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Electro-Tactile Display with Localized High-Speed Switching

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Abstract

The electro-tactile display with localized high-speed switching is a novel type of electro-tactile display based on H-Bridge circuit that uses only one electrical source at a time. By using this display electrical stimulations can easily be presented and measured simultaneously. In this paper, other new methods for electrical stimulation, including scan-type ectrical stimulation and dipole electrical stimulation, are introduced.

Key words: electro-tactile display, high-speed switching, electrical stimulation

1. Introduction

The electro-tactile display directly activates sensory nerves through electrical current from surface electrodes. Electrical stimulation is based on researches on the equivalent circuit of the nerve [1,2,3]. Compared with other tactile devices, the electro-tactile display can be made very small and flexible because we can arrange electrodes and the other instrument like a current source separately, and the only requirement on the skin is a set of electrodes. Therefore, this display can easily be mounted onto other haptic devices, and it effectively indicates complex sensations. In previous electro-tactile display systems, electrical currents from each electrode were controlled independently, requiring one current-control circuit module per electrode [4]. Hence such systems were quite expensive, and fabrication with uniform accuracy was difficult.

A novel electro-tactile display with localized high-speed switching is proposed here. The system is composed of only one current source and parallel H-Bridge switches, which are commonly used in motor drivers and cochlear implant[5].

2. Principle

2.1. Localized High-Speed Switching

Fig. 1 describes the basic concept of this display. The system is mainly composed of H-Bridge circuits arranged in parallel. Each electrode is connected to the bridge part of an H-Bridge circuit, and the current pathway is directed by flipping the switches on and off. By this flipping, electrodes can be in any of four states: "current source," "current sink," "open," and "internal short"(Fig. 2).

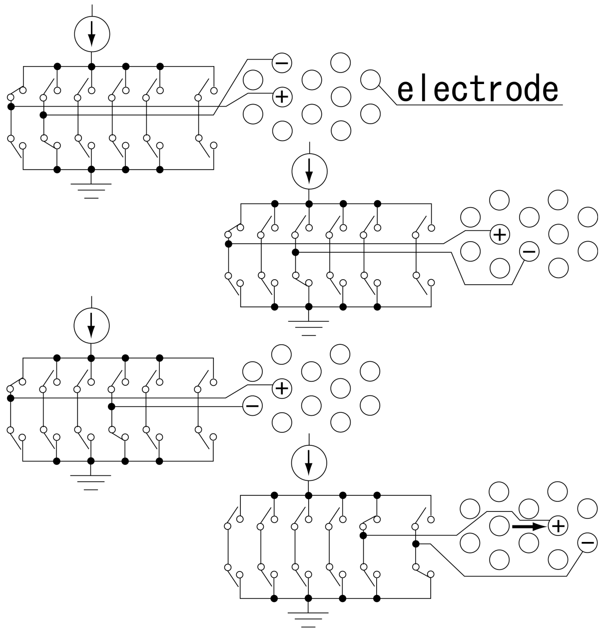

Fig. 1 Basic concept of the electro-tactile display with high-speed switching

At the start, the electrode for the stimulation point is

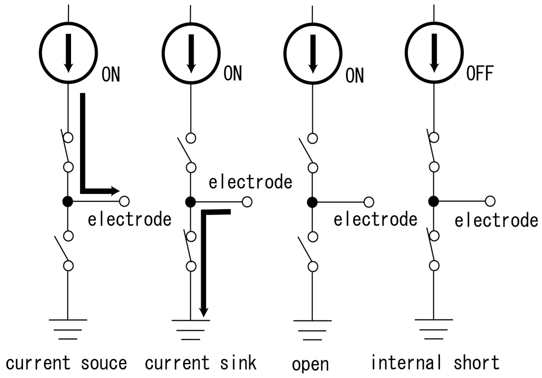

Fig. 2 Four states of electrode

determined, and the type of stimulation, anodic stimulation or cathodic one, is selected. If the anodic stimulation is chosen, the upper switch which leads to the stimulation point is turned on, and then, lower switches that are connected to the electrodes around the point are turned on one by one. In this process, only one electrode is retained as the cathodic one at any time. This is how quasi-concentric electrodes are made (the method is called QCE), and the stimulation point is changed in a manner similar to video display.

