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Measuring Finger Peripheral Signal Based on Electrical Synchronization

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Abstract: In this paper, we propose a method to measure tactile nerve signals on the skin noninvasively. The natural tactile nerve signals generated by mechanical touches are hidden behind thermal noises on the skin. In our method, we observe the tactile signals while synchronizing the firing by electrical stimulation. We expect the power of synchronized nerve signals can exceed the thermal noise. Synchronization is realized simply by stimulating mechano-receptors with electrical impulses. After the impulse, the stimulated receptors cannot fire until the refractory period ends. Then all receptors under over-threshold stress are expected to fire simultaneously.

Keywords: nerve signal, noninvasive measurement, tactile sensation.

1. INTRODUCTION

Measuring tactile nerve signals is a very attractive challenge in haptics. Conventional methods of nerve measurement generally insert thin needles into a nerve bundle to record the electrical activity. Though the method can obtain high S/N ratio, it is highly invasive. Moreover, the motion of the finger is restricted since the electrode position in a nerve bundle should be fixed. It isn't acceptable for measurement in active touch. The goal of our research is measuring tactile nerve signal using surface electrode non-invasively.

In the research, we select finger joint as the measurement position. The finger joint is an appropriate part to be measured from the following three reasons. First, the interference of myoelectric activity is small in a finger. Fingers are operated by tendon and don't have muscles in the ends of fingers. Secondly, the alignment of nerve bundle is well localized and determined (Fig.1). Finally, nerve bundles place near the skin surface in finger joints (Fig.2).

Measuring tactile nerve signal caused by mechanical stimulation on skin surface has been considered to be difficult. The reason is that single action potential measured on skin surface is hidden behind the thermal noise where the signal amplitude is 1/10 of the thermal noise. On the other hand, it is known that synchronized action potentials caused by electrical stimulation can be measured using surface electrodes, which is used in diabetes diagnosis. Therefore, we can expect tactile nerve signals are observable if they fire at the same time.

In natural situations, mechanoreceptor signals aren't synchronized because of the spatial distribution of skin strain (Fig.3). The timings when the strains of receptors go beyond firing threshold differ from one to another. Therefore the nerve signals connected to receptors are asynchronous and difficult to observe usually. In this paper, we propose a method to synchronize the tactile signal using refractory period controlled by electrical stimulation.

A potential application in engineering fields is to quantify tactile sensation using human finger as a sensor device. It is also useful as a tool to evaluate tactile displays. The major application will be found as a human interface to detect the contact between a finger and an object by monitoring the nerve signals.

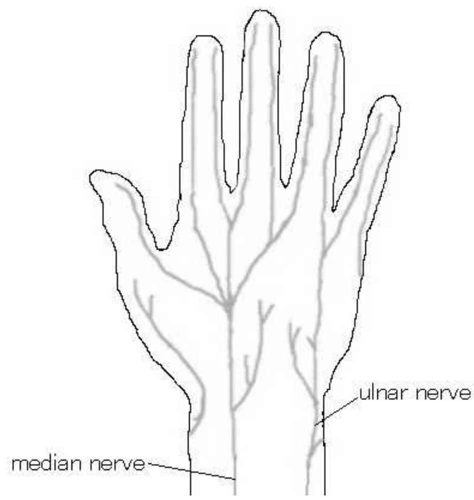

Fig. 1 Cutaneous nerves of a hand (palm side).

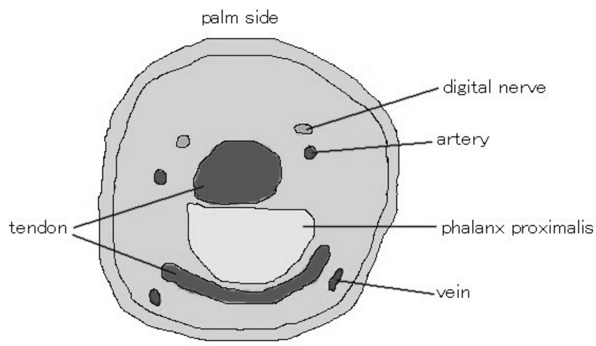

Fig. 2 Cross-section of an index finger at the proximal phalanx.

