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Robust Detection of Surface Myoelectric Signal Using A Nonlinear Device Network for Intuitive Man-Machine Interface

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Abstract– Robust myoelectric signal detection using a nonlinear device network and its application to man-machine interface are investigated. The detection system includes the Schmitt trigger network for detecting weak myoelectric signal using stochastic resonance (SR) effect together with multiple surface electrodes made of the carbon nanotube (CNT) composite papers. The system can robustly detect the signal even with extra motion of the body, whereas the conventional system suffers from large noise and cannot distinguish the signal in such case. The robot arm implementing the SR-based detection system is successfully controlled by the gesture of the subject even with his extra motion.

1. Introduction

Myoelectric signal is the active potential generated when the muscle is tensioned. The man-machine interface (MMI) applying the myoelectric signal can provide the intuitive machine control for the users: gesture control. Considering the easy use, the myoelectric signal should be taken from the surface of the body, instead of by the insertion of an electrode into the body. However, the signal generated inside the body is attenuated and is easily buried in noise. although the conventional detection technique successfully detects the weak myoelectric signal by differential amplification, it inevitably loses the function when the contact between the surface electrode and body is fluctuated. The concept of our technique is to detect the weak myoelectric signal using noise and fluctuation through stochastic resonance (SR), in which the response to the weak signal is optimized or enhanced by adding noise [1,2]. We demonstrate the robust myoelectric signal detection by the Schmitt trigger network causing the SR and its feasibility for the intuitive MMI through the robot arm control. So far, in the biological signal sensing research field, the SR was only investigated to enhance the sensitivity of the subject by adding noise to himself [5]. Recently our group achieved the high sensitive and robust myoelectric signal detection using the SR [3,4]. The contribution of this paper is the demonstration of the feasibility of our SR-based myoelectric signal detection system for the muscle tension detection, motion discrimination, and robot arm control.

2. Myoelectric Signal Detection System

Figure 1 shows our SR-based myoelectric signal detection system. The system integrates eight Schmitt triggers as nonlinear devices with hysteresis to cause the stochastic resonance. The devices form a summing network to obtain enhanced response in accordance with the framework of Collins's system [6]. The previous stage of the Schmitt trigger includes high pass filters (HPF) for offset canceling, a preamplifier, and a band elimination filter (BEF) for filtering 50 Hz ham noise. The second HPF prior to the Schmitt trigger is inserted to completely remove the offset fluctuation. Thus the imposed noise to the signal almost passes to the input of each Schmitt trigger. Each input of the first stage of the system is connected to a carbon nanotube composite paper (CNTcp)-based surface electrode. The performance of the CNTcp electrode is comparable to the conventional AgCl/Ag electrode, even with relatively high sheet resistivity [4]. The CNTcp electrode has advantages in the ease of processing, flexibility, soft texture, and disposable.

The SR-based system essentially achieves the high signal-to-noise ratio (SNR) by the threshold transfer characteristic of the Schmitt trigger, similar to the high

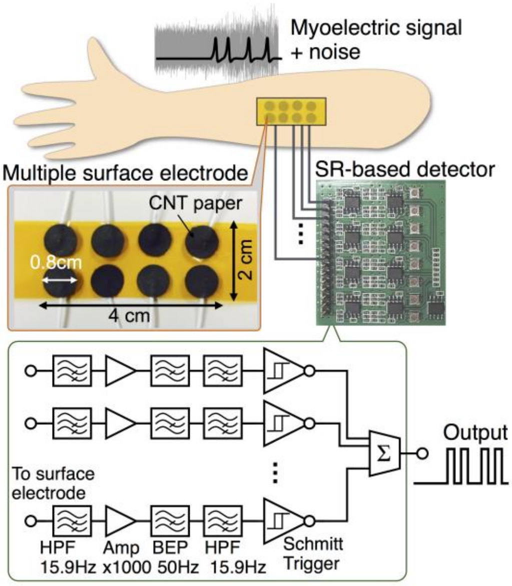

Fig. 1 SR-based myoelectric signal detection system.

