32nd Annual International Conference of the IEEE EMBS
Buenos Aires, Argentina, August 31 - September 4, 2010

Electrocutaneous Stimulation System for Braille Reading

Ana María Echenique, *Student Member, IEEE,* Juan Pablo Graffigna, *Member, IEEE* and Vicente Mut

Abstract— **This work is an assistive technology for people with visual disabilities and aims to facilitate access to written information in order to achieve better social inclusion and integration into work and educational activities. Two methods of electrical stimulation (by current and voltage) of the mechanoreceptors was tested to obtain tactile sensations on the fingertip. Current and voltage stimulation were tested in a Braille cell and line prototype, respectively. These prototypes are evaluated in 33 blind and visually impaired subjects. The result of experimentation with both methods showed that electrical stimulation causes sensations of touch defined in the fingertip. Better results in the Braille characters reading were obtained with current stimulation (85% accuracy). However this form of stimulation causes uncomfortable sensations. The latter feeling was minimized with the method of voltage stimulation, but with low efficiency (50% accuracy) in terms of identification of the characters. We concluded that electrical stimulation is a promising method for the development of a simple and unexpensive Braille reading system for blind people. We observed that voltage stimulation is preferred by the users. However, more experimental tests must be carry out in order to find the optimum values of the stimulus parameters and increase the accuracy the Braille characters reading.**

I. INTRODUCTION

Assistive technology (AT) brings the technical aids that allow individuals with disabilities to perform their daily activities, addressing to solve their functional needs. Its goal is to achieve these subjects can realize their activities on a particular context [1]. This means that the AT does not focus on solving the disability but to achieve functional outcomes sought by the person.

One of the main problems faced by people with visual disabilities is access to reading. In this sense, the Braille System is widely used by blinds and deaf-blinds, and it is characterized by its universality and simplicity.

In technical aid, usually the data enter to processor and it sends information to the subject through a human-technology interface (HTI). In the case of the blind, where augmentative devices are not adequate, it requires the use of touch or hearing. The touch stimulation has advantages over auditory one [2].

On the other hand tactile stimulation can be achieved by different means, for example: temperature, electricity, compressed air or mechanical changes (pressure or vibration), etc [3-6].

Electrical stimulation offers advantages over other methods. It has not thermal inertia, does not produce fatigue and does not wear moving parts. Therefore we can achieve a compact designs with solid state components of small size and low cost.

A tactile display is a device that presents information to the user (wearer of the device) by stimulating nerve receptors in the skin. This is a special kind of HTI.

Several types of mechanoreceptors are located in the human skin: (1) Meissner corpuscles and rapidly adapting mechanoreceptors (RA: Rapidly Adapting), (2) Merkel cells mecanoceptores slowly adapting type I (SAI: Slowly Adapting Type I), (3) Ruffini terminals or slowly adapting mechanoreceptors type II (SAII: Slowly Adapting type II), and (4) Pacinian corpuscles (PC: Pacinian Corpuscle) [9],[12].

As the population of SAII is very small, we were excluded this type from this work [5]. Investigations suggest that is possible to stimulate a simple type of mechanoreceptors. It would produce different tactile sensations. [7]

Fig. 1 shows the cross section of human skin. RA and PC perceive vibration; while SAI will generate sensations of pressure [7]. Sometimes RA and PC (rapidly adapting mechanoreceptors) are regarded as velocity and acceleration sensors, since they respond with one impulse to deformation. For the other hand, SAI function as position or displacement sensors, responding to the stimulus intensity and duration.

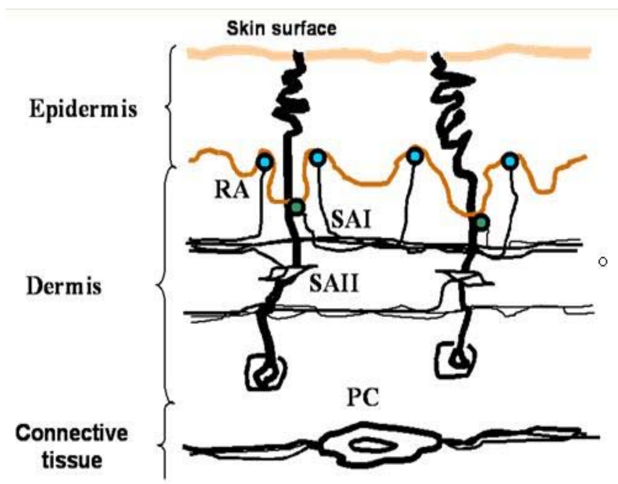

Fig. 1. Cross section of human skin. RA: Meissner corpuscle, SAI: Merkel cell, Ruffini SAIIA terminal, PC: Pacinian corpuscle . Extracted from [6].

