33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Filtering Essential Tremor Noise on surface EMG based on Squared Sine Wave Approximation

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***Abstract*—Essential Tremor (ET) refers to involuntary movements of a part of the body. ET patients have serious difficulties in performing daily living activities. Our ultimate goal is to develop a system that can enable ET patients to perform daily living activities. We have been developing an exoskeleton robot for ET patients. We make use of the electromyogram (EMG) signal to control this robot. However, the EMG signal of ET patients contains not only signals from voluntary movements but also noise from involuntary tremors. In this paper, we focus on developing a signal processing method to suppress tremor noise present in the surface EMG signal. The proposed filter detected attenuation ratio by the correlation between the last EMG data and one period squared sine wave. The filtered EMG signals indicated that essential tremor noise of the elbow flexed posture while holding a water-filled bottle was suppressed. In addition, voluntary information was less affected by the filter. Welch's t-value test confirmed that ease of extraction of voluntary movement was increased by the proposed filter.**

I. Introduction

A. Essential Tremor (ET)

ESSENTIAL TREMOR is a neurological disorder that causes rhythmic and involuntary movements. ET symptoms progress slowly with age. T.Goto reported that ET prevalence of over 40 years of age people was 6.1% in certain place of Japan [1]. While ET is not a life-threatening disorder, it can cause functional disability and social inconvenience. In most cases, tremor amplitude is large and causes total disability to the affected person. About 65% of ET patients have serious difficulty performing daily living activities (ex. eating, drinking, writing, etc.) [2], [3]. Although the most common types of tremors have been subjected to numerous studies, their mechanisms and origins are still unknown. Current approaches to therapy are divided into two methods. One is the medicine (beta blocker) to suppress overreaction of the sympathetic nerve. However, this medicine has many undesirable effects including decreasing heart rate. Another method is Deep Brain Stimulation (DBS), which has a very high level of invasiveness.

To solve this problem, we are developing a robotic upper extremity orthosis (Fig.1) that can not only mechanically suppress tremors, but can also voluntarily flex and extend the elbow joint [4], [5]. This wearable robot has one motor controlled by voluntary movement estimation from the surface electromyogram (EMG) signal input. The EMG signal includes information on the voluntary movement. However, in our study, the EMG signal comprises mixed information on voluntary movement generated from the motor area and involuntary movement generated from the sympathetic nerve. It is important to extract only the information on voluntary movement from the mixed EMG signal.

To overcome this difficulty, we have proposed some EMG signal processing methods combined with Neural Network learning algorithm. One was by selecting a frequency that was less affected by tremor, using Short Time Fourier Transform (STFT) [4], [5]. The other was by using average rectified value at regular time intervals, which detected by tremor period [6]. These approaches succeeded in increasing recognition accuracy, but discussed only the On/Off discrimination of motion. The reason they could not realize more accurate recognition or variable angular velocity motion

Fig. 1 Exoskeltal robot for ET patient [4] [5] whose concept is not only mechanically suppress tremors, but can also voluntarily movement.

Manuscript received March 28, 2011. This work was supported in part by the Global COE (Center of Excellence) Program "Global Robot Academia", Waseda University, Tokyo, Japan and The Minister of Economy, Trade, and industry "R & D Project to Create Regional Innovation", Japan.

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might be that these EMG signal processing methods cut off too much of voluntary movement information along with involuntary tremor effects. The purpose of this paper is, therefore, to develop a filter which reduces only tremor noise.

In previous research on tremor cancellation, K.Yano et al. developed an adaptive filter for force sensor data which was used in admittance control for the meal-assist manipulator [7], [8]. This filter estimated the tremor frequency, and suppressed Parkinson's tremor noise by using a band stop filter. C.N.Riviere et al. have proposed a filtering algorithm for physiological tremor during micro surgery [9]. The above studies purposed on reduction of tremor noise in motion signals measured by a force sensor, position meter, etc. In these signals, effects of tremor are observed as an additive noise. Therefore, once the noise frequency was detected, designing a real-time processing system was not difficult. On the other hand, it can be anticipated that tremor effect in EMG signals is a multiplicative noise because rhythmic muscle contractions and relaxations do not cause EMG offset ups and downs but cause amplitude fluctuation. For the reduction of multiplicative noise, the Cepstral Mean Normalization [10] (CMN) and maximum a posteriori estimation CMN (MAP-CMN) are widely recognized. CMN is not a real-time adapted method. MAP-CMN needs Cepstral Mean calculations from a signal of sufficient length to provide superior performance.

