A Wireless Assistive Device for Visually-impaired Persons using Tongue Electrotactile System

Thanh Huong NGUYEN[1,2,3], Thi Hue NGUYEN[1,2], Thi Lan LE[2], Thi Thanh Hai TRAN[2],
Nicolas VUILLERME[3,4], Tan Phu VUONG[1]

[1]*IMEP-LAHC, Grenoble Institute of Technology (GINP), Grenoble, France*
[2]*International Research Institute MICA, Hanoi University of Science and Technology (HUST), Hanoi, Vietnam*
[3]*Univ. Grenoble-Alpes, AGIM FRE 3405,CNRS-UJF-UPMF-EPHE, Grenoble*
[4]*Institut Universitaire de France*

Abstract— **People with low and lost vision are increasingly independent nowadays; besides, more and more resources and facilities have been developed to enable them adapt to daily life in an active way. Based on the idea of sensory substitution and the electrotactile stimulation on the tongue, a wireless small device was studied and designed in order to aid the visually-impaired people in getting more perception of their surrounding environment. The device was also fabricated and tested with normal people to understand the sensibility of human tongue in achieving the information from the device. With wireless part, the device is totally able to communicate with the host system and receive the command to help users perceive and direct in the environment.**

Index Terms—wireless communication and device;handicapped aid; blind mobility; sensory substitution; electrotactile device; tongue display unit

I. INTRODUCTION

According to the Global data recorded in 2010 by the World Health Organization (WHO), there have been 285 million visually-impaired people, 90% of whom live in developing countries [1] . The Vietnam Institute of Ophthalmology (VNIO) reported that in 2007 up to 380,000 people are blind whereas 1.6 billion persons have vision problems [2]. The number showing a high percentage of visually impaired people, which results from lack of trained professionals, limited resources and spatial spread of care.

Loss of sight is associated with independence loss due to the low perception of the environment. This problem leads to difficulties to take part in daily life and hinders the mobility of the visually-impaired people. For the last few decades, various types of aid devices and systems have been manufactured to provide blind users means of navigation, learning or getting to know the environment. Some of the systems which can detect obstacles on the path are White Cane [3], Mowat Sensor [4] and Sonicguide [5] while the others can help to globally navigate such as Talking Map [6], SWAN [7] or GPS System [8]. However, the above systems are not capable of doing both tasks simultaneously. To overcome the drawbacks of the mentioned single-purpose aided devices, Tachi et al. applied the mobile robot technology into an assistive system called Guide Robot Dog [9]. However, the system is rather bulky and requires users to act as an operator.

In 1972, Professor Paul Bach-y-Rita conducted an intensive study on the theory called Brain plasticity [10]. It is a characteristic of human brain to reorganize itself due to physical changes in life such as behavior, environment and neural processes or injury. Furthermore, thanks to this adaptive capacity of the brain, the handicapped people can gain environmental information from the rested available senses in place of the malfunctioned one. In this way, the environmental and necessary information is sensed by the handicapped people from the stimulation device through well-functioned perceptive organism like the way the impaired one naturally senses. Based on this pioneer study, Bach-y-Rita et al. [11] also developed a tactile visual substitution system in which the tactile sense is the effective replaceable modal for the vision.

In the daylight of the idea of Professor Bach-y-Rita, we want to propose a wireless tactile system which can help the visually-impaired people to live independently. Certainly, the auditory and other senses could totally be the efficient substitution; nevertheless, the tactile receptors connect to almost all surface of our body, hence, the choice is variable. In all tactile vision substitution system (TVSS) [12], the visual information is delivered to the brain through mechanical or electrical stimulation arrays in contact with the skin. Among the various parts of the body, i.e. back, abdomen, thigh, wrist, arm, finger or tongue that can be used to transmit information, the tongue seems to be the most appropriate because it is very sensitive and mobile. Additionally, the mouth has a liquid environment, the saliva which is a good conductive environment for transmitting electrical signal. Thirdly, the device reduces the workload of the ear which is often used in visually impaired people; instead, the ear can be freely used for other tasks. Some of the research groups have developed such TVSS systems. Bach-y-Rita et al. [13] constructed squared arrays of 4x4, 5x5, 6x6 electrodes for pattern identification while Vuillerme et al. [14] developed a matrix of 6x6 electrodes on the tongue for proprioception and balance improvement.