The most important difference between the existing stimulation method and QCE stimulation is the number of current path at every moment of stimulation. Generally, concentric electrodes are adopted for the electrical stimulation; however, with such electrodes, there are many current paths, and the stimulated space is enlarged as a result. At the same time, these existing isotopic stimulations hardly take care of the variation of subcutaneous tissue.

QCE stimulation simultaneously uses only two electrodes: anode and cathode. These dipoles are scanned around the stimulation point quickly. Hence, the stimulation is strongly localized, and the amplitude of the stimulation to the path under the skin can be adjusted in each instance.

2.2. Stimulation by Dipole

Dipole stimulation has many advantages over existing methods. For example, about one third of the current is required for stimulation because of the localization of the current paths. This reduces the load on the system and makes it easy to build this display.

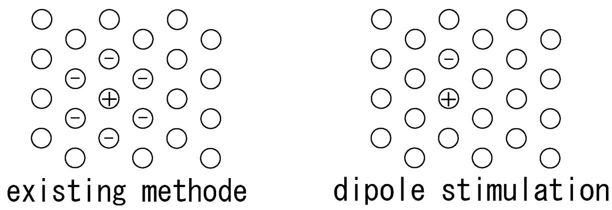

Fig. 3 Methods of stimulation

2.3. Impedance Sensing

As the density of the electrodes increases, the stimulation must be more finely controlled. For example an electrode located on a sweat gland could cause pain. The condition of the skin must be known so that the stimulation can be adjusted to the structure under the skin. In this display, the tactile sense can be shown, and the impedance of the skin can be calculated at the same time. To make the only two side paths, one for voltage and the other one for current, the voltage and current between the anode and cathode in the dipole are measured as shown in Fig. 4. The values are applied to the equivalent circuit (Fig. 5), where a symmetric property in the skin between the anode and cathode is assumed. This is why localized stimulation can be shown and high-resolution impedance map of the skin surface can be obtained with dipole stimulation.

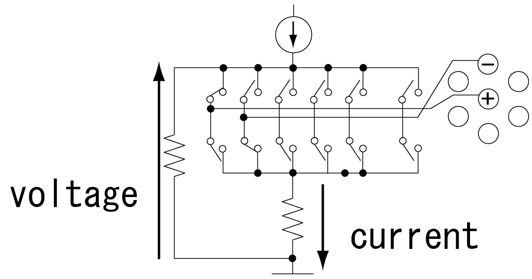

Fig. 4 Side paths to measure the voltage and the current

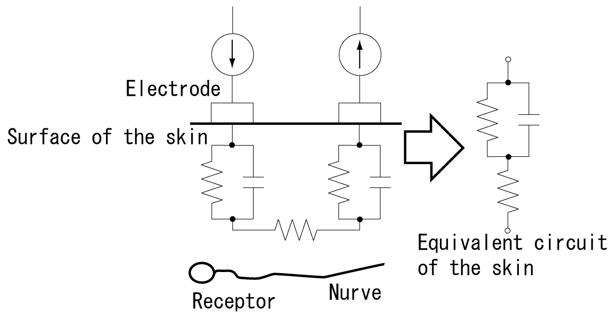

Fig. 5 Equivalent circuit of the skin

2.4. Selected Stimulation

There are many receptors under the skin. Meissner's corpuscles and Merkel cells exist near the surface as shown in Fig. 6. Meissner's corpuscles are assumed to be concerned with low-frequency vibration, and Merkel cells with pressure. It is likely all tactile sensations are the result of the combination of activity of these receptors, which are called "tactile primary colors" a name taken from the primary colors in vision. Actually the receptors were activated selectively in the previous research [6]. Anodic stimulation showed low-frequency vibration, Cathodic stimulation showed pressure because