ET is the most widely known disorder that has an action tremor. The action tremor is displayed while performing some actions or while maintaining a posture. The tremor intensity is especially strong when the patient takes or transits a specific posture. Therefore, tremor effect on the EMG signal fluctuates wildly in one motion. CMN or MAP-CMN is not suitable for tremor filtering.

Therefore, it is necessary that developing a real-time adapted method canceling multiplicative tremor noise. In this paper, we hypothesize that rectified tremor EMG can be approximate to predefined base wave. Furthermore, we propose a filter cutting a signal which has high correlation with squared sine wave. The purpose of this paper is primary evaluation of proposal filter which can increase ease of voluntary movement extraction from tremor patient's EMG data.

II. Analysis of Essential Tremor Noise on Surface EMG Signal For Base Wave Detection

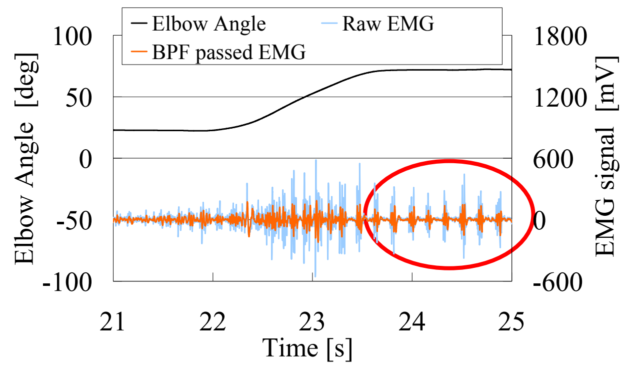
To design the tremor canceling filter, it is necessary to determine the features of tremor noise. We have measured an ET patient's EMG signals with the elbow joint angle.

A. *Subject*

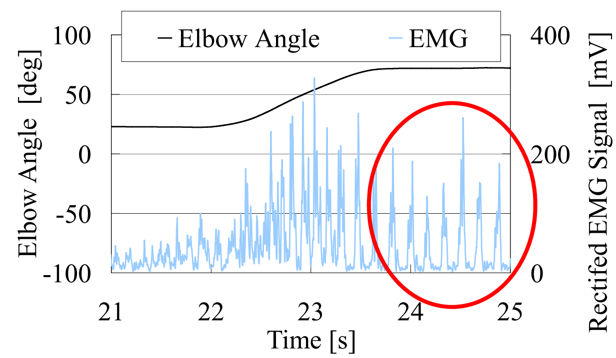
The subject of this experiment was an ET patient (male, around 60 yrs) who experienced tremor symptoms especially in forearm adduction-abduction movement.

We gave the subject a detailed account of our experimental objectives, explained that he was entitled to stop the

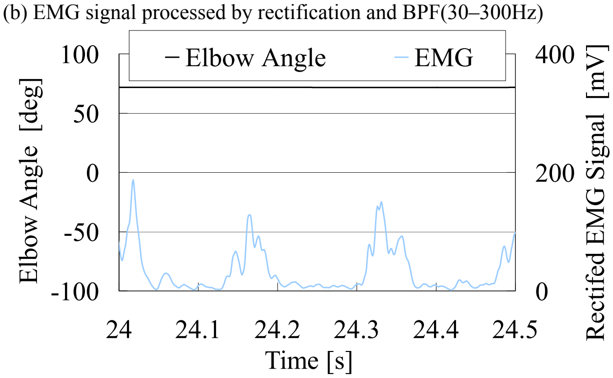
Fig. 2 Measurement of surface EMG signal and elbow joint angle.The subject performed elbow flexional movement while holding a bottle filled with water (mass 550(g)).



(a) Raw EMG signal of the one elbow flexing action.



(b) EMG signal processed by rectification and BPF(30–300Hz)



(c) Enlarged data of the elbow joint was stable on flexed position
Fig. 3 EMG signal of the one elbow flexing action.

experiment whenever they desired, and obtained their consent. Furthermore, he practiced the elbow flexional movement in advance of the experiment to get used to the experimental movement.

This experiment was approved by the Institutional Review Board in Waseda University.