SNR in the digital signal transmission. This signal truncation process is effective, because the intensity of the muscle tension is basically coded into the density of the action potential pulse train, not the amplitude of the pulse. On the other hand, the surface myoelectric signal is composed of the action potentials from many muscle fibers and the potential generated deep in the body is attenuated remarkably. The SR-based system detects such weakened signal using the stochastic resonance caused in the Schmitt trigger. The multiple surface electrodes average out the contact fluctuation that occurs in uncorrelated manner between the electrodes. We already confirmed that the SR can be caused on the aperiodic myoelectric signal in the nonlinear device [3].

3. Detection Characteristics

Figure 2 shows the measured surface myoelectric signals using our technique and conventional bipolar lead technique. The signals were taken from the surface of the forearm of the subject without and with the movement of the shoulder as extra motion. The hysteresis width of each Schmitt trigger device was adjusted to be approximately 100 mV. Without the shoulder motion, both techniques detect the myoelectric signal clearly. The output waveform of the SR-based system showed the pulses having mostly uniform height. However each pulse had different width: the amplitude of the original myoelectric signal was reflected in the width of the output pulse. In the case with the motion of the shoulder, the output from the conventional technique was tremendously disordered all the time and it was impossible to distinguish the myoelectric signal from the noisy waveform. The large noise in the bipolar lead was generated because the balance of the contacts of the two surface electrodes was broken and the fluctuation is not canceled out but amplified. On the other hand, our technique could successfully detect the myoelectric signal even with the motion of the shoulder. It should be noted that the noises generated from the contact fluctuation were uncorrelated between the electrodes and this provided a positive effect on the detection performance in terms of the stochastic resonance in the summing network [6].

The observed waveforms show that high sensitivity and noise robustness of our system is attributed to the combination of the SR mechanism and the noise rejection by the double thresholds. Myoelectric signal is represented by the pulse train. Its bandwidth is 2 Hz ~ 10 kHz and widely overlaps with that of the noise. Considering these points, rejection of the signal component out of the thresholds is a rational way compared to the filtering in the frequency domain. On the other hand, the weak myoelectric signal generated in the deep inside of the body will be filtered out when the noise is eliminated using a low pass filter (LPF). The SR mechanism helps to detect the such signal component.

Table I summarizes the evaluated output SNRs for the various detection techniques. The unipolar lead detects the signal using one surface electrode and filters the noise using a low pass filter (LPF) with a linear amplifier. The performance of the commercially available device is also shown. The SR-based technique showed the highest SNR in the examined ones in both without and with the motion of the body. The myoelectric signal detector in the recent commercial myoelectric prosthesis has a very powerful dynamic filter that can detect the signal even in the motion of body. However it needs the learning process and takes much machine power for signal processing. Our technique can reduce such machine cost and is expected to give faster response. In addition, our technique can achieve high SNR comparable to that using the needle electrode. The surface electrode technique detects the signal from a bundle of the muscle fibers, whereas the needle electrode can detect the action potentials from a few muscle fibers. The former is appropriate for the MMI application and the latter is necessary for medical examination and analysis.

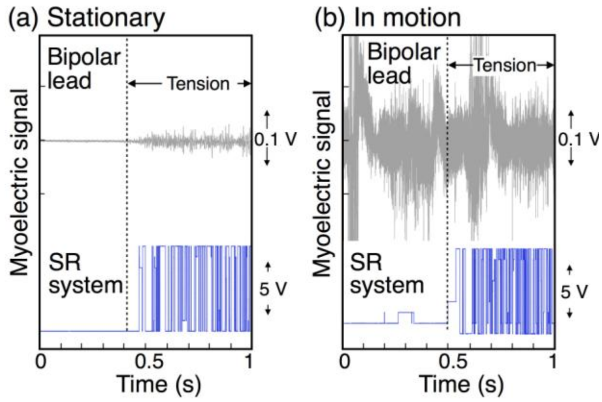

Fig. 2 Myoelectric signals taken on the forearm of the subject (a) without and (b) with the motion of the shoulder. Bipolar lead is a conventional myoelectric signal detection technique.