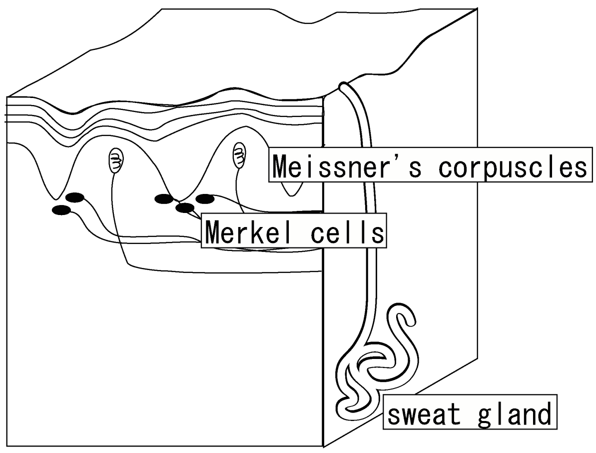

Fig. 6 Structure under the skin

anodic was superior when used in conjunction with Meissner's corpuscles, and Cathodic, with Merkel cells (Fig. 7).

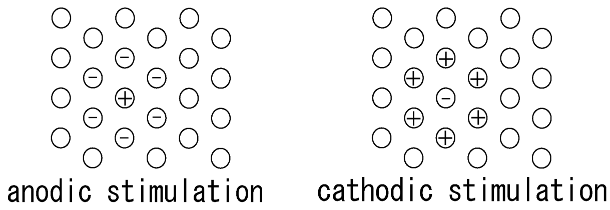

Fig. 7 Anodic and cathodic stimulation

3. System

The block diagram of the whole system is shown in Fig.7. The system consists of five primal components: the PC, current source, upper and lower switches, impedance meter, and electrodes. Impedance meter measures the voltage on the switches and the current through it.

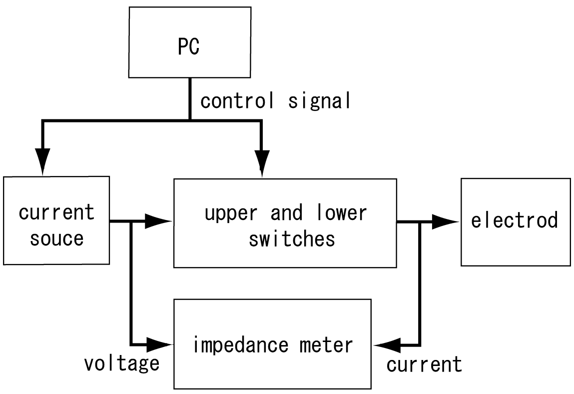

Fig. 8 Block diagram of the system

The details follow.

3.1. Current Source

The current source is divided into two parts, a voltage-to-current converter and a current mirror supplied by a 380[V] source (Fig. 9). In the pilot study, it was affirmed that this instrument can produce a 30[us] pulse width wave. The current source is controlled with the digital out put board (DO board) on the PC (PCI-2794, Interface).

3.2. Upper and lower switches

Upper and lower switches enable each electrode to take one of the four states: "current source," "current sink," "open," and "internal short." All switches are also controlled with the DO board on the PC (Fig. 10). The board and switches are insulated with photo-couplers (HCPL-2601, Agilent Technologies) to protect the PC from reverse. These switches have two requirements. One is speed. The QCE stimulation must have a frequency that is faster than the time constant of the skin electrical impedance. The other is that it must be able to withstand the high voltage that is required to stimulate nerve fibers from electrodes on the skin surface. As a result, the following power transistors are used: 2SJ130 (Hitachi Semiconductor) for the upper switches, and 2SK3113 (NEC Electronics) for the lower switches, which may result in a quite large capacitance.