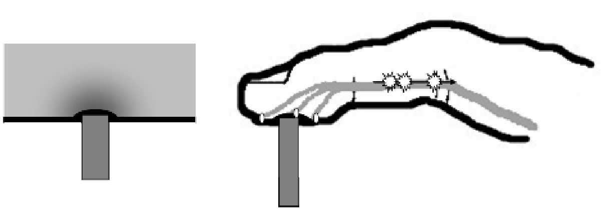

Fig. 3 (Left) Spatial distribution of skin strain is shown. (Right) Firings of receptors are not synchronized in natural situations.

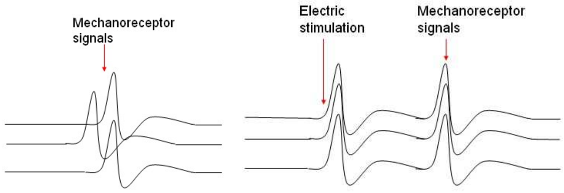

Fig. 4 Expected nerve signals. (Left) Usual mechanoreceptor signals caused by mechanical contact. (Right) Mechanoreceptor signals synchronized by electric stimulation.

2. SYNCHRONIZATION OF TACTILE SIGNALS USING REFRACTORY PERIOD

To synchronize tactile signals, we use the "refractory period" of the nerves. Refractory period is the period of time during which a receptor lose the ability of firing after the preceding firing. A receptor cannot fire by any stimulation during the refractory period after the last firing. Therefore if we excite the receptors by electric stimulation, the excited receptors are silent until the refractory period ends. If enough strain is given to receptors in that time, the receptors are expected to fire concurrently after the end of refractory period (Fig.4).

3. METHODS OF EXPERIMENTS

3.1 Experiment 1: Estimation of refractory period

The purpose of the experiment is estimating dispersion of the span of refractory period. In the proposed method we assume that dispersion of the span of refractory period is sufficiently small for the synchronization. We verified validity of the assumption.

A schematic of the experiment is shown in Fig.5. Median nerve was stimulated electrically and compound action potential was measured on finger joint. This method is known as antidroic method and used for nerve conduction velocity test.

Measurement electrodes were placed on the joints of the left index finger. Before electrode application, the skin was abraded using preparation gel and cleaned with alcohol. The electrodes' shapes were ring type. The electrical signal from the measurement electrodes was amplified by Tektronix differential amplifier (model ADA400A) and viewed on a Tektronix digital storage oscilloscope (model TDS3054B). Measuring ground was placed on palm using disposable Ag-AgCl electrode.

Electrical stimulations were generated from a constant current circuit that was controlled by a digital IO board connected to a laptop computer. Stimulation electrodes were set on the wrist skin near the median nerve. For the purpose of electrical isolation between measurement part and stimulation part, the current circuit and the computer were driven by respective batteries.

Under the setup, we observed the nerve signals for two-pulse sequence with ΔT separation Current pulse, 0.1ms 10mA, was generated between stimulation electrodes. The pulse interval ΔT was increased from 1.0 ms to 2.0 ms at intervals of 0.1 ms. Ten trials were done for each ΔT. On each trial, we recorded average signals of 16 time stimulations given at 20 ms intervals (Fig.6).

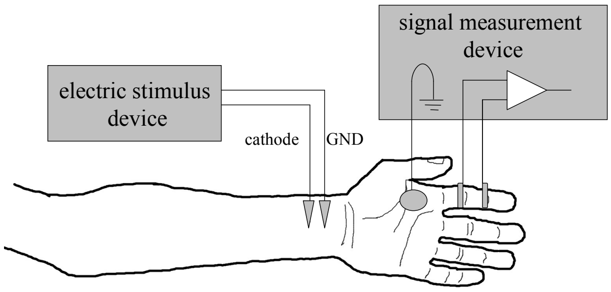

Fig. 5 Setup of experiment 1.