Table 1 Evaluated signal-to-noise ratio (SNR) for various surface myoelectric signal detection techniques.

	Stationary	In Motion
Unipolar lead	15 dB	10 dB
Bipolar lead (Conventional)	20 dB	undetectable
Commercial detector	16 dB	undetectable
This work	**40 dB**	**20 dB**

Figure 3 shows the forearm tension dependence of the detected myoelectric signals. The tension was quantitatively measured using a hand dynamometer. The density of the action potentials obtained by the conventional technique was clearly changed depending on the strength of the tension. The output waveforms in the SR-based system also depended on the tension, however, the change was not so obvious as in the conventional technique when the tension was 30% and 50%. We evaluated the power of the obtained signal, P_S. In the case of the conventional technique, P_S for 30%, 50% and 70% was 1.36 V^2, 2.16 V^2, and 7.17 V^2, respectively. On the other hand, in the case of the SR-based technique, P_S for 30%, 50% and 70% was 4.70 V^2, 5.77 V^2, and 6.35 V^2, respectively. These results showed that P_S in the SR-based technique gave linear response compared to the conventional technique. The SR-based technique has possibility to detect weak tension better than the conventional technique.

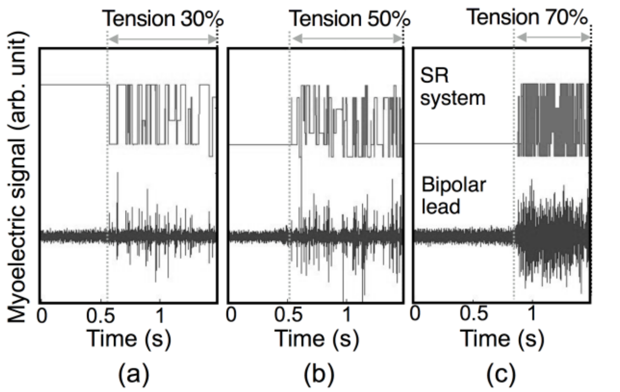

Fig. 3 Forearm tension dependence of myoelectric signals by SR-based and conventional bipolar lead techniques for tension (a) 30%, (b) 50% and (c) 70%.

4. Motion Identification

For the MMI by gesture control, it is necessary to discriminate and identify the various motions. Physiology suggests that a person has various muscles and each motion of the subject is attributed to the different muscle. Therefore the identification is achieved by analyzing the myoelectric signals taken from several surface electrodes on the appropriate positions of the body. We examined the identification of the wrist motion, palmar and dorsal flexion, using our detection system. Mainly two different muscles contribute to the two motions of the wrist. Then the two multiple surface electrode arrays, electrodes A and B, were attached on the forearm near the related muscle positions as shown in **Fig. 4** and the signals were taken using the two detectors independently. Measured waveforms are shown in **Fig. 5**. When the palmar flexion took place, the myoelectric signal was induced only in the electrode A. On the other hand the signal was induced in the electrode B when the dorsal flexion took place. Then the wrist movement was identified by evaluating the difference of the two myoelectric signal power. We found that the SR-based system gave clear power difference between the two wrist motion compared to that of the conventional bipolar detection system.

