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Portable hand motion classifier for multi-channel surface electromyography recognition using grey relational analysis

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ABSTRACT

This paper proposes the portable hand motion classifier (HMC) for multi-channel surface electromyography (SEMG) recognition using grey relational analysis (GRA). SEMG provides information on motion detection of flexion and extension of fingers, wrist, forearm, and arm. A portable HMC is developed to identify hand motion from the SEMG signals with an electrode configuration system (ECS) and GRA-based classifier. The ECS consists of seven active electrodes place around the forearm to acquire the multi-channel SEMG signals of corresponding muscle groups. Six parameters are extracted from each electrode channel and various 42 (7 Channels by 6 Parameters) parameters could be constructed as specific patterns. Sequentially, these patterns are sent to the GRA-based classifier to recognize 11 hand motions. Twelve subjects including eight males and four females participate in this study. Compared with the multi-layer neural networks (MLNNs) based classifier, GRA demonstrates the processing time, computational efficiency, and accurate recognition for recognizing SEMG signals. It takes about 0.05 s CPU time to identify each hand motion which is close to a real-time process. Therefore, the GRA-based classifier could be further recommend to implement in prosthesis control, robotic manipulator or hand motion classification applications.

1. Introduction

SEMG is a technique for evaluating and recording the activation signal of muscles. It is measured using an instrument, the called an electromyograph, to produce a record, the called an electromyogram. An electromyograph detects the electrical potential generated by muscle cells when these cells contract and also are at rest. SEMG signals are the sum of the potential generated in the muscle fibers including flexor carpi radialis, flexor carpi ulnaris, brachioradialis, pronator teres, supinator, biceps brachii, and triceps brachii, etc. They contain important information such as muscle force, muscle impedance, and human hand and arm motion. Human intended motion can be identified from the SEMG signals. They are used in many clinical and biomedical applications (Reaz, Hussain, & Mohd-Yasin, 2006). For clinical applications, they are used to identify the neuropathic and myopathic diseases. They are also used for prosthesis control (Huang & Chiang, 1999, 2000; Kuribayashi, Okimura, & Taniguchi, 1993), dynamic gesture recognition system (Kim, Jang, & Bien, 1996), and robotic manipulator control system (Fukuda, Tsuji, Shigeyoshi, & Kaneko, 1999, 2003). Currently, these signals can be also used to control a portable tool for an electronic device such as a mobile phone, personal digital assistant (PDA), and two-dimension mouse (Chan, Lau, & Li, 2008; Chen, Lau, & Ng, 2005). To design a portable tool, the EMG sensor (Cram, Kasman, & Holtz, 1998; Du, Shyu, & Hu, 2006; Shyu, Chen, Tatn, & Hu, 2002), real-time signal processing, classification capability, on-line learning technique (Nishikawa, Yu, Yokoi, & Kakazu, 2001), and hardware implement (Huang & Chiang, 2000; Popescu, Burdea, Bouzit, & Hentz, 2000) for portable classifier have become an essential task. Above literatures indicate that most of the hand motions can be identified from SEMGs using the electrode configuration system, feature extraction, and artificial intelligent techniques, and also provide promising results.

In literatures (Du et al., 2006; Shyu et al., 2002) have proposed a hand motion identification system which can discriminate 11 hand motions. This system used a wristband SEMG acquisition system consist of active electrodes to acquire SEMG signals from the forearm. Several features, such as the integral of the EMG (IEMG), waveform length (WL), variance (VAR), zero crossing (ZC), Slope Sign Changes (SSC), Willison amplitude (WAMP), and wavelet features were extracted from each SEMG channel. Multi-layer neural networks (MLNN) based classifier (Du et al., 2006; Fukuda, Tsuji, Kaneko, & Otsuka, 2003; Huang & Chiang, 1999; Kim et al., 1996; Kuribayashi et al., 1993; Nishikawa et al., 2001; Shyu et al., 2002) has been used for hand motion identification in this study. MLNNs

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use error back propagation to adjust network parameters and achieve a non-linear mapping relationship. The local minimum problem, slow learning speed, multi-layer structure determination, and the weight interferences between different patterns are the major drawbacks. The wavelet is a dilated low-frequency function or a constricted high-frequency function by changing wavelet coefficients for feature extraction. Significant features are suited to classify different patterns at specific dilation and translation parameters. Suitable wavelet coefficients must be chose with a tedious procedure of wavelet decomposition. In literatures (Chan, Yang, Lam, Zhang, & Parker, 2000; Su, Zhao, Huang, & Chen, 2001), Fuzzy-based EMG classifier has also presented to hand motion identification. Ruled-based method needs to determine the linguistic variables, membership functions, and inference rules. The inference rules and defuzzifier must be continuously modified according to the subject's condition.