This work was supported by grants from Universidad Nacional de San Juan of Argentina (code 21/I849)

A M. Echenique and J.P. Graffigna are with Gabinete de Tecnología Médica, Universidad Nacional de San Juan, San Juan, Argentina (e-mail: amechenique@gateme.unsj.edu.ar,jgraffig@gateme.unsj.edu.ar)

V. Mut is with Instituto de Automática (INAUT), Universidad Nacional de San Juan,San Juan, Argentina (e-mail: vmut@inaut.unsj.edu.ar).

II. METHODOLOGY

The work is divided into three phases: (1) Preliminary tests, (2) reading Braille using current stimulation (3) reading Braille using voltage stimulation. For the last two phases we used different prototypes, which were connected to a PC by USB port using an interface developed in previous works [15],[16].

A. Preliminary tests

In order to define the methodology in current stimulation, we study the mechanisms of electrical stimulation. It is usually done through an alternating current on the surface of the skin, achieving nerve activation in an indirect way [7], [8]. This way, cathode (negative) current activates the nerve cell axons oriented horizontally on the skin surface. On the contrary, when applying anode (positive) current, the nerve cell axons oriented vertically (like the RA axon) are stimulated. According to the studies made [4]-[6] and [9]-[12], the mechanoreceptors are sensitive to stimuli in the 40-600 Hz range.

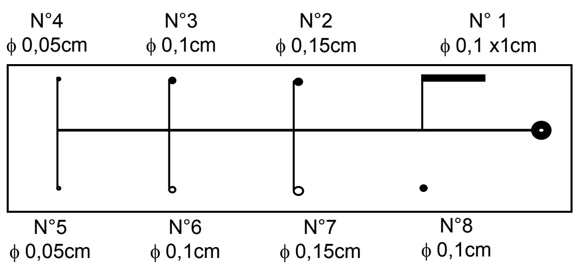

Fig. 2. Forms, types and sizes of electrode stimulation plate

In the phase, we work on different electrode designs. At first we use a single coaxial electrode and then we design a printed circuit board with seven electrodes of different shapes and sizes (see Fig. 2). With the exception of electrode N° 1, all the others are based on circular points, stuffed or hollow, with different diameters. This board has a real relief (without electrical stimulation), which is called "electrode" N°8.

Wetting tests is performed with stimulation at frequencies and intensities of current.

The experimental prototype based on current stimulation

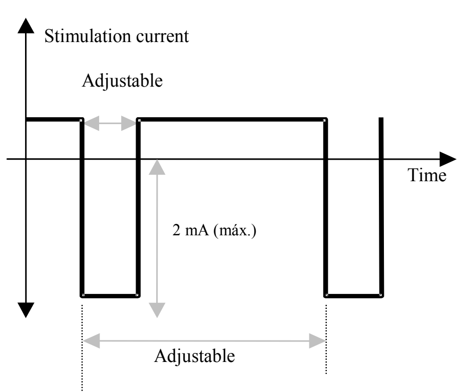

Fig. 3. Waveform of stimulating current pulse.

causes an electrical signal which waveform is shown in Fig. 3. To avoid the accumulation of charges we match the positive and negative areas of the stimulation pulse.

We design two current sources of 2mA (max) in the negative phase and an output of 0.5 mA (max) in the positive phase of the signal [14].The current is limited due to safety factors.

The frequency range is adjusted according to the background in the subject, from approximately 10 Hz to 1.1 KHz. Because the time recovery phenomenon of nerve fibers [13], we do not work with greater frequency values.

B. Current stimulation method

From the experiments made in preliminary tests we apply the method of current stimulation to a cell Braille with 6 electrodes (shown in Figure 4). The stimulation parameters on which we work are: character duration, character type indicator, frequency and pulse width. The character duration is adjusted from 1s to 10s in steps of 1s. The selection of pulse width is performed in steps of 10µs in the range of 150µs to 300µs, according to the experiments in the first phase. The pulse width and the frequency are automatically available for the user. The frequency selection has four different values in the range of 278 to 1111 Hz.

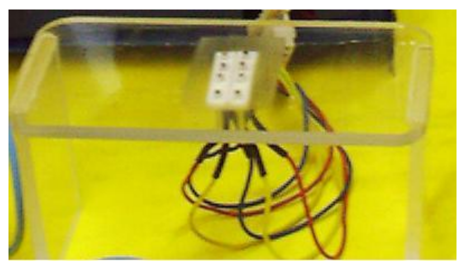

Fig. 4. Braille cell

C. Voltage stimulation method

Based on the results described on the current stimulation [14], third phase is carried out for the method of voltage stimulation. This stimulation is done according to the waveform used in current, replacing this variable by voltage [15]. The upper limit is set at 240V.

