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Pattern recognition of electromyography signals based on novel time domain features for amputees' limb motion classification☆

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ABSTRACT

Feature extraction is essential in Electromyography pattern recognition (EMG-PR) based prostheses control method. Time-domain features have been shown to have good performance in upper limb movement classification. However, the performance of EMG-PR prostheses driven by the existing time-domain features is still unsatisfactory. Hence, this study proposed three new time-domain features to improve the performance of EMG-PR based strategy in arm movement classification. EMG signals were recorded from the residual arms of eight amputees while performing different upper limb movements. Then, the newly proposed features were extracted and used to classify their limb movements. Experimental results showed that the proposed features could achieved an average classification accuracy of 92.00% ± 3.11% which was 6.49% higher than that of the commonly used time-domain features ($p < 0.05$). With three additional metrics, the proposed features also performed better, which suggest that the new features may be potential for improving the clinical performance of EMG-PR prostheses.

1. Introduction

Surface electromyogram (EMG) recordings from the muscles of a residual limb have been proposed and used as an input signal to control motorized myoelectric prostheses and other rehabilitation robots because of their noninvasive nature [1–4]. Also, simultaneous proportional control method for upper limb prostheses control was recently proposed. The clinically viable myoelectric controller mapped the amplitude of EMG signals recorded from the skin surface of amputees' residual arm to control prosthesis with a single degree of freedom (DOF) [1,5]. However, such rehabilitation device could not meet the needs of most users thereby leading to the development of other forms of myoelectric control systems such as, the three-state amplitude controller, three-state rate-sensitive controller, and the myo-pulse controller [6]. Meanwhile, body-powered harnesses, mechanical switches, and force-sensitive resistors were later built into each of the above controller in

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Table 1
Demographic data of the recruited subjects.

S/No.	Subject	Residual limb	Age	Residual limb length	Amputated since
1	TH1	Left	49 years	20 cm	3 years
2	TH2	Left	46 years	25 cm	9 years
3	TH3	Right	35 years	27 cm	5 years
4	TH4	Right	36 years	26 cm	7 years
5	TR1	Left	31 years	44 cm	9 years
6	TR2	Right	26 years	39 cm	6 years
7	TR3	Left	31 years	43 cm	10 years
8	TR4	Left	27 years	41 cm	8 years

order to achieve better prostheses control strategy. These conventional methods for the control of myoelectric prostheses work well in some cases, but could only restore limited number of arm functions (limited DOF) with restricted intuitiveness of use for the amputees. Recent development in rehabilitation robotics had revealed EMG pattern recognition (EMG-PR) based control strategy as a promising technique since it has the potential to control more DOFs than the conventional control strategies that usually require independent control sites for each motion type [7]. The control strategy based on EMG-PR involves performing EMG signal measurement (to capture more reliable myoelectric signals), feature extraction (to retain the most discriminating information from the signal), classification (to predict one of a subset of intended limb motions), and issuing control commands (translating the control commands to drive a multifunctional prosthesis).

The performance of this state-of-the-art control strategy (EMG-PR) depends largely on the attributes of the features extracted from the EMG signals, which are mainly characterized by large variations and non-stationary properties [8]. These properties of EMG signals have made it relatively difficult to extract a robust set of features from which arm movements could be effectively decoded and used to control prosthetic devices. Notwithstanding, over the years, a number of efforts have been made to extract the proper sets of features from recorded EMG signals for accurate classification of various limb movements. As a result, features from time-domain, frequency domain, and time-frequency domain have been proposed for amputees' limb motion classification [9]. Among these, time-domain features have gained wide application over the years since they relatively require little computing resources (processing power, memory, and computation time) that relates to the fact that microcontrollers in upper limb prosthetic devices are characterized by limited computing resources. However, the control performances of the current prosthetic devices with multiple DOFs are unsatisfactory yet, which has affected their acceptance rate among upper limb amputees [10]. One of the possible major reasons would be that existing time-domain features only provide limited neural information in identifying different classes of arm motions.

In this study, we proposed a new set of time-domain features to characterize the EMG patterns with an attempt to enhance the performance of EMG-PR based strategy in classifying arm movements in amputees. The performances of the proposed time-domain features were investigated and compared with those of the conventional time-domain features using four different evaluation metrics, and the results obtained clearly show that the newly proposed features have the potential to improve the classification performance of a prosthetic device with multiple DOFs.

The rest of this paper is organized as follows: Section 2 presents the Materials and methods while Section 3 presents the experimental results and discussion, and Section 4 presents the conclusion of the study and possible future research directions.

2. Material and methods

2.1. Subject information

A total of eight subjects with upper limb amputation including four transradial (TR) and four transhumeral (TH) amputees were employed in this study. The residual limb of the subjects were carefully examined to be sure that the limbs are proper with respect to the requirement of the current study. That is, there were no muscle damages or neurological issues with their residual limbs, and they all had a unilateral amputation. The demographic data of the recruited amputees is presented in Table 1 as follows.

Prior to the commencement of the study, the subjects gave written informed consent and provided permission for publication of their photographs for scientific and educational purposes. The entire protocol of the study was approved by the Shenzhen Institutes of Advanced Technology's Institutional Review Board, Chinese Academy of Sciences, China.

2.2. Equipment and data collection

A high density EMG measurement system (*Refa 128 model, TMS International, Netherlands*) was integrated with the TMSi Polybench software package and used to record surface EMG signals corresponding to various arm motions from the residual arm muscles of the recruited subjects. Before placing the EMG electrodes, the forearm skin of the subjects was cleaned with abrasive paste and alcohol wipes in order to guarantee good electrode-skin contact, which would minimize the impedance and improve the fidelity of the recorded signal [11]. In this study, a high-density electrode array was adopted to record the