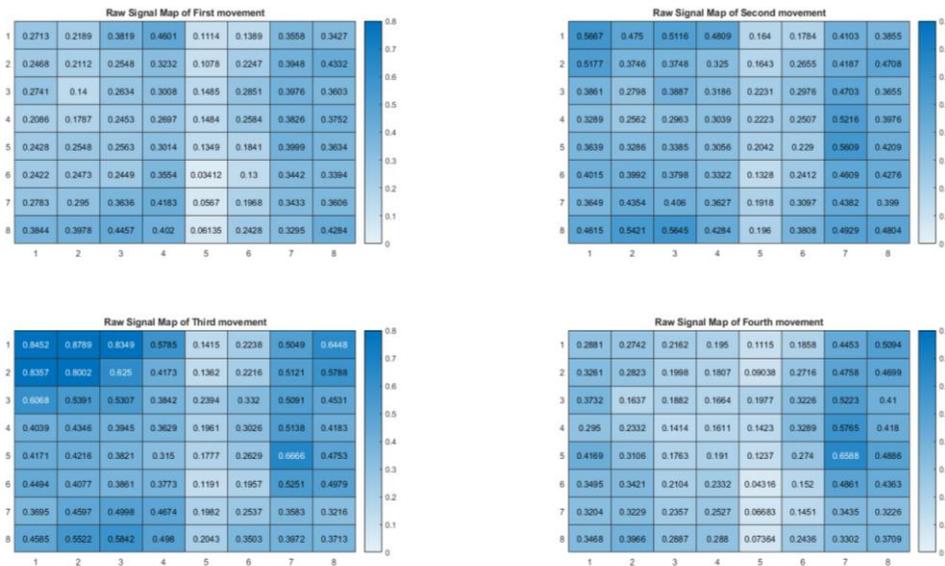


Figure 3. Spatial map of raw signal (normalized) for 64 channel EMG. 2A. Map of index finger, 2B. Map of second finger, 2C. Map of ring finger, 2D. Map of last finger

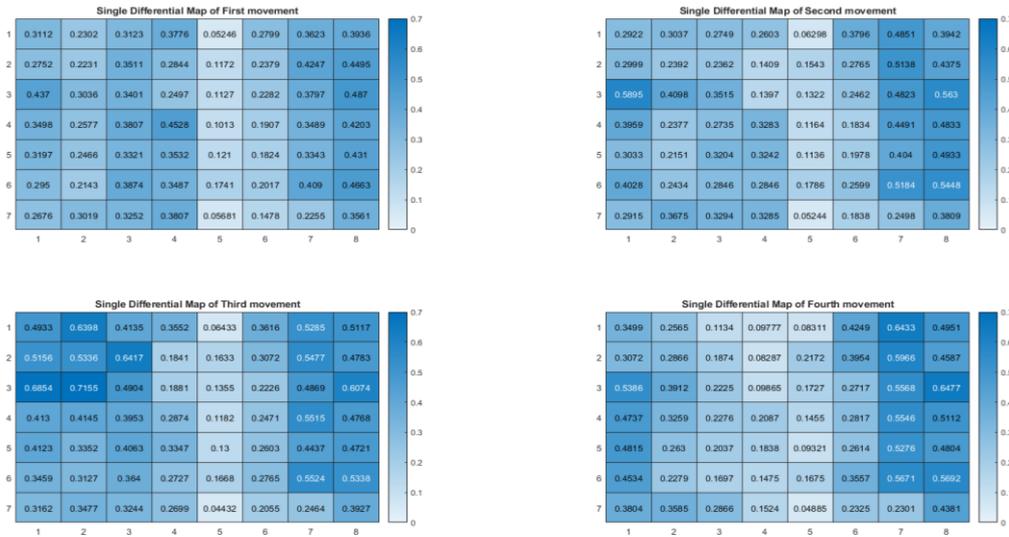


Figure 4. Spatial map of single differential (normalized) of EMG signals. 3A. Map of index finger, 3B. Map of second finger, 3C. Map of ring finger, 3D. Map of last finger

