sEMG Signal Separation for Wrist Angle Estimation

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Abstract— This document

1. Introduction

Myoelectric signal activity had been known to increase with the muscle movement intensity[1]. With electromyography (EMG), myoelectric signal can be recorded and aid in researches including gait analysis[2], fatigue evaluation[3], motor neuron disease diagnosis[4], and prosthesis control[5]–[8].

Surface EMG (sEMG) is widely employed in EMG signal recording, because of its ease of use and non-invasiveness. sEMG records the summation of action potential generated by a group of motor neurons, as the muscle tissue between the motor neurons and surface electrode acts as a volume conductor. sEMG signal is affected by the crosstalk of multiple muscle groups[9].

sEMG signal can be assumed to be linearly mixed action potential originating from different muscle groups, the effect of crosstalk can be mitigated through the use of blind signal separation (BSS) algorithm. A popular BSS method, Independent Component Analysis (ICA), were employed to increase the classification accuracy in gesture recognition[10]. However, since the probability distribution of a sEMG signal is close to Gaussian distribution, ICA cannot be applied effectively to separate the action potential from sEMG signal[11]. ICA was mostly used to remove motion artefacts[12].

Crosstalk between muscle groups can be easily observed from the forearm. Multiple muscle groups are present in the forearm, in charge of functions including wrist motion and hand gestures[13].

This paper focus on the estimation of wrist angle with the sEMG signal recorded from the forearm. To mitigate the effect of crosstalk, this paper proposed the separation of sEMG signal power with two BSS methods, and compare their results.

The two BSS methods are Non-negative ICA (nICA) [14] and Temporal Decorrelation Source Separation (TDSEP) [15]. nICA treats the data as a group of data point and minimize the mutual information of the data; TDSEP decorrelates multi-channel time series, minimizing the correlation between time series.

Relationship between sEMG signal and muscle tension is highly non-linear[16]. Neural networks are utilized in previous research to model the non-linear relationship[5], [8], [17]–[21]. In this thesis, Long Short Term Memory (LSTM) is used to estimate the wrist angle. LSTM is a type of Recurrent Neural Network (RNN) that includes internal memory cell inside the network. The internal memory can help LSTM model time series, which made it suitable for wrist angle estimation.

1. Methodology

The proposed sEMG wrist angle estimation system consists of feature extraction, signal separation, and angle estimation. The following describes the detail of these steps.

1. sEMG Signal Feature Extraction

In this thesis, windowed Root Mean Square (RMS) is used as the feature for wrist angle estimation. RMS can be used to extract signal power. RMS of sEMG signal represents the muscle activity, and is calculated using the following formula.

|  |  |
| --- | --- |
|  | (1) |

Where is the sEMG recording at time , and is the number of sample point in 200 milliseconds. The result of windowed RMS is shown in Fig. 1, sEMG signal after windowed RMS is smoother and non-negative.

|  |
| --- |
| E:\Ubuntu\sEMG\Paper\pic\wRMS.png |
| Fig. 1 Windowed RMS of sEMG  (a) raw sEMG signal (b) windowed RMS sEMG signal |

1. sEMG Signal Separation

sEMG signal originates from deep within the muscle, affected by the crosstalk of multiple muscle groups[9]. Assuming the mixture of sEMG signal is linearly mixed, it is possible to separate the signal between different muscle groups. The technique is called Blind Source Separation (BSS). If the measured signal is linearly mixed, it can be expressed as

|  |  |
| --- | --- |
|  | (2) |

where is the sEMG recording, is the original myoelectric signal, and is the mixing matrix. In sEMG recording, mixing matrix models how myoelectric signal mixed within the muscle. Since both the mixing matrix and source signal is unknown, BSS is performed to search for the un-mixing matrix, and independent components are retrieved. Un-mixing matrix translates the mixed signal so that

|  |  |
| --- | --- |
|  | (3) |

In this thesis, two BSS methods are tested and compared. The two BSS methods are Non-negative ICA (nICA) [14] and Temporal Decorrelation Source Separation (TDSEP) [15].