To avoid accumulation of charges, we applied a high pass passive filter. Its function is to obtain a biphasic signal with mean value equal to zero.

Because there is wide variation in the values of electrode-skin impedance in different subjects, we prepare a voltage regulation system, which is controlled by the user.

Experiments are performed on a line with 32 Braille cells (see Fig. 5).

Fig. 5. Braille line

The aim is to make reading in Braille, through stimuli in the fingertip, avoiding uncomfortable sensations.

D. Experimental protocol

In three phases, the following protocol was done:

- Wash hands thoroughly.
- Clean with alcohol electrode prototypes.
- Set the parameters of the experimental prototype.
- Clean with alcohol fingertip to stimulate.
- Clean with alcohol toe area where place the return electrode (Fig. 6). This electrode is used for the electrical return of current or voltage stimulus.
- Put the return electrode in the index finger and tighten.
- Place the hand in the most comfortable position as possible.
- Place your fingertip on the electrodes and adjust the desired intensity of the stimulus.
- Record the different sensations perceived.
- Allow to rest the finger.

In the prototypes designed for phases 2 and 3, we perform a series of tests, such as training prior to the reading test. The methodology used in the second phase is to present sequentially the characters of a sentence on the cell. In the third phase the individual must read a complete sentence distributed in the 32 Braille cells of the line.

This experiment was performed in blind and visually impaired adults who have good performance in reading Braille [14],[15]. These tests are assessed with the reading of Braille paper, prior to experimentation. Because we are evaluating perceived sensations by blind and visually impaired, the results are qualitative.

Fig. 6. Return electrode

III. RESULTS

Thirty three trials were conducted electrical stimulation with different prototypes and methods of stimulation.

Preliminary testing of direct current stimulation were done in the **first phase** with 21 blind and visually impaired adults, in order to experience different tactile sensations. The variables tested were type of electrode, stimulation frequency, pulse duration and intensity of current.

The electrode obtained better results in experimentation is the N° 3 of 0.1 cm in diameter (see Fig. 2).

Fig. 7. Experiments with Braille cell.

The frequency from which it achieves a feeling of pressure point (similar to the tip of a pin) is about 1 KHz with a pulse width of 200µs. In contrast, in the range of low frequencies, the subjects felt a slight vibration.

The comparison between the electrodes and a real highlight ("electrode" N° 8) gave excellent results. The feelings generated by the relief, are very similar to those obtained with electrical impulses.

Experimentation for the **second phase** was carried out with a group of 7 blind people [14]. The best reception of the stimulus was obtained with the same values as the previous phase in terms of frequency and pulse width, and permanence of character 10s.

Later the sentence reading test in Braille code (Fig. 7). The latter was successful, since 100% of the participants could read, on average, 85% of the characters, adapting quickly to the reading system. It also became clear that this test required a good level of concentration, which in some cases had to be repeated more than once to achieve the final results of the test. In some cases, unpleasant sensations perceived by removing your finger from the electrode. This feeling, is that by reducing the area and kept constant the current value, the current density increases.

In the **third phase**, the voltage stimulation was carried out with 5 people, perceiving the same tactile sensations described in the current stimulation, in terms of frequency range. Persons under experimentation (Fig. 8) showed that the perceived sensation is much smoother and less traumatic than in the case of stimulation current, thus eliminating the

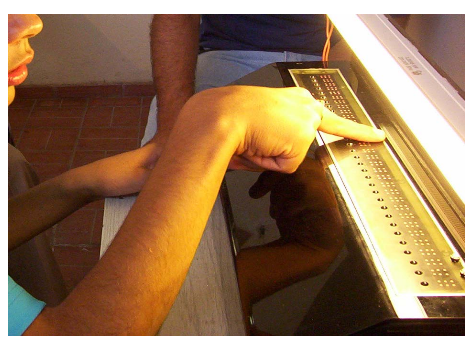

Fig. 8. Reading test using the Braille line prototype.

unpleasant sensation of electric discharge. The trials were conducted with the same waveform and parameters of previous phases. During the reading test, people recognized the number of active electrodes in each character. However, the location of those displaced appear to produce errors in the letter identification tests as indicated by [7],[13]. For this reason, the reading system produces a lower accuracy (50%) of character identification than the other method.

In some people observed a loss of sensitivity to pass the test. This is due to natural phenomenon of sensory adaptation examined by Leung [16]. In such cases had increased the amplitude of the stimulus.