To development a portable tool, the proposed method must be convenient to implement in the hardware, such as DSP processor or portable device. The grey theory provides the applications of cluster analysis, relational analysis, and decision for the grey system (Deng, 1989). Its analysis makes use of minor data and does not demand strict statistical procedures and inference rules. For an adaptation application, the GRA has a flexible pattern mechanism with add-in and delete-off patterns, and can be expandable or reducible without adjusting any parameter (Chang & Yeh, 2005; Lin, 2006, 2008). It also has a feedforward mathematical operation for processing numerical data. To overcome the drawbacks, portable HMC is proposed for modeling a prototype tool consists of multi-channel ECS and GRA for SEMG signals recognition. The wristband of seven active electrodes was placed around the forearm to acquire multi-channel SEMG signals. This electrode system needs no set at specific placement whatever places them at random. For each channel, six parameters were extracted from each SEMG signal, including ***IEMG***, ***WL***, ***VAR***, ***ZC***, ***SSC***, and ***WAMP***. Then GRA is applied to recognize 11 hand motions with various constructed patterns. With 12 subjects, the tests will show that proposed HMC appears computational efficiency and accurate recognition.

2. Electrode configuration system (ECS)

Many methods have been applied to EMG signal processes with frequency-domain and time-domain techniques, such as Fourier transform, wavelet transform, and autoregressive parametric model. These are employed to generate the feature vector, and then use the frequency information, wavelet features, and parametric features to detect the multiple hand motions. However, frequency-domain technique is limited by the complex computation, the number of samples, and window selections. The parametric features can be easily adapted in the real-word processes, and can be directly computed in real-time (Huang & Chiang, 1999). Therefore, the parametric features are use to extract feature form the ECS in this study. The ECS is divided into two stages: SEMG signal preprocessing and feature extraction, as shown in Fig. 1. Each stage is delineated as below.

2.1. SEMG signal preprocessing

In order to detect the hand motions, the beginning and ending of each hand motion should be clearly identified (Du et al., 2006; Fukuda et al., 2003; Shyu et al., 2002). First, SEMG signals are acquired from D active electrodes (Signal-to-Noise Ratio: 80 db, Gain: 5000, BioEngineering SenseTech Corp. Taiwan), and DAQ card (NI DAQCared-6036E, National Instruments) is an analog-to-digital (A/D) converter (Sampling frequency: 1 kHz) between the wristband and notebook as shown in Fig. 1. The portable acquired device can obtain SEMG signals from the wristband ECS on the forearm. To identify the beginning and ending of the operator's motions, the squared sum $S(n)$ of $EMG_d(n)$ is used to determine each hand motion is regarded as the action, and $S(n)$ could be calculated as (Fukuda et al., 2003):

$$S(n) = \sum_{d=1}^{D}(\mathrm{EMG}_d(n) - \mathrm{EMG}_d^{mean})^2 \geqslant \theta, \quad n = 1, 2, 3, \ldots, N \qquad (1)$$

$$\theta = \max\{S(n)\} \times 0.3$$

where N is the number of sampling point and $\mathrm{EMG}_d(n),\ n = 1, 2, 3, \ldots, N$, is defined as the nth sampled data; D is the number of active electrode (Channel Number), $d = 1, 2, 3, \ldots, D$ ($D = 7$ in this study); EMG_d^{mean} is the mean value of the d channel, which is measured while the arm is relaxed. When $S(n)$ exceeded the specific threshold θ, the acquisition window is start to pick up the sampled data as shown in Fig. 2. In signal processing stage, the duration must at least exceed 0.5 s that can confirm the action having been stimulated.

2.2. Feature extraction

When $S(n)$ exceeds the specific threshold θ, acquisition window acts to pick up the meaningful sampled data. Then preprocessing data could be obtained form SEMG signal, and can be represented as $X = [x_1, x_2, x_3, \ldots, x_{n'}, \ldots, x_{N'}]$, where N' is the total number of sampled data that can be picked up in the acquisition window.

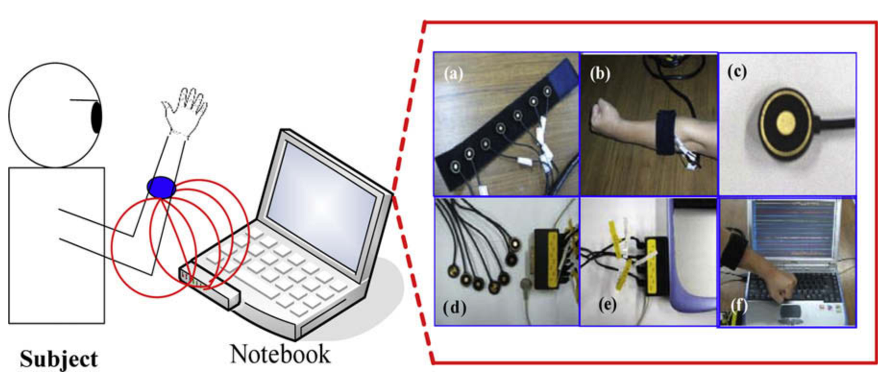

Fig. 1. The hardware overview of HMC system. (a) The wristband with seven active electrodes; (b) the wristband on the forearm; (c) the active electrode with differential preamplifier (SNR: 80 db, Gain: 5000, Diameter: 14.2 mm); (d and e) DAQ card with 5 V (DC) power source (16 Inputs/2 Outputs, 200 kb/s, 16-bit Multifunction I/O); and (f) real-time SEMG signals acquisition.