B. *Methodology*

The subject performed elbow flexional movement while holding a bottle filled with water (mass 550g) to simulate the movement of drinking water. At this point, the target movement time was fixed at 1.25s throughout the practice, and this pace was maintained using a metronome. The subject performed the experimental movement 10 times. The EMG signals were obtained through surface electrodes (Biometrics Ltd.) and DataLog (Biometrics Ltd.) and were sampled at the rate of 1000Hz. The electrodes were placed on the biceps brachii. The angle of the elbow was obtained by a goniometer (Biometrics Ltd.) and was also sampled at the rate of 1000Hz. The voluntary movement term of the subject were determined by the angle obtained by the goniometer. Fig.2 shows the conditions of the measurement.

C. *Base Wave Detection for Tremor Noise Approximation*

Fig.3(a) shows the raw and band pass filtered (30–300Hz) EMG data with the elbow joint angle at a flexion action. When the subject held a flexed position, approximately 5Hz increase and decrease in the EMG amplitude occurred. This was in accordance with the knowledge that the ET frequency is between 4Hz and 10Hz. In addition, if the tremor effect would be an additive noise, the EMG data of holding the flexed position should be steady. But pulses of approximately 5Hz were found to remain. This indicates that the tremor effect was a multiplicative noise. The rectified and band pass filtered (30–300Hz) EMG data is showed at Fig.3(b), and Fig.3(c) shows enlarged data when the elbow joint was in the flexed position. The EMG signal showed repetitive sharp peaks rising and smoothly falling down to the neighborhood of zero. When the tremor noise was a rectified sine wave or triangle wave, both ends of one peak should have had some gradients. Therefore, this study hypothesizes that tremor noise can be approximated to squared sine wave.

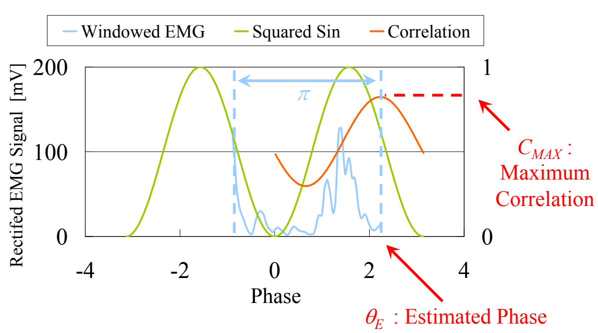


Fig. 4 Phase estimation algorithm. This algorithm searches for the maximum correlation between the base wave and the windowed EMG.

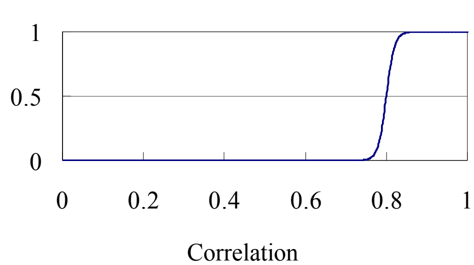


Fig. 5 Sigmoid function for attenuation ratio detection

III. Signal Processing Method of Filtering Tremor Noise

This section describe about real-time filtering algorithm designed as (1).

$$s_n = \left(1 - A\left(e_n, e_{n-1}, e_{n-2}, \ldots, e_{n-N+1}\right)\right)e_n \tag{1}$$

Where s_n is the filtered signal and n is the number of samples. Attenuation ratio A which cancels multiplicative effect should be calculated from only present and past surface EMG data e_n, e_{n-1}, $e_{n-2}, \ldots, e_{n-N+1}$. These EMG data was preprocessed by rectification and band-pass filtering (30–300Hz). The BPF is of the Chebyshev II type, with damping coefficient 0.7. The number of windowed EMG data units N is detected by the tremor frequency F and data sampling period as (2).

$$N = \left|\frac{1}{F\Delta t}\right| \tag{2}$$

We calculated Attenuation ratio A with correlation parameter C_{MAX} between measured EMG data and pth powered sine function at phase θ_E (3).

$$A = f\left(C_{MAX}\right)\sin^p \theta_E \tag{3}$$

The details of calculation method are described as follows.

A. *Approximate to Squared Sine Wave*

As described in Section II, the filter is based on the hypothesis that tremor noise could be approximated to squared sine wave. Attenuation ratio is detected by the gain function and squared sine function of the phase θ.