The eventual goal of our project is to set up a whole practical system which can process directly the visual information into the electrical signal on the tongue. In this paper, we introduce a demonstrator of a small wireless tactile device inside the mouth which receive the command and performs the stimulation signals to achieve information of navigation. While all of the electrode arrays constructed for TVSS on tongue have the squared form, in our study, the round form is made and tested for the first time. Although the system is not completed, by making some tests with sighted adult humans, we have demonstrated that the stimulation burst is affective at each pulse of 100ms and the tongue can recognize pulses after a period of 500ms. After that, this parameter is used to exercise the test subjects in a simple orientation discrimination task. The perception of all test participants shows that at 3.3V, the stimulation on the tongue can generate clear feeling, to some extent, compared to previous report that the tongue requires 5-15V [15] for stimulation.

II. INTRODUCTION OF SYSTEM ARCHITECTURE

As introduced in the Introduction part, the Tongue Display Unit (TDU) which is based on the patent of Professor Bach-y-Rita is the prototype which is applied into our TVSS system. Because the device is stimulated with the tongue, not the eye or optic nerve, it can work with non-disabled people and also those with visual impairments. However, the system will be developed to address the needs for the purpose of small dimension and wireless communication which have never been done.

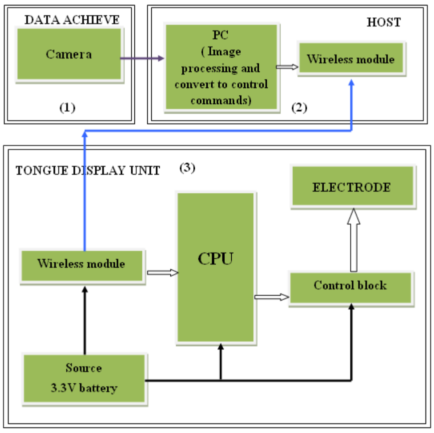


Figure 1. Schematic diagram of the whole system

In our system, there are three parts:

(1) Data acquisition: User can wear a pair of sun-glasses which includes a camera capturing images from the environment. The video output is sent to the Host system.

(2) Host system: The computer translates output from camera into a pattern of command and then sending wirelessly to the TDU.

(3) TDU: Central Processing Unit (CPU) converts the command to electronic pulses that will be sent to an array of electrodes placed in contact with the tongue. The TDU contains five functioning blocks: a battery providing energy to all the components, a CPU processing the command signal into a encoded signal, a control block processing the encoded signal to pulse to be sent to the electrodes and the wireless module that receives the wireless signal from the camera. An array of electrodes is around 2.5 meters square that stimulates the receptor cells on the surface of the tongue to the brain, i.e., tactile or touch receptors on the tongue send impulses to the somatasensory cortex in response to stimulation.

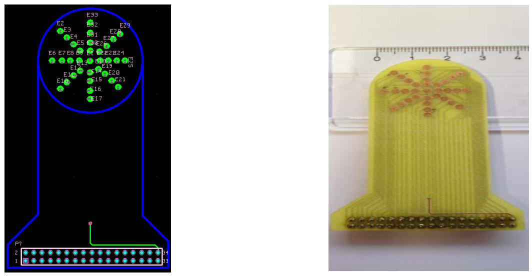
In this paper, we will focus on the design and fabrication of the wireless TDU device, especially the new form of the electrode grid. Next, we will assess the performance of it through the sensitivity test on the tongue.

III. DESIGN OF THE TED DEVICE

In this paper, in order to verify the performance of a new form of the electrodes as well as the impact of electrical signals from such electrodes, a demonstrator of the TED will be fabricated and verified.

a) Matrix of electrodes

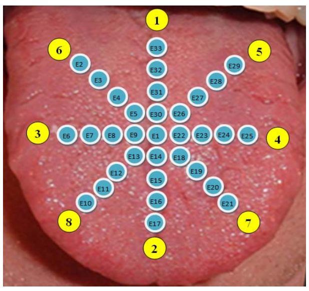
The array of electrodes is composed of 33 electrode pins. In the center of each pin, a hole is made to connect with the bottom layer to plays a role as the negative terminal. Each via has diameter of 0.1mm. Outside the hole of each pin, a copper circle of 2 mm diameter is connected to the positive terminal. These pins are arranged on a round grid with 1mm interelectrode spacing. The total dimension of the grid is a circle of 4 cm diameter. Figure 2 shows the design and real image of the fabricated electrode plate



a) b)

Figure 2. Round matrix of electrodes: a) in design; and b) in reality

For orientation navigation, the circle has 4 diagnonals, each diagonal is a series of 9 electrodes. For orientation navigation, we define these diagonals into 8 directions. In this way, navigation is easier since the direction information is translated directly to the tongue. Figure 3 shows the idea of our electrode design.