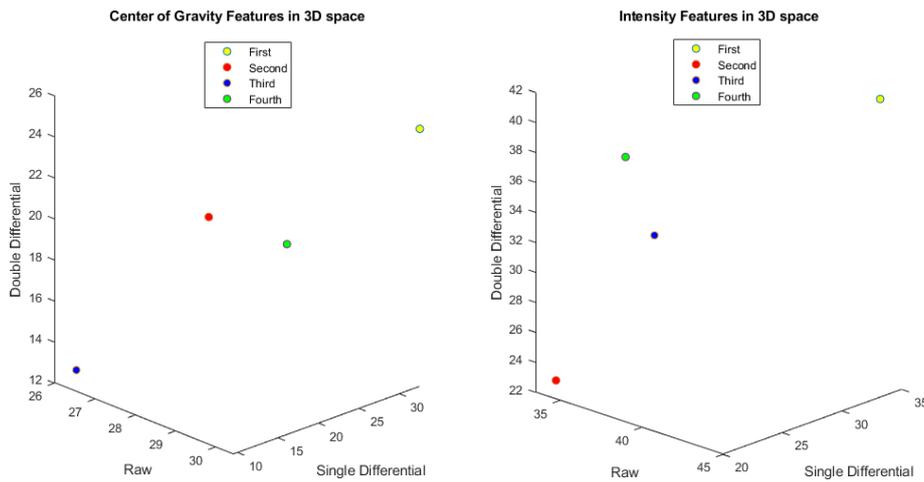


Figure 5. Features displayed in 3D space, 4A. Center of gravity space (grid number), 4B. intensity space (mv)

TABLE I. VALUES OF FEATURES EXTRACTED FROM THE ACQUIRED SIGNALS

Features	Signal Type	Axis	Finger Movement			
			Index	Second	Ring	Fourth
Center of Gravity (Coordinates)	Raw	X	4.44	4.38	4.54	4.30
		Y	4.91	4.56	4.22	4.53
	Single Diff.	X	4.52	2.66	2.38	3.97
		Y	5.53	3.34	2.60	4.77
	Double Diff.	X	3.54	2.90	2.56	3.08
		Y	4.96	4.30	3.29	4.12
Intensity (mV)	Raw		44.90	33.51	39.33	34.25
	Single Diff.		33.30	21.70	21.99	26.51
	Double Diff.		41.82	22.30	33.99	36.08

IV. CONCLUSION

The signal analysis carried upon raw and multiple differential signal with the help of spatial mapping and extracted features indicated properties that differentiated between finger movements. Some properties in spatial images like increased top-left array intensity is characteristic to ring finger whereas very minimal activity of in the electrode region of 1 to 40 was characteristic to fourth finger, index and second finger characteristically showed much more spread of equi-intensity channels but were spanned to different regions of electrode array. Extracted feature sets characterized by center of gravity and average intensity centroid also occupied different places in 3D space suggesting differences in the feature sets. Furthermore, this suggests than using both category feature sets together would further enhance the distinction between individual finger movements.

The preliminary results from the acquired HD-EMG signals indicates that multichannel signal mapping has distinctive features which could be used for the classification of individual finger movements in the future studies. In our further study, we aim to develop a robust classifier based upon the spatial as well as spatio-temporal properties acquired by recorded signals from HD-EMG as an extension of the current stage for increased myoelectric finger control during rehabilitative training for hand.

CONFLICT OF INTEREST

The authors declare no conflict of interest

AUTHOR CONTRIBUTION

Prabhav Mehra was responsible for analyzing the collected data and reporting the results; Manya Dave was involved in collection of HD-EMG data from the subjects; Ahsan Khan was responsible for pre-processing of the collected data; Prof. Raymond K. Y. Tong supervised the research project; all authors had approved the final version.

ACKNOWLEDGMENT

This research is supported by the CUHK T Stone Robotics Institute (C4930759), the CUHK Knowledge Transfer Project Fund (KPF18HLF12), and the Hong Kong Information and Technology Fund (ITF) (ITS/065/18FP).

Corresponding Author: Prof. Raymond Tong, Department of Biomedical Engineering, The Chinese University of Hong Kong, Shatin, HKSAR, Contact: +852 3943-8454, Email: kytong@cuhk.edu.hk.