To estimate the phase of the present tremor noise, the algorithm searches for the maximum correlation C_{MAX} between the phase squared sine wave vectors B_m (m=1,2,...,N) and the windowed EMG vector E_n (Fig.4). The correlation function is expressed as follows (3) (4) (5) (6).

$$C = \frac{E_n \cdot B_m}{\left|E_n\right|\left|B_m\right|} \tag{3}$$

$$E_n = \left\{e_{n-N}, e_{n-N+1}, \ldots, e_n\right\} \tag{4}$$

$$B_m = \left\{b(m-N), b(m-N+1), \ldots, b(m)\right\} \tag{5}$$

$$b(x) = \sin^2 xF\Delta t\pi \tag{6}$$

B_m is the one period squared sine wave beginning at phase $(m\text{-}N\text{+}1)F\Delta t\pi$. E_n is the present and passed $1/F$[s] sampled EMG data.

B. *Gain Function*

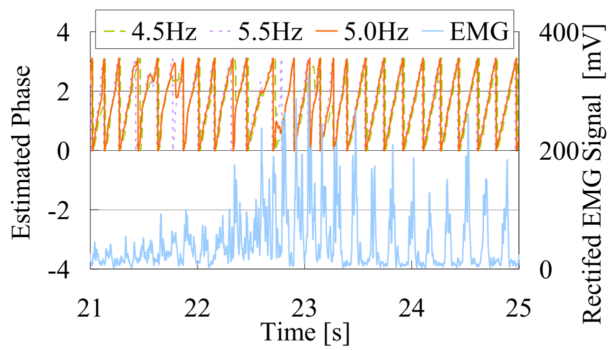
The maximum correlation C_{MAX} is also a parameter of the gain function. The gain of the attenuation ratio is defined by the sigmoid function (7).

$$f(C_{MAX}) = \frac{1}{1+\exp(-a(C_{MAX}-offset))} \qquad (7)$$

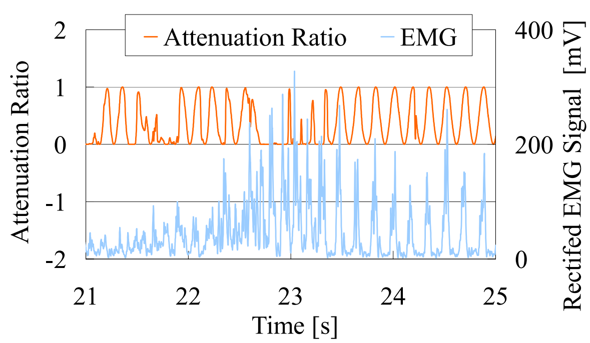
The gain a of the sigmoid function was set at 100. The *offset* value was set at 0.8. Fig.5 shows the shape of the gain function. When the vector of the last EMG data E_n is not conceivable to any squared sine wave B_m, the attenuation ratio is set at approximately 0.

C. Results

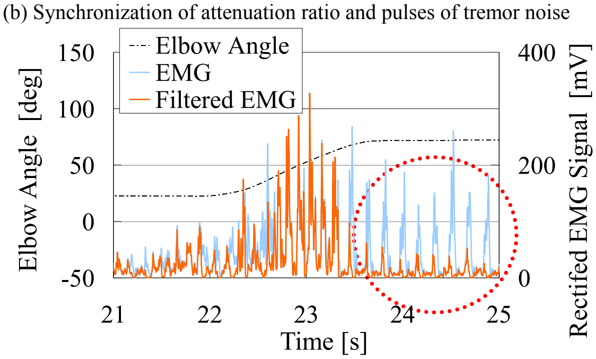
The tremor frequency F was roughly estimated to be 5Hz by counting the EMG pulses when the elbow was held in flexed position. Fig.6(a) shows three estimated phase data of tremor frequencies F set around 5Hz. It indicates some margin of tremor frequency definition, because the estimated phase processions overlapped severely.



(a) Phase estimation results around 5.0Hz squared sine wave.



(b) Synchronization of attenuation ratio and pulses of tremor noise



(c) Result of proposal filter effect
Fig. 6 Examples of calculation results.

Fig.6(b) is an example of the calculated attenuation ratio that tremor frequency is defined to be 5Hz. It shows the suppression of the attenuation in the middle of flexing action. Additionally, it was also confirmed that the peaks of the attenuation ratio were in synchronicity with the EMG pulses.