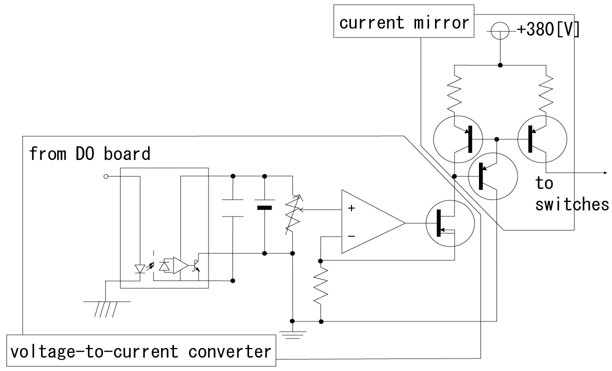

Fig. 9 Current source

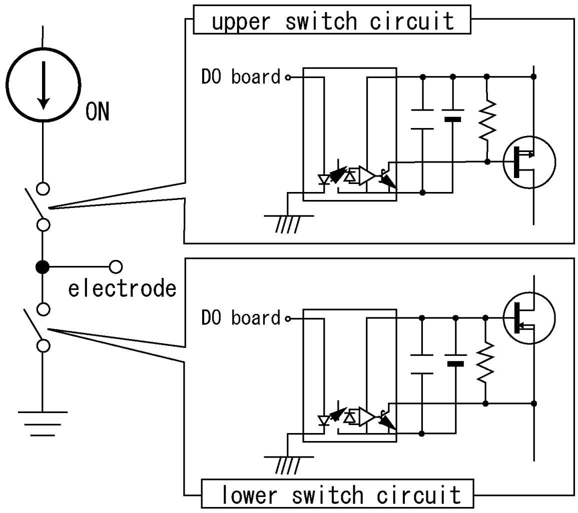

Fig. 10 Upper and lower switch circuit

3.3. Electrodes

For this display, seven stainless steel electrodes were arranged in closest packing. The distance between adjacent electrodes was 2.5[mm], and the diameter of each electrode was 1.0[mm]. Although stainless is highly rust-resistant, after a long period of stimulation, a thin oxidized layer of rust was evident on the surface. Polishing the surface constantly with a metal polish solved this problem.

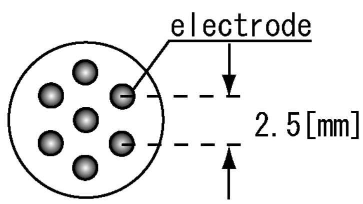

Fig. 11 Electrodes

4. Experiment

4.1. Performance Evaluation

The purpose of the switching procedure was to make concentric circle electrodes virtually through the high-speed scanning around each individual stimulation point. To realize this QCE mechanism, the switching speed should be faster than the time constant of skin and nerve fibers (a few hundred microseconds). Contrary to these requirements, the system did not function properly. The output waveform was distorted through the upper and lower switch circuit, which works as a low-path filter. Switching procedures were devised to solve this problem. Extra switching procedures that make the “Internal short” state were added to the end of the each stimulation, and any electrical charge in the display was cleared during the interval between switching. Fig. 12 is the time chart. As a result, the stimulation waveform is presented as gathered pulse waves in Fig.13. The form is called “burst wave”. In this experiments, the values of each parameter are adopted (the frequency is 100 [Hz], and the pulse width is 50 [us]). At each moment, there was only one current path as shown in Fig. 14

