Haptic Sensation Enhancement via the Stochastic Resonance Effect and Its Application to Haptic Feedback for Myoelectric Prosthetic Hands

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Abstract

In this paper, we propose a highly realistic haptic feedback method for myoelectric prosthetic hands. Although several haptic feedback methods have been studied, this study attempts to create realistic sensory feedback through prosthetic hands by not only using feedback methods but also by improving the haptic sensation based on the stochastic resonance effect. In the experiment, contact information obtained from a microphone attached to the fingertip of a prosthetic hand was transferred through a vibrotactile stimulator near the elbow fossa, and white noise vibration was also applied near the elbow fossa to verify the improvement of tactile sensitivity of the fingertips. The results demonstrated the possibility of transmitting tactile information for myoelectric prostheses through sensory enhancement of the user.

Keywords: Myoelectric Prosthetic Hand, Haptic Sensation, Stochastic Resonance, Haptic Feedback

1. Introduction

To realize a prosthetic hand that resembles a human hand, it is necessary not only to consider the mechanism of the prosthetic hand but also to establish a sensory feedback method, such as tactile sensation. Sensory information has a vital function in daily activities because the sense of touch conveys various properties or information of objects [1]. However, it is said that when prosthetic users touch objects with their prosthetic hands, they feel vibrations through the socket, making it difficult to accurately acquire tactile information through the prosthetic hand. Although myoelectric prosthetic hands have evolved to imitate motor functions of human hands [2], many current devices are deemed insufficient given their inability to deliver relevant sensory information.

The senses are broadly classified as cutaneous and deep senses, and restoration of these senses shows its improvement for the daily life of forearm amputees [3]. Various methods of cutaneous sensation feedback such as touch, pressure, pain, warmth and cold have been investigated. In the past, a simple transducer attached to a small speaker [4] was proposed, and in recent years, Ueda et al. have transmitted the warmth or coldness of an object by transmitting the temperature detected by a temperature sensor at the fingertip to a device on the upper arm [5], Osborn et al. developed electronic skin, which can transmit pain to the user by detecting differences in the shape and texture of objects at the fingertips and sending signals to peripheral nerves [6], and various other skin sensations can now be transmitted. Alessia et al. measured the acceleration of the fingertip and controlled the oscillator of a socket to enable discrimination of roughness [7], Christian et al. detected pressure from a silicon bulb and confirmed that the magnitude of pressure could be discriminated by inflating the silicon pad at the cut using a monofilament [8].

These various sensory feedback methods provide only pseudo feedback, and it is difficult to reproduce actual sensation. This is due to practical issues such as the danger of direct sensory feedback, including pain, and the fact that the cutaneous sensation near the amputation site is different from that at the fingertip, where feedback is provided in the noninvasive approach. Therefore, we consider improving the user's sensation.

Minamizawa et al. have made it possible to reproduce tactile sensations through vibration stimulation by recording and playing back tactile data [9]. Jianyao et al. measure the acceleration of the fingertip and transmit the vibration as an audio signal to enable roughness discrimination [10]. Research has also been conducted to enhance the sensory perception on the human side of receiving feedback, enhancing the ability to detect signals by applying noisy vibrations to the human hand or foot [11], [12]. This phenomenon is called stochastic resonance, and looking at the case of vibration to the upper limb, it has been reported that applying noise to the wrist and fingers improves tactile sensitivity at the fingertips [13],

[14]. However, the application of these sensory enhancements using audio feedback and stochastic resonance to prosthetic hands has not been fully investigated.

This study applies these methods to a prosthetic hand and provides tactile feedback near the elbow fossa using voice. In addition, by focusing on the phenomenon of probability resonance, we attempt to enhance the sensation obtained by the sensory feedback method of the prosthetic hand, thereby increasing the realism of the sensation through the prosthetic hand.

2. Sensory feedback and enhancement

The proposed myoelectric prosthetic hand sensory feedback method is based on the TECHTILE toolkit [9] and consists of a microphone (AT9904, audio-technica), an audio amplifier (LP-2024A+, Lepy), and vibration actuators (AFT14A903A, Alps Alpine). In this paper, a microphone is attached to the fingertip of a prosthetic hand to record friction and vibration sounds when touching an object as an input signal for vibration stimulus generation. The signal is output as vibration through an audio amplifier using an actuator attached near the elbow fossa.

In this study, we further focused on the stochastic resonance effect to improve sensory function. The vibration used is low-pass filtered white noise with a cutoff frequency of 300 Hz and is output from a PC via an audio amplifier with another actuator. These processes generate tactile sensations and simultaneously enhance the sensation near the elbow fossa, resulting reproduction of human fingertip sensation.

3. Verification of differences in fingertip sensation

In this section, we first discuss the difference between the cutaneous sensation at the fingertips of a person and the sensation when using a prosthetic hand. In this section, we first describe the difference between the cutaneous sensation at the fingertips of a person and the sensation when using a prosthetic hand. We compared and verified the sensitivity of the skin sensation at the fingertips when touching an object and the sensation of the prosthetic hand near the elbow through the socket.