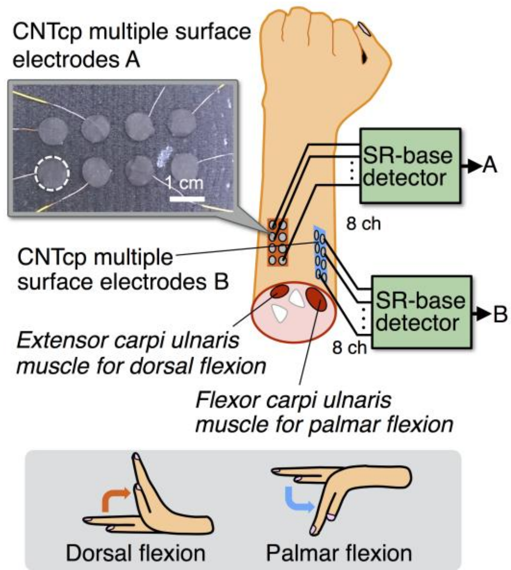

Fig. 4 Setup for motion identification

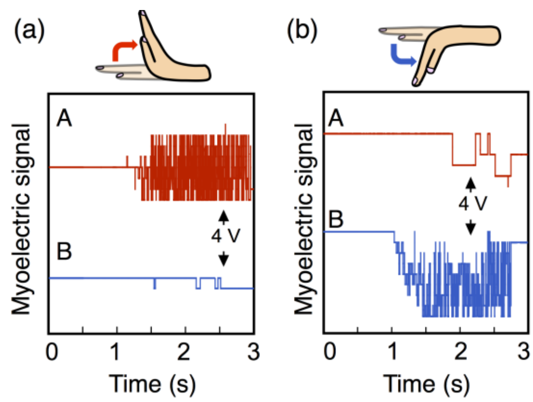

Fig. 5 Measured myoelectric signals in surface electrodes A and B for (a) dorsal flex and (b) palmar flexion.

5. Robot Arm Control

To demonstrate the feasibility of the SR-based myoelectric signal detection technique for the robust MMI, we designed the robot arm control system implementing the SR-based detection technique as shown in **Fig. 6(a)**. This system consisted of two detectors together with a microcomputer. The system identified the two motions of the wrist, palmar and dorsal flexion. In accordance with the identified motion of the subject as described in the previous section, the wrist of the robot arm moved upward or downward. The CNTcp-based surface electrode array was easily attached to the arm of the subject using an arm band, without electrolytic paste and tight binding. A snapshot of the demonstration is shown in **Fig. 6(b)** (the movie of this experiment will be shown at the presentation). The robot arm could be correctly controlled in accordance with the motion of the wrist of the subject. In addition, such controllability was maintained even with the extra motion of the shoulder, whereas the system using the conventional technique became uncontrollable in such case. The obtained results demonstrated the feasibility of our technique for the robust MMI.

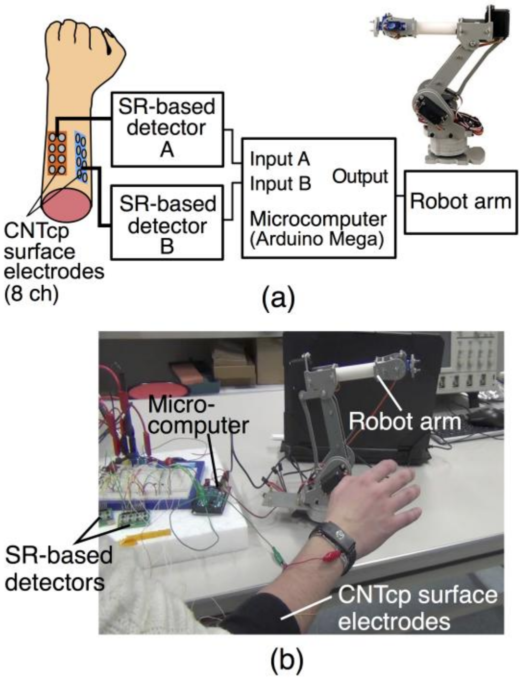

Fig. 6 (a) Diagram of the robot arm control system and (b) snapshot of the demonstration.

6. Conclusions

Robust detection of the myoelectric signal using a 8 Schmitt trigger summing network and its application to man-machine interface were presented. Weak myoelectric signal was detected using the stochastic resonance in the Schmitt trigger network together with multiple surface electrodes made of the carbon nanotube (CNT) composite papers. The SR-based system could robustly detect the signal even with extra motion of the body, although the conventional system missed the signal in such case. The feasibility of the SR-based myoelectric signal detection system for the intuitive MMI was demonstrated by the robust control of the robot arm implementing the SR-based system.

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