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Optimization of Human Tactile Sensation Using Stochastic Resonance

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Abstract

The development of tactile sensors and its data processing are crucial to advance robotics for allowing robots to explore and handle objects. Robots must sense the tactile feelings caused by contact between their hands and a human. This paper presents an influence of the stochastic resonance (SR) on tactile sensation that can enhance sensitivity by superimposing proper noise upon otherwise undetectable weak signals to detect the target signals. To investigate the SR of human tactile sensation and elucidate the mechanism of tactile SR, we performed a sequence of psychophysical experiments applying tangential directional vibration with a size of 2.5 mm and 8 mm stimulus point. We examined the difference threshold (DL) variation obtained from these experiments to clarify which condition of vibration direction and stimulus size causes the strongest SR. Furthermore we compared these results of tangential stimulus with results of normal stimulus obtained from our prior study. The experimental results show that neither normal nor tangential DL is significantly affected by stimulus point size. Moreover, tactile sensing precision is enhanced by appropriate noise and the characteristics of SR with tangential stimulation are quite different from those with normal stimulation.

Keywords: Stochastic resonance; sensor; tactile sensing; tangential; psychophysical experiments

1. Introduction

Stochastic resonance (SR) is a counterintuitive phenomenon observed in many non-linear and multi-stable systems [1] whereby the addition of random noise to a weak signal causes the target signal to become more easily detectable or enhances the precision of the interpretation of the signal information after it passes through the system. Since SR in biological systems allows for high adaptability to a wide variety of stimuli, as described in several papers [1-3], it has attracted considerable attention from many researchers. We opine that, since noise is intrinsically included in tactile sensing, the SR mechanism is attractive for robotic tactile sensing. It appears that the human mechanism of tactile SR can aid us in producing a new design of robotic tactile sensor based on SR.

On the other hand, sensational thresholds presenting vibrotactile stimuli on the skin have been studied [4-7]. These studies describe four kinds of mechanoreceptive units in human skin, such as the fast adaptive type I unit (FA I), fast

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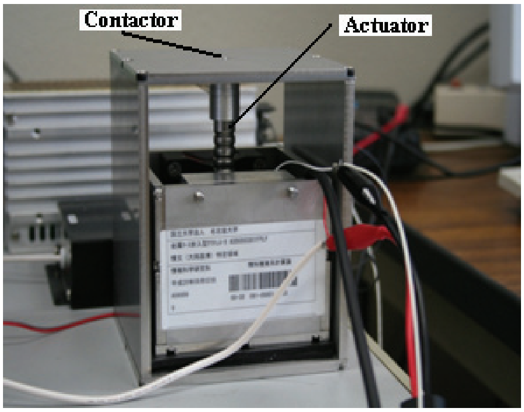
adaptive type II unit (FA II), slowly adaptive type I unit (SA I), and slowly adaptive type II unit (SA II). Their ability to detect vibration stimuli depends on stimulus direction and size: FA I detects normal vibration and does not depend on stimulus size; FA II detects both normal and tangential vibration and depends on stimulus size; SA I detects normal low frequency vibrations and static pressure; and SA II detects tangential vibration and does not depend on stimulus size.

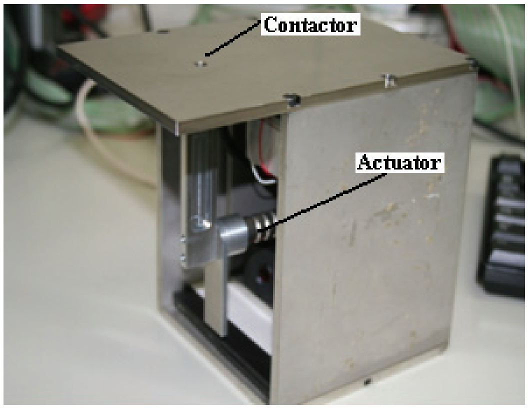
Although a series of psychophysical experiments is effective for investigating the mechanism of mechanoreceptive units in SR, there are only a few studies related to this issue. Collins examined the influence of SR on the absolute threshold of tactile sensation [8]. In the study, the tactile absolute threshold decreases with an appropriate noise. Since this result indicates that sensitivity is enhanced by SR, we developed a new electronic circuit capable of generating an SR to emulate this effect [9]. The signal-to-noise ratio (SNR) obtained from the circuit changed depending on the noise intensity and the local maximum appeared under a proper noise. Furthermore, we performed a series of psychophysical experiments using normal stimulus to examine variation in the difference threshold (DL) under noise [10]. It was found that the DL is smallest under appropriate noise. In our study, we introduced a neural network model composed of nonlinear neurons with a bi-stable equilibrium condition to explain this result. Although the original sensor data did not represent the morphology of the fine texture, the neural network model extracted the morphology and distinguished the fine texture's wave amplitude.

Although the abovementioned Collins study and our works revealed one SR aspect of tactile sensing, these experiments were performed using normal vibration. Since FA-II and SA-II units accept not only normal but also tangential vibration, tangential vibration tests are required to progress the mathematical model of tactile SR.

In this study, we performed two series of psychophysical experiments using tangential vibration in the subsequent experiments. The present experiments were conducted on the basis of the Parameter Estimation by Sequential Testing (PEST) method [11], which was adopted as a psychophysical experiment in our previous study. In order to investigate the dependence of DL on the size of the stimulus point, either a smaller (2.5 mm) or larger (8 mm) stimulus point was adopted as a probe to apply mechanical vibration to the human subject's finger. The former normal vibration experimental results were compared with the present experimental results in order to examine the effect of vibration direction on tactile SR.



(b) Tangential



(b) Normal

Fig. 1. Vibrating stimulation generator using piezoelectric actuator.

2. Experimental Apparatus

We developed a technique composed of an experimental apparatus and a computer program based on Parameter Estimation Sequential Testing (PEST). The experimental apparatus was composed of a personal computer, a piezoelectric actuator, and a piezoelectric actuator driver to generate step waves. The actuator installed in a stainless steel box and equipped with a contactor (Fig.1). To change the diameter of the contactor easily, it has been assembled with small screws. Since subjects put their fingers on the box’s top plate, the box is insulated from the actuator with a rubber cushion. We used a half-sine pulse signal as a tactile stimulus in these psychophysical experiments. The frequency of the tactile signal was around 6 Hz in all four experiments. The tactile stimuli and noise were generated by the PEST program and a noise generator program based on the block diagram shown in Fig. 2. The signal generator program (plus noise or not) is included in this system.