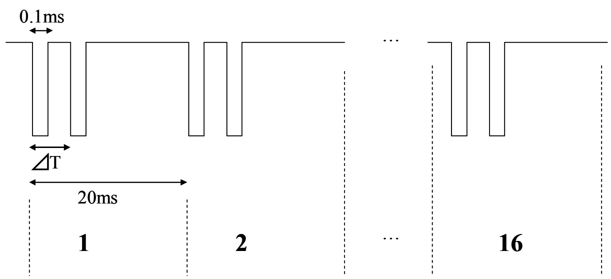

Fig. 6 Waveform of stimulus current in each trial (experiment 1).

3.2 Experiment 2: Observing influences of mechanical stimulation

In this experiment we compared the nerve signal waveforms under two types of mechanical stimulation with the waveform of no mechanical stimulation.

The difference between experimental 1 and 2 is that a mechanical stimulator on the end of the index finger is placed. Electrical stimulation is also different. Single current pulses, in this case, was generated at 20ms intervals (Fig.7). The apparatuses of the electrical stimulation and signal measurement are the same as experiment 1.

Stationary pressure and sine wave oscillation were selected as the mechanical stimulation in this experiment. The electrical stimulation was provided during mechanical stimulations. In stationary pressure case, two plates sandwiched the index finger as shown in Fig.8 (a). The displacement of the plate was about 2.5 mm from the initial position of zero pressure. In sine wave oscillation case, an acrylic bar (2 mm diameter) was attached to the center of a loudspeaker and vibrated the ball of the index finger (Fig.8 (b)). The loudspeaker was driven at 30 Hz sine wave by function generator. The strength of the stimulus was three times as large as that of the least perceptible stimulus.

For no mechanical stimulation case and stimulation case 10 trials were done. Averaged waveforms were calculated and its high frequency component noise was reduced by low pass filtering. The difference waveform between the two mechanically stimulated cases and the case without mechanical stimulation were obtained.

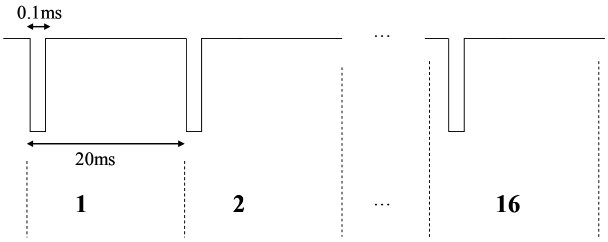

Fig. 7 Waveform of stimulus current in each trial (experiment 2).

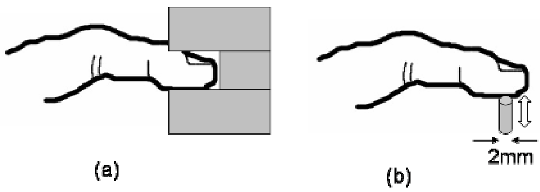

Fig. 8 Mechanical stimulator of experiment 2. (a)Stationary pressure. (b) Sine wave oscillation.

4. RESULTS

4.1 Experiment 1

Examples of the observed waveforms are shown in Fig.9. The large amplitude pulses that appeared at 0.0 and ΔT [ms] are stimulus signals. About 3ms later from the artifact, the compound action potential is observed. This result is consistent with popular conduction velocity 50m/s (the distance between electrical stimulation and measurement electrode was about 15 cm in this experiment).