The participant was a healthy university student seated on a chair wearing an eye mask and earplugs (Fig. 1) In the experiment, the participant was given a piece of paper with five pieces of sandpaper of different roughness (#400, #600, #800, #1000, and #1200.) on the front side and one randomly selected piece of sandpaper from the five pieces on the front side on the back side, and asked to touch all the sandpapers on the front and back sides. The sandpaper with the same coarseness as the one on the reverse side was selected from the sandpaper on the front side, and the percentage of correct responses was recorded. The test consisted of one trial in which each roughness was presented twice at random (10 in total). One trial was performed with the human hand and one trial with the prosthetic hand.

The discrimination rate of the human hand was 70%, and that of the prosthetic hand was 10%. These results indicate that fingertip sensation cannot be obtained through the socket of the prosthetic hand. From a questionnaire survey after the experiment, the participant answered that when they touched the sandpaper with their prosthetic hands, they felt almost no vibration through the sockets, suggesting that discrimination was impossible.


(a) Human hand (b) Myoelectric prosthetic hand

Fig. 1. Scenes from the verification experiment.

4. Sensory enhancement experiment

4.1 Determination of vibration perception threshold

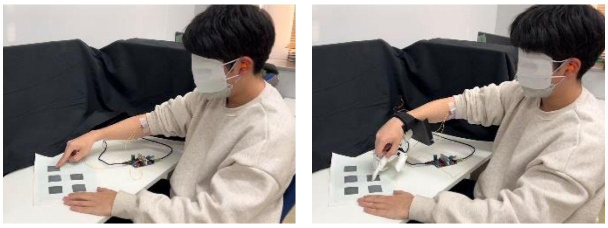
To determine the vibration perception threshold (the maximum vibration that the participant cannot feel) before the experiment, the participant was asked to wear an eye mask, relax with hands on a desk, and present the vibration. The intensity of noise was increased and decreased until the participant was unable to distinguish between it being on or off. The average value was obtained by repeating each trial three times. The threshold is referred to as 1T.

4.2 Verification of the effect of stochastic resonance

We tested whether the tactile sensitivity was affected by applying white noise near the elbow fossa to one healthy university student. The participant was asked to touch a piece of sandpaper with his hand and a prosthetic hand (Fig. 2), and the percentage of correct responses for each was recorded. Five vibration intensity conditions (0.5 T, 0.75 T, 1 T, 1.25 T, and 1.5 T) were applied randomly. One trial was conducted for each vibration condition with a 30-second rest between trials. The hand and prosthetic hand were tested separately.

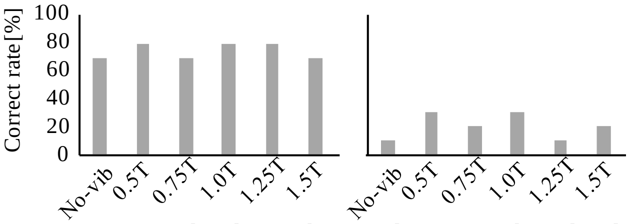
Fig. 3 shows the experimental results. The result for the no-vibration condition (no-vib) was obtained from the experiment in Section 3. In both cases, the correct response rate tended to be higher than that of the no-vibration. A questionnaire survey of the participant after the experiment showed that there was no significant difference in the perception of the vibration caused by the white noise.

Fig. 4 shows signals recorded from the microphone while touching sandpapers with the prosthetic hand and their FFT results. The threshold value was set to -30 dB, and the range from the first detection of a signal above the threshold value to the last detection of a signal above the threshold value was clipped. The extreme values of the absolute values of the signals were extracted and averaged to obtain the amplitude. The results show that the roughness of #400 tends to be easily discernible, with an



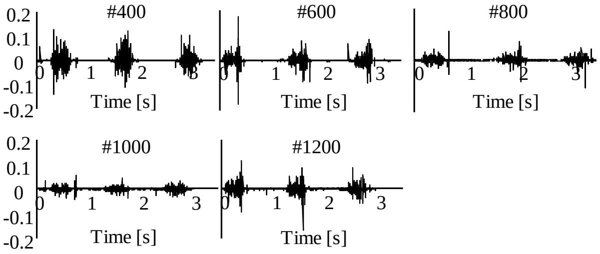
(a) Human hand (b) Myoelectric prosthetic hand

Fig. 2. Scenes from the sensory enhancement experiment.