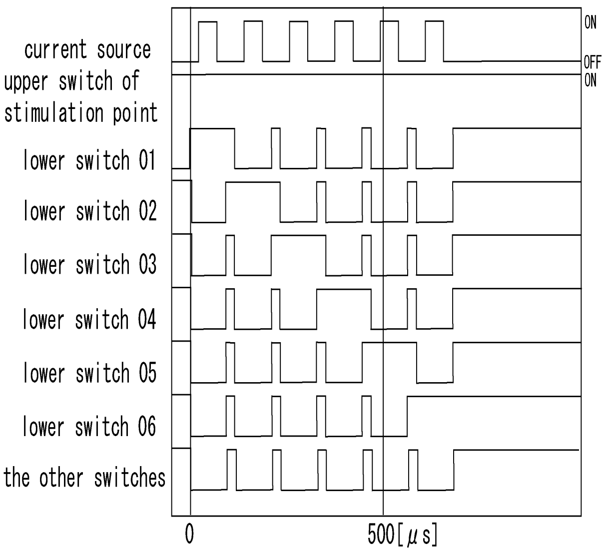

Fig. 12 Time chart example

(The number of the lower switches indicates the order of the scan.)

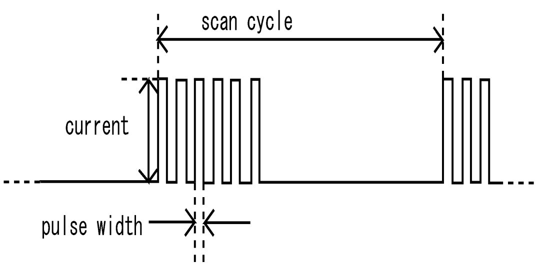

Fig. 13 Burst wave

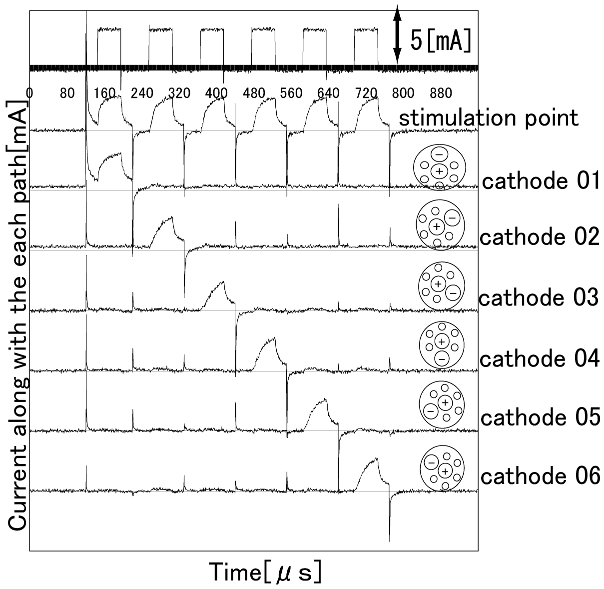

Fig. 14 Actual current through the electrodes

(The number of the cathodes indicates the order of the scan.)

4.2. Impedance Sensing

In this display, the electrical voltage between electrodes and the electrical current through the skin cannot be measured directly. Hence, at first, the equivalent circuit of the upper and lower switches must be obtained. An on FET can be regarded as a resistance, and an off FET as a capacitance. As a result, the system can be considered to be a H-Bridge circuit (Fig. 15). With this system, the voltage and the current are measured, and the test resistance is identified. In this identification, least-squares method was adopted (Fig. 16,17). The result with an uncertainty of about fifty percent was obtained. The equivalent circuit of the skin and the real skin surface haven’t been tested yet. However, after fine identification of this system, the skin impedance can be obtained, and the values of resistors and capacitance in the equivalent circuit can be calculated.