1- Straight forward
2- Backward
3- Turn left
4- Turn right
5- Turn right and forward
6- Turn left and forward
7- Turn right and backward
8- *Turn left and backward*

Figure 3. The representation of the directions of the matrix of electrodes on the tongue

b) Control circuit for electrodes

To specify and control the stimulus waveform, pattern and trial events, a control circuit needs to be made. In the future, it will be minimized to place inside an orthodontic retainer. This circuit is desired to generate low current (the mean current for tongue subjects was 1.62 mA [13]), the source battery has low voltage in order not cause high leakage current and consume little power. The block diagram of this circuit can be depicted in Figure 4.

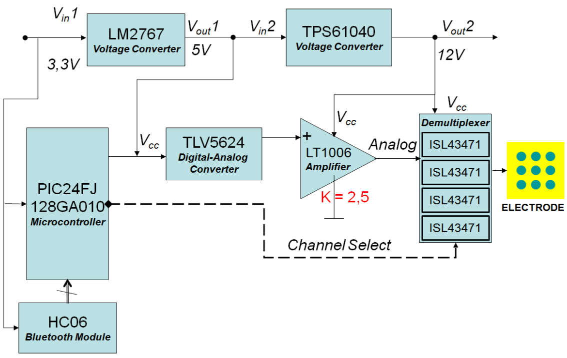


Figure 4. Schematic diagram of the TED device

In Figure 4, the central element is the microcontroller which produces the stimulation signals to the right electrodes on the dorsal part of the tongue. The whole device is powered by a 3.3V Lithium battery which has small output current.

As the purpose is to test the electrode impact on the tongue, only the matrix of electrode is placed inside the mouth, the other parts is fabricated in a separate circuit to prevent severe problem in case of leakage. However, in the future, mounting the whole device within the mouth is the final goal. This can be done by packaging the circuit inside an orthodontic retainer since the groups of Vuillerme [16] has ever made (Figure 5).

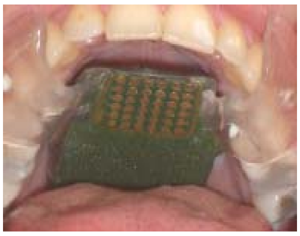


Figure 5. Prototype of a wireless 6x6 TDU in an orthodontic retainer [12]

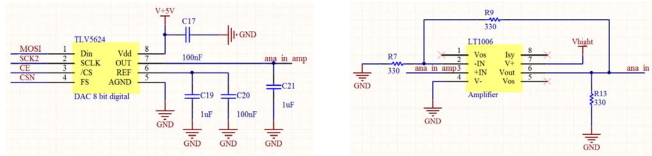
In the following part, detailed descriptions of each block in the schematic diagram in Figure 4 will be indicated. The names of all electronic components were indicated specifically.

- *Source (power supply)*

A Lithium battery with diameter of 20mm and height of 3.2mm is used, which supplies a voltage of 3.3V and a current of 135 mA.

- *Voltage Converter Circuits*

This design is specifically for future use. According to Robineau et al.[15], the range of stimulus voltage is 5-15V. But when we connected directly the electrode to the voltage generator and applied different voltage, the tongue started to have clear feeling at 3V and, at 10V, the tongue started to hurt. Hence, in our circuit, for safety reason, the voltage range was reduced to from 3V to 10V. Since the battery supply 3V power, voltage converters need to be used. In addition, for more flexible voltage modification, a DAC (Digital Analog Converter) was used. Normally the DAC needs 5V power supply. As a result, two voltage converters are necessary for the circuit, one for 5V conversion and the other for 12V conversion. The schematic diagrams of the DAC and amplifier is shown in Figure 6.



a) b)