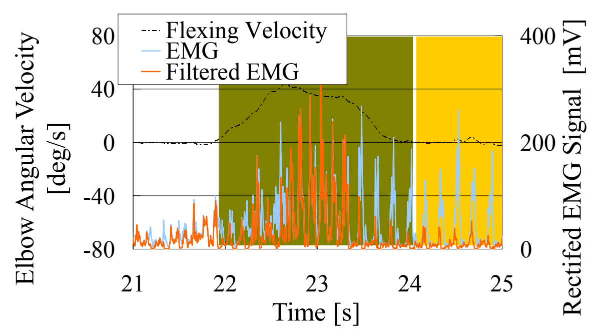
Fig.6(c) shows a comparison between only BPF passed EMG and the proposed filter passed EMG whose tremor frequency is defined to be 5Hz. The proposed filter suppressed the EMG of holding the flexed position to be steady, and had no significant effect on the EMG of holding extended position or during flexion action.

D. Discussions

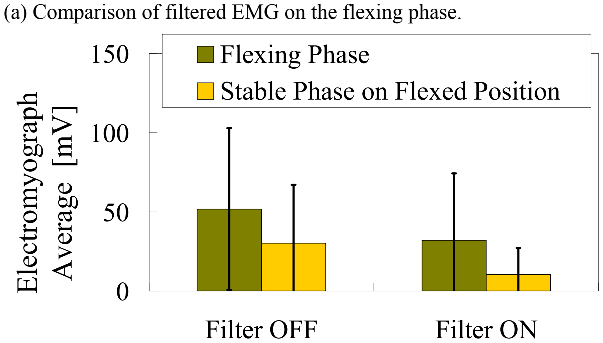
To detect the optimum tremor frequency definition, we evaluated the filtered EMG data by Welch's t-test. We divided EMG data to three phases of elbow joint state: the stable phase on the extended position, the flexing phase, and the stable phase in flexed position. The two stable phases were defined at one second from the zero cross point of the elbow joint angular velocity. The angular velocity v_n was calculated by the five point method for the first derivative as follows:

$$v_n = \frac{g_{n-2} - 8g_{n-1} + 8g_{n+1} - g_{n+2}}{12\Delta t} \qquad (8)$$

Where g_n is the elbow joint angle passed LPF which is of 10Hz cutoff frequency, 0.7 damping coefficient, and Chebyshev II type. Fig.7(a) shows an example of phase division. The black line is the elbow angular velocity. The stable phase on the extended position is expressed as the white space. The flexing phase is expressed as the green space. The stable phase on the flexed position is expressed as



(a) Comparison of filtered EMG on the flexing phase.



(b) Comparison of filtered EMG on the stable phase in flexed position.
Fig. 7 Filter effects different by base wave settings.

the yellow space.

The t-value between the flexing phase EMG voltages and the stable phase on flexed position indicates the ease of voluntary movement recognition. T-value is expressed as follows:

$$\text{t-value} = \frac{\left|\overline{X} - \overline{Y}\right|}{\sqrt{\frac{U_x}{s} + \frac{U_y}{t}}} \tag{9}$$

The t-values were calculated by eight trials data of the elbow flexing action. The $\overline{X}$ and the $\overline{Y}$ mean the average of EMG voltages in the flexing phase and the stable phase on flexed position, and the U_x and U_y mean the standard divisions of EMG voltages in these two phases. The total sampling numbers were 19019 points in the flexing phase s and 8000 points in the stable phase on flexed position t. Fig.7(b) shows the each-phase average voltages of EMG passing only BPF and passing the proposed filter whose tremor frequency is defined at 5Hz. The t-value rose from 38.9 to 60.0 by the proposed filter.

IV. Conclusion

We have developed an exoskeleton robot for ET patients. In this paper, we focused on developing the signal processing method to suppress the tremor noise present in the surface EMG signal. The proposed filter detected attenuation ratio by the correlation between last EMG data and one period squared sine wave. The filtered EMG signals indicated that essential tremor noise of the elbow flexed posture while holding a water-filled bottle was suppressed. In addition, voluntary information was less affected by the filter. Welch's t-value test confirmed that ease of extraction of voluntary movement information was increased by the proposed filter.

In the future, we will develop an accurate and stable recognition algorithm based on this study, and will finally conduct the clinical test to demonstrate the effectiveness of our system.

ACKNOWLEDGEMENTS

We sincerely thank the subjects for participating in our experiment.

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