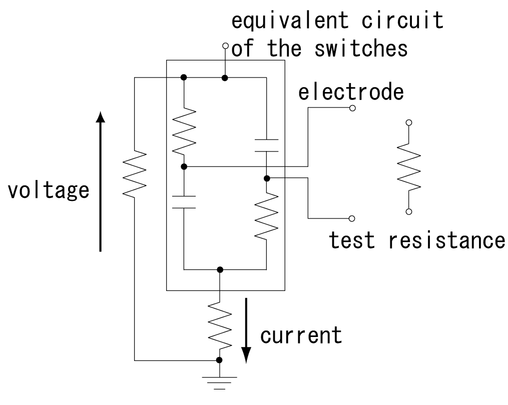

Fig. 15 Equivalent circuit of the switches

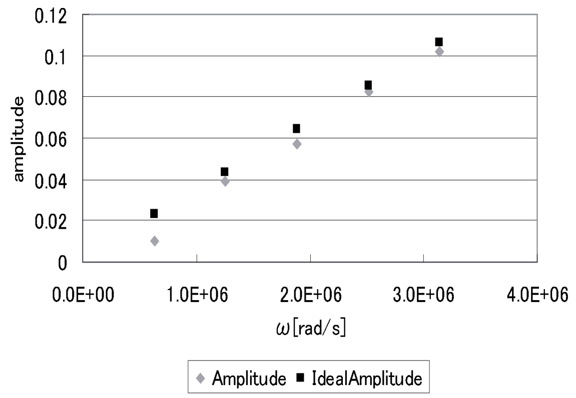

Fig. 16 Amplitude fitting

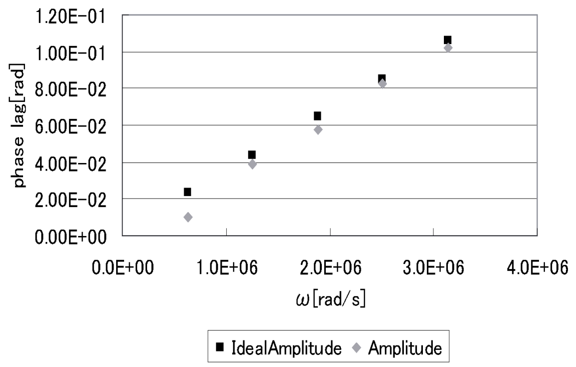

Fig. 17 Phase lag fitting

4.3. Differences in the Switching Methods

The objective of this experiment is to determine the best way to make a QCE stimulation. Six scanning methods were tested, three for anodic and the other three for cathodic current pathways. The methods, called "rotation scan," "interlace rotation scan," and "diagonal line scan" shown in Fig. 18, were psychophysically tested and compared with existing stimulation methods, in which all surrounding electrodes were connected to the ground. Subjects adjusted pulse height for each trial and comment on the quality of the stimulation and spatial extensity.

Compared with existing types, anodic and cathodic QCE stimulations are broader and have time instability. In addition, with the cathodic methods, it was more difficult to recreate concentric stimulation than with the anodic ones. For example, cathodic methods can easily cause a pain because the current required to show stimulation is close to the current which causes pain, and the current that is a little bit smaller than sufficient value can show only quite unclear point stimulation. Moreover, these difficulties hardly depend on scanning methods. Among these scan methods, "rotation scan" method is indicated to be closest to existing concentric electrode method.