Figure 6. Schematic diagrams of: a) DAC block and b) Amplifier block

The IC (Integrated Circuit) LM2767 of Texas Instruments was to increase the 3V battery to 5V and TPS61040 of Texas Instruments was to rise from 5V to 12V. Both of them are low power IC. The detailed schematic diagram can be easily found in the datasheet of these two ICs. Besides these two converters, in order to modify the voltage, a DAC must be used in combination with an amplifier. The DAC TLV5624 is an 8−bit DAC which has 2^8 levels of voltage; therefore, there will be 256 voltages in the range from 3V to 12V. It is rather sufficient for choosing a suitable stimulation voltage. The gain of the amplifier is 2.5 because from 12V/5V=2.5. The single amplifier LT1006 consumed small power compared to many other ones.

- *Signal generation*

A low cost PIC24FJ128GA010 microcontroller of Microchip Technology was used for the following three functions: (1) choosing the stimulation voltage, (2) choosing the electrode to send signal and (3) communicating and receiving the command from the wireless module. Consequently it connects to the DAC, to the demultiplexers and wireless module. The following will be the flow chart of algorithm implemented for PIC in this paper (Figure 7).

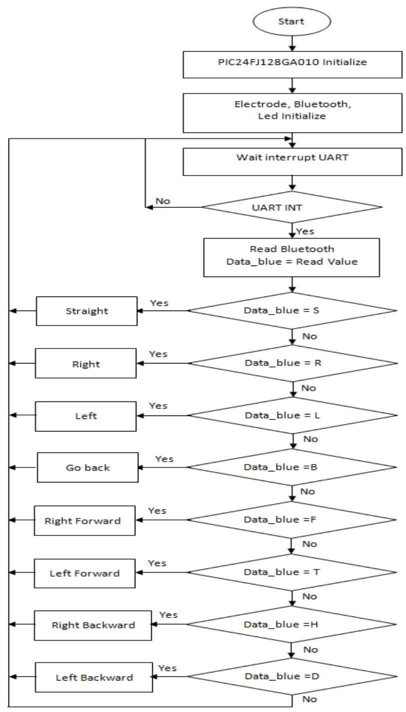


Figure 7. Flow chart of controlling algorithm for matrix of electrodes

This flow chart illustrates the general idea of the entire control problem. We can extend to the more number of electrodes and the demand of the problem, for example a matrix of 64 electrodes which generates the alphabet and at each sequence of the type of four last sequences will be replaced by a character in the alphabet.

Using the demultiplexer is to connect the microcontroller to the selected electrode because of the limited number of output pin in the microcontroller. Demultiplexer IC named ISL43741 of Intersils which has two blocks of 1:4 demultiplexer, which results in 8 outputs. This IC is used due to the small dimension and low consumption. The program in the microcontroller receives the information from the wireless module to activate one certain electrode at a time. The selection of the right outputs among 8 outputs from 2 inputs is based on the table of truth in the datasheet of ISL43741.

- *Wireless communication block*

From the host computer, the signal will be sent wirelessly to the tongue display unit by using a Bluetooth module with our own antenna. Our proposed antenna is of the dipole type because it is required to radiate radio waves power uniformly in all directions. This antenna can well support for the blind who cannot direct themselves in advance. The antenna is designed to operate at 2.4 GHz to comply with the Bluetooth protocol. Our scenario in the future is to operate the system inside the classroom; Bluetooth is the most appropriate protocol. Figure 8 shows the antenna that was made in our group, which has recently been published in the Proceedings of European Conference on Antenna and Propagation [17].

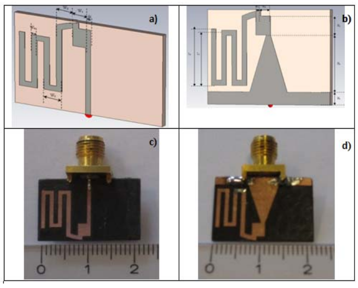


Figure 8. Dipole antenna for tongue-placed electro-tactile device: Design model for the antenna at the a) front and b) back; Fabricated antenna at the c) front and d) back

IV. DATA COLLECTION

The control block was programmed to send the control signal to the dorsal part of the tongue via electrical stimulation. The round array of 33 electrodes is divided into eight series of impact pulses corresponding to eight directions. The device was tested to assess the sensitivity of participant to each direction at the same voltage amplitude. In this primary test, the voltage was set to the basic voltage from the battery which is 3.3V. The circuit was designed and fabricated successfully, as given in Figure 9.