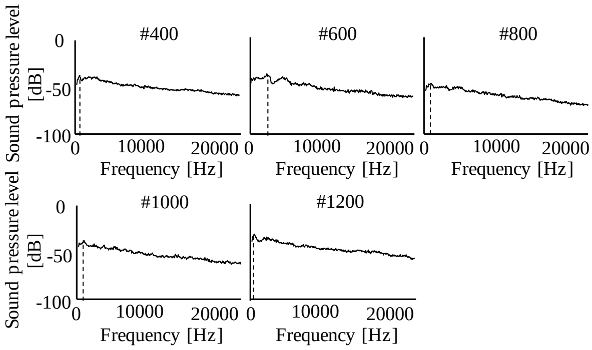


(a) Human hand (b) Myoelectric prosthetic hand

Fig. 3. Results of the sensory enhancement experiment.



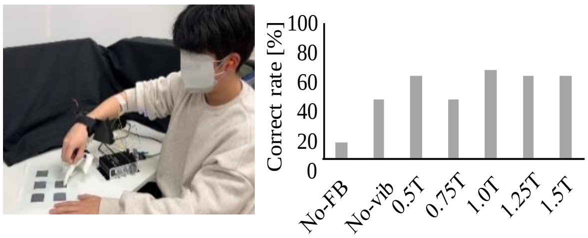
(a) Sound waveform



(b) FFT

Fig. 4. Recorded signals and their FFT results.

amplitude of approximately 0.021, which is larger than the others. In addition, #1000 tended to be misidentified as #800. This may be because the amplitude of #800 was about 0.012, close to the amplitude of #1000 of about 0.009, and the frequency band peaks were similar at around 900 Hz. The amplitude of #600 and #1200 were approximately 0.017 and 0.014, respectively. However, #600 had a peak near 2500 Hz and #1200 had a peak near 400 Hz, which may have affected the discriminability of the two samples. The identification rate through the socket of the myoelectric prosthetic hand was 30%.



(a) Experimental scene (b) Experimental result

Fig. 5. Tactile feedback experiment.

5. Simulation of tactile generation near the elbow fossa

Although we were able to improve the tactile sensitivity of the fingertips by adding white noise near the elbow fossa in Section 4, the result of the prosthetic hand was low (30%). Therefore, we conducted an experiment in which vibration stimuli were applied near the elbow fossa based on the measured audio signals.

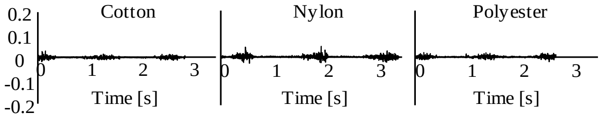
The participants were two healthy university students. White noise vibration was added simultaneously with feedback from the vibratory stimulation of the audio signal using two vibrotactile stimulators attached near the elbow fossa. The same procedure as in Section 3 was used to record the percentage of correct responses by touching the sandpaper with the prosthetic hand in five vibration intensity conditions.

The results of the experiment are shown in Fig. 5(b), which compares the cases without voice feedback (No-FB, the result shown as No-vib in Section 4), with tactile feedback only (No-vib), and with tactile feedback and white noise vibrations. The results show the average of two participants. Except for 0.75T, the result was higher than that without vibration, and the highest response rate was obtained when the vibration intensity was 1T. A questionnaire survey of the participants after the experiment suggested that the correct rate increased because the participants were able to feel strong vibrations due to the tactile feedback. These results indicate that some fingertip sensation can be obtained by vibration stimulation based on audio signals near the elbow fossa and tactile sensitivity enhancement by white noise vibration.

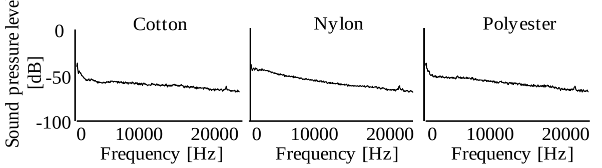
6. Verification of tactile sensation generation with a prosthetic hand

Based on the results obtained in Section 5, an experiment was conducted with a healthy university student as a participant to verify whether tactile feedback and white noise vibration could provide a realistic sensation when touching objects with a prosthetic hand. In the experiment, three different textures of cloth (nylon, polyester, and cotton) were traced with the prosthetic hand to test whether it could reproduce the sense of touch.

From the experimental results, when the participant touched the cloth with the prosthetic hand, the participant could not feel much difference in texture and could not reproduce the tactile sensation. Fig. 6 shows the sound waveforms and FFT results of touching the cloth with the



(a) Sound waveform



(b) FFT

Fig. 6. Recorded signals and their FFT results.

prosthetic hand. The amplitudes of both results were almost the same (0.006) and the peak frequency bandwidths were similar at around 100 Hz, suggesting that the feedback vibration stimuli were similar and therefore could not be determined.

7. Conclusion

This paper showed that vibrotactile feedback and stochastic resonance effects near the elbow fossa can provide some fingertip sensation when touching an object through a prosthetic hand. However, it is difficult to distinguish objects with small amplitude or similar frequency bands. In the future, we plan to improve the feedback method to detect slight differences in vibration.

Acknowledgements

A Robust Approach for Reproducing the Haptic Sensation of Sandpaper With Different Roughness During Bare Fingertip Interaction.

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