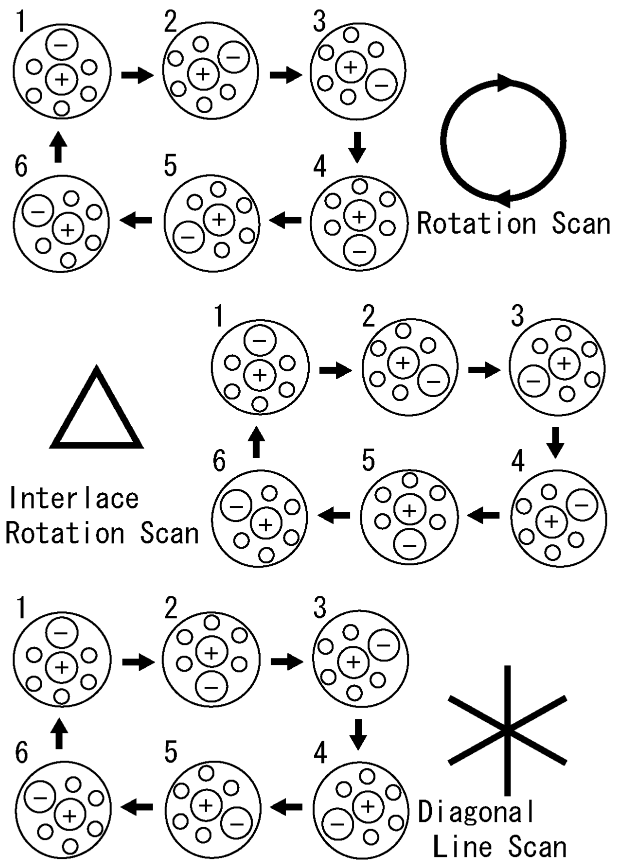

Fig. 18 Scanning methods

(The number of each display indicates the pulse order in the burst wave.)

4.4. Dipole Stimulation

The stimulation with only one dipole electrode pair was researched to determine the reason for the advantage that the anodic stimulation had over the cathodic one.

Although the dipole stimulation was not thoroughly examined, the stimulation was very important. Each characteristic of QCE stimulations depends mainly on that of the dipole stimulation because all scan-type stimulations consist of dipole stimulation at each moment. A pilot study showed that this stimulation has a line segment or two points that have different intensity. Nevertheless, dipole stimulation has some line-shape broadness. Whether the dipole stimulation can show certain direction or not, even if it has some deviation about the strength, were researched.

Two adjacent points were chosen randomly, one for an anode and the other for a cathode. Subjects indicated the segment that was shown in the display. The burst waveform was used in a comparison with the scan-type stimulation, and the frequency was 50[Hz]. The pulse width was 50[us].

The results are shown in Tab. 1. About the direction of the segment, if the answer was not the accurate segment itself, but parallel with the true, it was considered correct as shown in Fig. 19. The phrase "including anode" means that the segment that the subjects answered contained the anode of the true stimulation, as shown in Fig. 20. The same applies to the phrase "include cathode."

Tab. 1. Results of direction test

The direction is correct	48.7%
"Including anode"	90.0%
"Including cathode"	50.0%

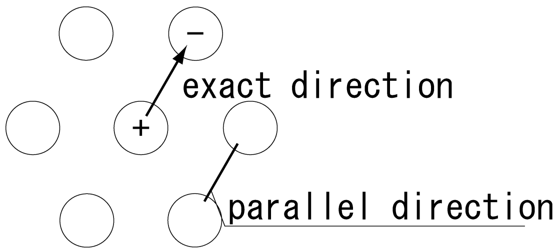

Fig.19 Direction of the segment

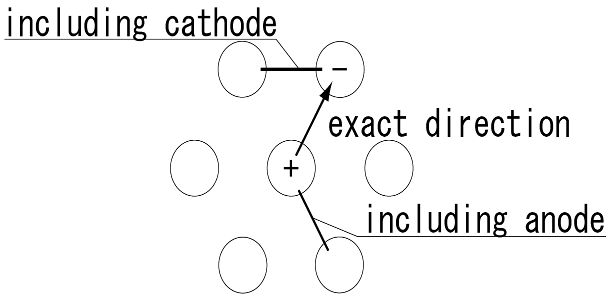

Fig. 20 "Including anode" and "including cathode"

Almost all anodic electrodes are cognized exactly. Hence the accuracy of direction mainly depends on the percentage of cathodic electrodes answered correctly. These results fit those of 4.3.

5. Results

The objective of this paper, that was to prove the advantages of a noble electro-tactile display with localized high-speed switching, was accomplished. In fact, compared with existing display, this one requires less voltage. The unified current path can show localized sensation and observe fine impedance of the skin.

More research will be required to determine some fundamental characteristics, such as the length of an ideal electrode interval and the method to acquire a more accurate current waveform. Moreover, to make this display work effectively, the uses of an impedance sensing system will need to be studied, and the best scan-type stimulation for QCE stimulation will need to be determined.

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