1. Non-negative ICA

In nICA[14], the original signal is assumed to be non-negative, which is true in the case of muscle power. First, ZCA whitening is performed on the recorded signal

|  |  |
| --- | --- |
|  | (4) |

where is the whitened signal with the covariance matrix being an identity matrix. The whitening matrix can be found by performing Eigendecomposition on the covariance matrix of . To eliminate the mutual information, nICA rotates the whitened signal with rotation matrix

|  |  |
| --- | --- |
|  | (5) |

where is the un-mixed signal. The cost function of the rotation matrix is expressed as

|  |  |
| --- | --- |
|  | (6) |

where , the value is zero when is negative. The cost decreases as more samples are rotated to be non-negative. After rotation, the resulting signal is the un-mixed signal.

1. Temporal Decorrelation Source Separation

In TDSEP[15], time series are separated by minimizing the cross-correlation across multiple time lags. To find the optimal un-mixing matrix , the cost function is defined as

|  |  |
| --- | --- |
|  | (7) |

where is the channel of the recorded signal, is a series of time lags, and denotes time average. A way to find the un-mixing matrix is to perform gradient descent to minimize the cost function with respect to . However, gradient descent is computationally costly, [15] proposed the following method to find the approximation of .

First, ZCA whitening is performed on the recorded signal , the result is the whitened signal . Correlation matrices are found under different time lag, the collection of these matrices is . Lastly, using the method proposed by [22], a rotation matrix can be found by simultaneously diagonalizing all matrices in . The rotation matrix ***Q*** is the approximation of the optimal un-mixing matrix .

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Title must be in 24 pt Regular font. Author name must be in 11 pt Regular font. Author affiliation must be in 10 pt Italic. Contact email address must be in 9 pt Courier Regular font.

TABLE I  
Font Sizes for Papers

|  |  |  |  |
| --- | --- | --- | --- |
| Font Size | Appearance (in Time New Roman or Times) | | |
| Regular | Bold | Italic |
| 8 | table caption (in Small Caps),  figure caption,  reference item |  | reference item (partial) |
| 9 | Contact author email address (in Courier), cell in a table | abstract body | abstract heading (also in Bold) |
| 10 | level-1 heading (in Small Caps),  paragraph |  | level-2 heading,  level-3 heading,  author affiliation |
| 11 | author name |  |  |
| 24 | title |  |  |

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1. Section Headings

No more than 3 levels of headings should be used. All headings must be in 10pt font. Every word in a heading must be capitalized except for short minor words as listed in Section III-B.

1. Level-1 Heading: A level-1 heading must be in Small Caps, centered and numbered using uppercase Roman numerals. For example, see heading “III. Page Style” of this document. The two level-1 headings which must not be numbered are “Acknowledgment” and “References”.
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Fig. 2 A sample line graph using colors which contrast well both on screen and on a black-and-white hardcopy

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Figures must be numbered using Arabic numerals. Figure captions must be in 8 pt Regular font. Captions of a single line (e.g. Fig. 2) must be centered whereas multi-line captions must be justified (e.g. Fig. 1). Captions with figure numbers must be placed after their associated figures, as shown in Fig. 1.



Fig. 3 Example of an unacceptable low-resolution image



Fig. 4 Example of an image with acceptable resolution

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Tables must be numbered using uppercase Roman numerals. Table captions must be centred and in 8 pt Regular font with Small Caps. Every word in a table caption must be capitalized except for short minor words as listed in Section III-B. Captions with table numbers must be placed before their associated tables, as shown in Table 1.

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* example of a website in [6]
* example of a web page in [7]
* example of a databook as a manual in [8]
* example of a datasheet in [9]
* example of a master’s thesis in [10]
* example of a technical report in [11]
* example of a standard in [12]

1. Conclusions

This template is partly based on the template used for the 19th ISSTT (Groningen, 2008) and the 21st ISSTT (Oxford, 2010), which was in turn based on “Sample IEEE Paper for A4 Page Size” provided by courtesy of Causal Productions (www.causalproductions.com).

Acknowledgment

The heading of the Acknowledgment section and the References section must not be numbered.

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