IV. Discussion and Conclusions

Different experimental tests with visually impaired and blind individuals was accomplished in order to establish the perceived tactile sensations by current and voltage stimulation methods. Due to the high sensitivity of touch sense that blind people developed normally, we observe that fingertip weeting was not necessary in the majority of the cases. In conducting the tests for extended periods (> 30 min), it was observed that the nerve fibers remain sensitized with little response to new stimuli.

In the current stimulation, we found that its threshold depends mainly on the impedance of the fingertip, which is variable in each subject. The unpleasant sensation with the current stimulation was experienced when approaching or removing your finger from the electrode, due to changes in the impedance offered to the stimulus. On the other hand, this effect significantly decreases with voltage stimulation because the current through the skin is proportional to the impedance offered by it. Another factor to consider is the phenomenon of sensory adaptation dependent on the amplitude and frequency of the stimulus.

With regard to Braille reading tests, we obtained better results in the recognition of characters using the current stimulation. The voltage stimulation produces some errors in the definition and character recognition. Displaced perception of the stimulus is produced by indirect stimulation of the axon, rather than the stimulation of mechanoreceptors. However, at this late stage there was not other evidence that would alter the parameters for best results in Braille reading.

Further research must be carry out in order to find optimum parameters of the stimulus in order to ensure proper recognition of the characters in Braille reading.

Acknowledgments

The authors wish to express our gratitude to the 33 blind and visually impaired persons who consented to perform the experiments. These people are students of ***Luis Braille the Special Education School*** located at San Juan in Argentina.

References

[1] A. M Cook and S M. Hussey. Assistive Technologies, Principles and Practice. Publisher: C.V. Mosby . 2002.

[2] Lenay C, Gapenne O, Hanneton S, Sensory Substitution: Limits and Perspectives.. Université de Technologie de Compiègne. 2003.

[3] Vidal- Verdú, f y Hafes, M: Graphical Tactile Displays for Visually-Impaired People. IEEE Trans Neural S and Rehab Eng, V15, N1, 2007.

[4] Asamura N, Tomori N and Shinoda H. A Tactile Feeling Display Based on Selective Stimulation to Skin Receptors. Proc. IEEE Virtual Reality Annual International Symposium '98 . pp.36-42. 1998

[5] Asamura N, Yokoyama N and Shinoda H. A Method of Selective Stimulation to Epidermal Skin Receptors for Realistic Touch Feedback Proceedings of IEEE Virtual Reality '99 Conference pp274-281. 1999.

[6] Asamura N, Yokoyama N, y Shinoda H. Selectively Stimulating Skin Receptors for Tactile Display IEEE Computer Graphics and Applications Nov- Dec 1998 pp32-37. 1998

[7] Kajimoto H, Naoki K, Taro M. and Susumu T. Tactile Feeling Display using Functional Electrical Stimulation In Proc. of The 9th Int. Conf. on Artificial reality and Telexistence pp.107-114. 1999

[8] Kajimoto H, Kawakami N, Tachi S Optimal Design Method for Selective Nerve Stimulation and Its Application to Electrocutaneous Display School of Information Science and Technology, The University of Tokyo, Bunkyo-ku, Hongo 7-3-1, Japan. 2002

[9] Iggo. Sensory Receptors in The Skin of Mammals and Their Sensory Functions Rev. Neurol (Paris),141,10, pp.599-613. 1985

[10] Ikei I, Wakamatsu K, and Fukuda S Texture Presentation by Vibratory Tactile Display ProcVRAIS ’97 pp. 199-205. 1997

[11] Rattay F Electrical Nerve Stimulation Springer-Verlag. 1990

[12] Vallbo A B Properties of cutaneous mechanoreceptors in the human hand related to touch sensation Human Neurobiology, 3, Springer-Verlag pp.3-14. 1984

[13] Serra W, Lanzone M, Echenique A M y Graffigna J P. Touch Display electrocutaneous (in Spanish). XV Congreso Argentino de Bioingeniería (SABI2005). 4 pages. Entre Ríos. Argentina pp 92. 2005

[14] Rossini D, Pereyra P, Echenique A M, Graffigna J P y Ensinck G Braille Cell Electrostimulation (in Spanish). Iberdiscap 2006. Vitoria. Brasil. 2006

[15] Puertas A, Pures P, Echenique AM, Graffigna JP Y Ensinck G. Braille line using electrical stimulation. Journal of Physics: Conference Series. ISSN: 1742-6596, vol. 90, doi:10.1088/1742-6596/90/1/012091, pp. 1-8. http://iopscience.iop.org/1742-6596/90/1/012091 2007

[16] Leung, Y. Y., S. J. Bensmaia, S. S. Hsiao, And K. O. Johnson. Time-course of vibratory adaptation and recovery in cutaneous mechanoreceptive afferents. J Neurophysiol 94: 3037–3045, 2005; doi:10.1152/jn.00001.2005