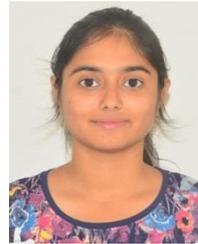
REFERENCES

- [1] M. Rojas-Martínez, M. A. Mañanas, and J. F. Alonso, "High-density surface EMG maps from upper-arm and forearm muscles," *Journal of NeuroEngineering and Rehabilitation*, vol. 9, no. 1, p. 85, Dec. 2012.
- [2] A. A. Al-Tae and A. Al-Jumaily, "Optimal feature set for finger movement classification based on sEMG," in *Proc. 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Honolulu, HI, 2018, pp. 5228-5231.
- [3] R. N. Khushaba, S. Kodagoda, M. Takruri, and G. Dissanayake, "Toward improved control of prosthetic fingers using surface Electromyogram (EMG) signals," *Expert Syst. Appl.*, vol. 39, no. 12, pp. 10731-10738, September 2012.
- [4] N. Celadon, S. Došen, I. Binder, P. Ariano, and D. Farina, "Proportional estimation of finger movements from high-density surface electromyography," *Journal of NeuroEngineering and Rehabilitation*, vol. 13, no. 1, August 2016.
- [5] N. Sezgin, "A new hand finger movements' classification system based on bicoherence analysis of two-channel surface EMG signals," *Neural Computing and Applications*, vol. 31, no. 8, pp. 3327-3337, 2019.
- [6] M. Jordanić, M. Rojas-Martínez, M. A. Mañanas, J. F. Alonso, and H. R. Marateb, "A novel spatial feature for the identification of motor tasks using high-density Electromyography," *Sensors*, vol. 17, no. 7, 2017.
- [7] D. Bai, S. Chen, and J. Yang, "Upper arm motion high-density sEMG recognition optimization based on spatial and time-frequency domain features," *Journal of Healthcare Engineering*, 2019.
- [8] M. Jordanić, M. Rojas-Martínez, M. A. Mañanas, and J. F. Alonso "Spatial distribution of HD-EMG improves identification of task and force in patients with incomplete spinal cord injury," *Journal of NeuroEngineering and Rehabilitation*, vol. 13, no. 1, p. 41, Apr. 2016.
- [9] A. H. Al-Timemy, G. Bugmann, J. Escudero, and N. Outram, "Classification of finger movements for the dexterous hand prosthesis control with surface electromyography," *IEEE Journal of Biomedical and Health Informatics*, vol. 17, no. 3, pp. 608-618, 2013.

Copyright © 2020 by the authors. This is an open access article distributed under the Creative Commons Attribution License ([CC BY-NC-ND 4.0](https://creativecommons.org/licenses/by-nc-nd/4.0/)), which permits use, distribution and reproduction in any medium, provided that the article is properly cited, the use is non-commercial and no modifications or adaptations are made.



Prabhav Mehra received his master's degree in Biological Sciences and bachelor's degree in Electrical and Electronics at BITS-Pilani, India. He is currently working as a Research Assistant at the Department of Biomedical Engineering, CUHK. His area of interest includes Biomedical Signal processing, Supervised Learning, Neuromuscular Engineering, Rehabilitation Robotics and Neuromuscular Physiology.



Manya Dave is currently pursuing her B.Tech degree from the Department of Electrical Engineering at Indian Institute of Technology Ropar, India. She worked as a Junior Research Assistant in the Department of Biomedical Engineering, Chinese University of Hong Kong for a period of three months in summer 2019. Her areas of interest include Biomedical Signal Processing, Image Processing, and Applied Deep Learning.



Ahsan Khan is currently a PhD candidate in the Chinese University of Hong Kong. He is interested in rehabilitation sciences, medical imaging and cognitive neuroscience. He has got relevant research experience in some of the well reputed institutes in the world including National Institute for Physiological Sciences (NIPS), Japan, Hong Kong Polytechnic University (PolyU), and Pakistan Institute of engineering & Applied Science (PIEAS).



Raymond Kai-yu Tong is a Biomedical Engineer and he is currently a Professor and Chairman in the Department of Biomedical Engineering, CUHK. His research interests include Rehabilitation Robotics (e.g. Hand of Hope), Brain-Computer Control Interface (BCI), Neural Engineering, Functional Electrical Stimulation (FES) and Cognitive Assessment Software. Prof. Tong is recognized for his works in innovation and applied scientific research in neuro-rehabilitation for stroke patients and the elderly. His research, innovation and service have received Awardee of the 2013 Hong Kong Ten Outstanding Young Persons; Winner Award (e-Health) in the Asia Pacific ICT Award 2012; and HKIE innovation awards for young members (2008), gold awards in international invention exhibitions (04', 07', 10', 15' & 16').