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Design and Myoelectric Control of an Anthropomorphic Prosthetic Hand

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Abstract

This paper presents an anthropomorphic prosthetic hand using flexure hinges, which is controlled by the surface electromyography (sEMG) signals from 2 electrodes only. The prosthetic hand has compact structure with 5 fingers and 4 Degree of Freedoms (DoFs) driven by 4 independent actuators. Helical springs are used as elastic joints and the joints of each finger are coupled by tendons. The myoelectric control system which can classify 8 prehensile hand gestures is built. Pattern recognition is employed where Mean Absolute Value (MAV), Variance (VAR), the fourth-order Autoregressive (AR) coefficient and Sample Entropy (SE) are chosen as the optimal feature set and Linear Discriminant Analysis (LDA) is utilized to reduce the dimension. A decision of hand gestures is generated by LDA classifier after the current projected feature set and the previous one are "pre-smoothed", and then the final decision is obtained when the current decision and previous decisions are "post-smoothed" from the decisions flow. The prosthetic hand can perform prehensile postures for activities of daily living and carry objects under the control of EMG signals.

Keywords: electromyography, anthropomorphic prosthetic hand, myoelectric control, pattern recognition, prehensile gestures

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1 Introduction

The anthropomorphic prosthetic hand is often mounted on an amputee and can be controlled by EMG. The sEMG signal is a noninvasive electrical biosignal which can represent the muscles activities. Myoelectric control has been widely used to control peripheral devices[1,2], especially prosthetic limb[3], through extracting the information from the sEMG and evaluating the contraction state of the muscles.

1.1 Multifunctional anthropomorphic prosthetic hand

The ideal prosthetic hand is supposed to be the same with the human hand in shape and features. According to the performance, the prosthetic hands can be divided into cosmetic hand, body-powered hand and EMG prosthetic hand. During the last decade, several multifunctional anthropomorphic prosthetic hands with EMG control have been developed by some companies and research institutions[4–12]. Underactuation[4], variable compliance couplings and module design are often adopted in the multi-DoF hands which have functions similar to the human hand. The i-Limb hand has five independently controlled fingers which is controlled by simple open and close signals from two electrodes[5]. Dalley *et al.* developed a hand with 16 joints driven by 5 independent actuators which provided 8 hand postures[6]. The Smarthand consists 5 fingers and 4 DoFs, with 40 sensors used for automatic control and feedback delivery[7]. The Southampton Remedi-Hand has 5 fingers and 6 DoFs, which are controlled by feedback control system with dynamic force sensors and piezo-resistive resistors[8]. The UB hand III is a humanoid robot hand which is based on an endoskeleton made of rigid links connected with elastic hinges, and is actuated by sheath routed tendons[9]. The HIT/DLR prosthetic hand has strong capability of self adaptation with multi sensors and 5 fingers actuated by 3 motors[10]. The hand with three articulated fingers driven by 4 DC motors through a special underactuated transmission was developed by Zollo *et al.*[11] The Fluidhand is actuated with flexible fluidic actuators which constitutes a new hybrid concept of an anthropomorphic five fingered hand and a three

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jaw robotic gripper[12]. The hands mentioned above all have appearance and size similar to human hand and can perform prehensile postures for activities of daily living.

1.2 EMG pattern recognition method

To meet the increasing DoFs of prosthetic hands and provide more reliable and dexterous control[13], the pattern recognition method in a supervised way is widely used[14,15]. The fundamental preprocessing parts of the pattern recognition method includes data preprocessing, data windowing, feature extraction and classification[14]. The corresponding features are extracted from various muscle activities, and then the features are assigned to classes which represent relevant limb motions, that are the patterns. These patterns are learned by an algorithm which is then used to classify the limb motions[16]. The accuracy of the pattern recognition in sEMG greatly depends on the selection and extraction of features. A variety of EMG features has been used to represent the original EMG signals, which can be divided into 3 categories: time domain, frequency domain and time-frequency domain[1]. The time domain features are calculated from the time series of raw EMG signals. It has good classification property and enables simple calculation. Hudgins *et al.* used 5 time domain features including MAV, Mean Absolute Value Slope (MAVS), Zero Crossings (ZC), Slope Sign Changes (SSC) and Waveform Length (WL) to recognize 4 forearm motions and gained an average accuracy rate of 91%, which proved the effectiveness of time domain features[17]. Kim *et al.* successfully classified four wrist movements by using Integrated Absolute Value (IAV) and Root Mean Square (RMS)[18]. Features in frequency domain mainly reflect the fatigue of the muscle and the recruitment of motion unit, which usually contain Mean Frequency (MNF), Middle Frequency (MDF), Peak Frequency (PKF), Mean Power (MNP) and Total Power (TTP)[19]. However, Phinyomark *et al.* found that frequency domain features had worse performance than that in time domain when using MNF and MDF to recognize the hand gestures[20]. Features in time-frequency domain mainly contain Wavelet Packet Transform (WPT) and Short-time Fourier Transform (STFT), which can analyze signals in time domain and frequency domain at the same time though the calculation is complex. Englehart *et al.* used WPT and LDA to classify four kinds of hand and wrist motions and gained an average accuracy rate of 98%[21].

Due to the instability and stochasticity of sEMG signals, it is difficult for only one feature to represent the relevant hand gesture[22]. Therefore, feature set (the combination of different features) is often used to describe the sEMG signals[17,18,23–25]. However, high dimension feature vector will result in redundant data and classification burden. Principal Component Analysis (PCA)[26–29] and LDA are often used in dimension reduction[30,31]. Hargrove *et al.* obtained a higher classification accuracy when using individual PCA to preprocess raw EMG signals[29]. Chu *et al.* recognized nine movements of forearm, wrist and palm with 4 electrodes and obtained the accuracy of 97.4%, by utilizing LDA to reduce the dimension of the features extracted by WPT from 1024 to 8[8]. Khushaba *et al.* used LDA to reduce a series of features to the dimension of 9 and got the accuracy of 90% when recognizing 10 independent and associated motions of fingers[31].

Based on our previous research[32,33] on the off-line test and on-line recognition, an anthropomorphic prosthetic hand is presented and its myoelectric control system is built. MAV, VAR, the 4th AR and SE are selected as the optimal feature set, and LDA is utilized to reduce the dimension of the features. A combination of “pre-smoothing” and “post-smoothing” method makes the recognition of continuous gestures possible. A virtual hand is built to display the recognition result. All those compose the myoelectric control strategy of the EMG prosthetic hand to execute grasping tasks.

2 Prosthetic hand design

An anthropomorphic prosthetic hand (Fig. 1) is designed, which is made of aluminium alloy. The prosthetic hand has 5 fingers, 15 joints and 4 DoFs, with similar appearance and size to the human hand. The thumb and forefinger have independent movements, while the middle, ring and little fingers move

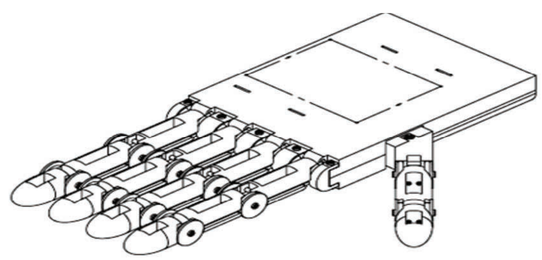

Fig. 1 The prosthetic hand.