Fig.9 shows the following findings. If ΔT is short, a single action potential is observed as shown in Fig.9 (a). On the other hand, if ΔT is long, two action potentials ((b) and (c) of Fig.9) are observed. We calculated the ratio of the two amplitudes (B/A of Fig.10) while changing ΔT. If ΔT is shorter than a refractory period, the nerve fiber can't fire. On the other hand, if ΔT is long enough, B/A approach 1.0. The amplitude of compound action potential depends on the number of firing nerve fibers. Therefore B/A estimates the ratio of excitable nerve fibers at the second stimulus timing.

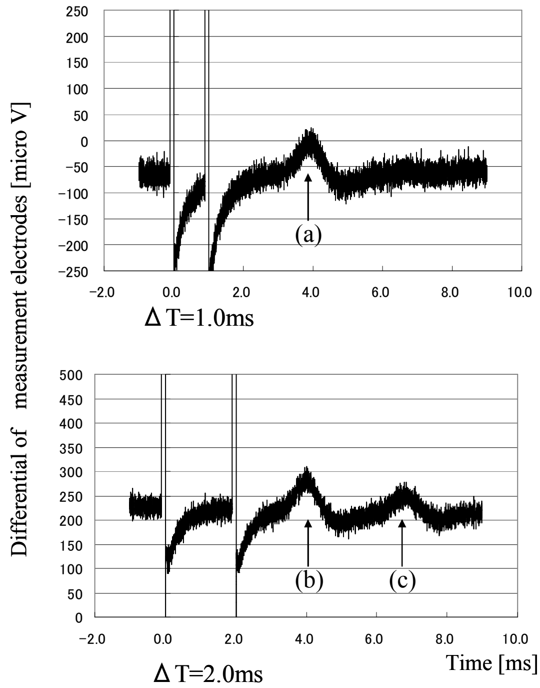

Fig. 9 Example of measured signals caused by double electrical stimulations.

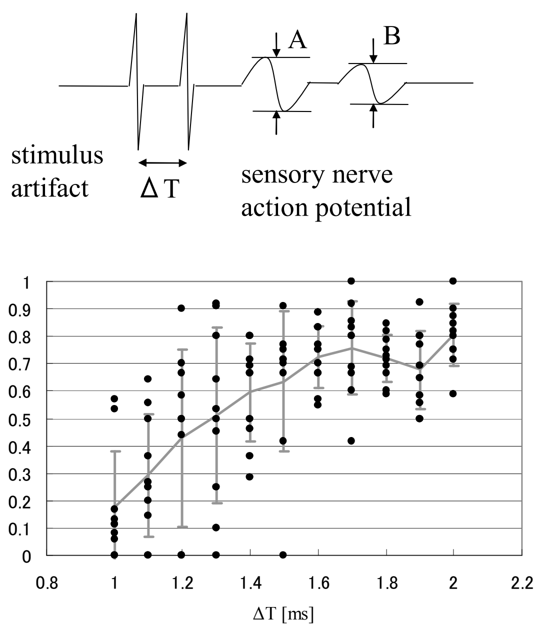

Fig. 10 Relationship between the interval of stimulations and the ratio of compound action potentials *B/A*.

4.2 Experiment 2

The difference between the cases with and without stationary pressure is shown in Fig.11. The difference between the cases with and without sine wave oscillation is shown in Fig.12.

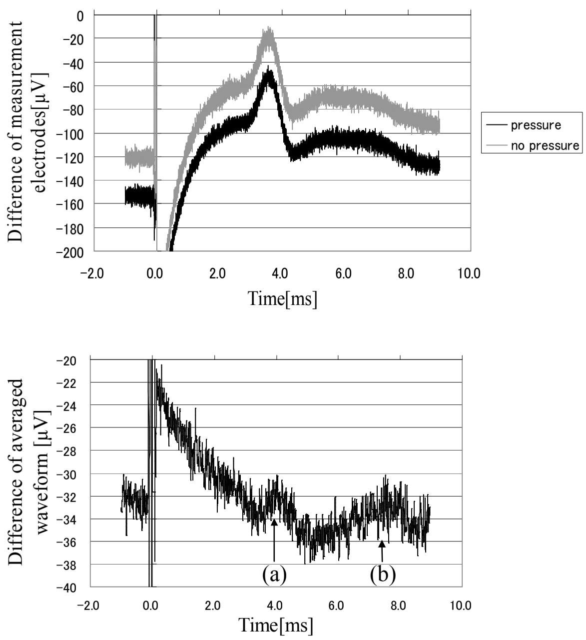

Fig. 11 Differential waveform between the cases with and without stationary pressure.

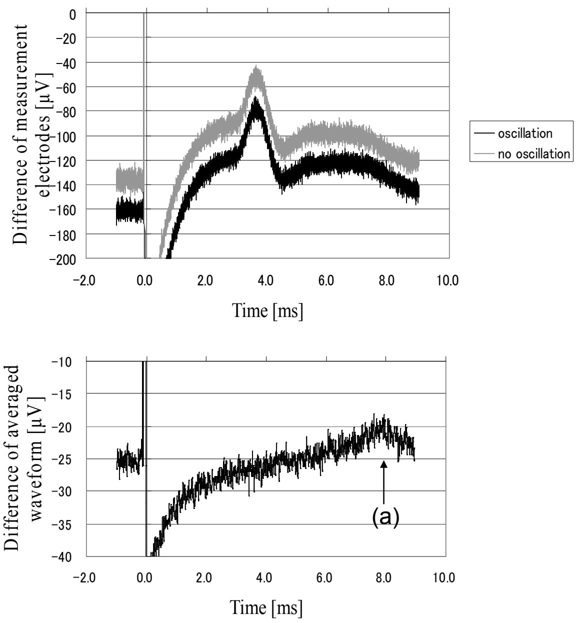

Fig. 12 Differential waveform between the cases with and without sine wave oscillation.

5. DISCUSSIONS

In Fig. 9, the waveforms of the compound action potentials synchronized by the electrical stimulation are clearly observed. That means the dispersion of the conduction velocity is small enough for synchronization. Fig. 10 shows that refractory periods disperse from 1.0 to 1.6 ms. The dispersion of refractory periods is considered to be caused by the attached position of the electrodes in each trial mainly. Fig. 13 shows the three of ten trials shown in Fig. 10. The electrodes were precisely stabilized within each trial, and the precipitous rising of the B/A ratio is observed.

Fig. 11 and Fig. 12 show the influence of mechanical stimulation. Discriminative waveforms were shown around (a) and (b) in Fig. 11 and around (a) in Fig. 12. The waveforms suggest that the measured nerve signals were influenced by the mechanical stimulations. In order to conclude that mechanical stimulation is observable with this method, we have to conduct statistical analysis using the data of multiple subjects.

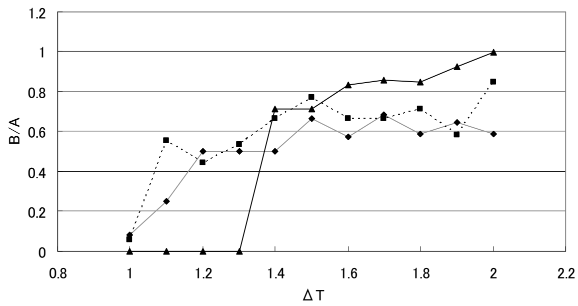

Fig. 13 Relationship between the interval of stimulations and the ratio of compound action potentials (electrode conditions were stabilized in the trials).

6. CONCLUSION

In this paper we proposed a new method to measure tactile nerve signals using synchronous refractory period caused by electrical stimulation. A pilot study showed that variance of the conduction velocity and the refractory period of each fiber is sufficiently small for observing the nerve signals by synchronization. We found differences between the nerve signal under mechanical stimulation and the signal under no mechanical stimulation. We are planning follow-up experiments to verify the difference is stably observable.

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