In Figure 9, the battery is the thin round brown one that is connected to the yellow circuit. The blue circuit is the PIC microcontroller. The other parts are for converter and wireless communication circuits. The matrix of electrodes is linked to the circuit by the cable. All the components are almost small components. In the future the circuit will be packaged, minimized and folded up to fit into the orthodontic retainer for the blind to wear.

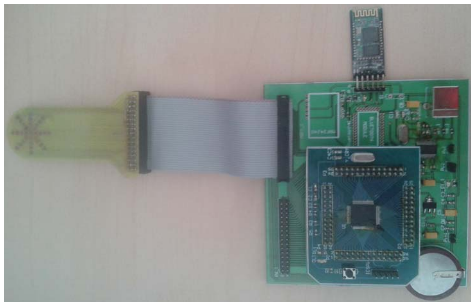


Figure 9. The control circuit of the TDU

In order to give electrical signal to the tongue, the circuit has to control the waveform of the pulse. Figure 10 shows the electrical waveform of this pulse.

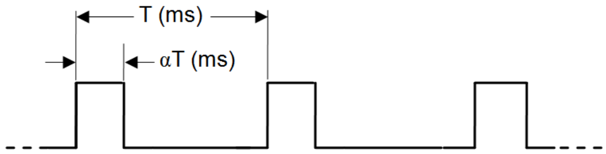


Figure 10. Electrical stimulation waveform

In Figure 10, active or ON electrodes are delivered electrical burst which last T period of time. Each active electrode receives burst of αT pulse. The current and voltage were the same for all ON electrodes. Inactive of OFF electrodes are open circuits. For all four test subjects, different values of T and α were tested. Four young healthy individuals voluntarily participate in this test. The sensitivity of their tongues for these parameters is given in Table 1.

TABLE I. TEST RESULTS OF ALL PARTICIPANTS FOR DIFFERENT VALUES OF STIMULATION BURST AND PULSE

0 - Weak; 1 - Clear and good; 2 - Strong

T (ms)	α	Participant			
		A	B	C	D
100	0.2	1	1	0	1
	0.5	2	2	1	2
	0.8	2	2	2	2
500	0.2	2	2	1	2
	0.5	2	2	2	2
	0.8	2	2	2	2
1000	0.2	2	2	1	2
	0.5	2	2	2	2
	0.8	2	2	2	2

The number 0, 1, 2 in Table 1 assess the level of feeling when the tongue received each burst of electrical stimulation. According to Table 1, the feeling of the tongue of different people is sometimes different but for T = 100 ms and $\alpha = 0.2$ gives the best results. The longer period of burst and pulse give so strong impact that some of the test participants can mistake between two bursts and the pulses could not be discriminate clearly. With this value of such burst, all of the participants were required to take part in the training within two hours. The training session consists of two steps: (1) to learn preset directions in order to know which places on the tongue corresponds to which direction; and (2) step was to check how each participant felt on the tongue and how exactly he/she could distinguish one direction to the others. Each participant had to carry the matrix of electrodes in the mouth in a way that the electrode surface was in contact with the dorsal part of the tongue. Each participant was individually tested and had no information about this test in advance or from the others. After around two hours of training, the test results for all participants are shown as in Table 2.

TABLE II. TEST RESULTS OF ALL PARTICIPANTS AFTER ONE AND A HALF HOUR OF TRAINING

Participant							
A		B		C		D	
Input	**Output**	Input	**Output**	Input	**Output**	Input	**Output**
4	**4**	8	**8**	5	**5**	1	**1**
5	**7**	4	**4**	7	**0**	2	**2**
2	**2**	6	**6**	4	**4**	3	**3**
1	**1**	5	**7**	5	**6**	4	**4**
7	**0**	8	**5**	2	**2**	5	**1**
3	**3**	7	**0**	3	**3**	6	**6**
8	**8**	6	**8**	4	**4**	7	**2**
2	**2**	5	**5**	5	**5**	8	**0**
6	**6**	4	**4**	1	**1**	4	**4**
1	**1**	2	**2**	5	**5**	3	**3**
5	**5**	1	**1**	2	**2**	2	**2**
4	**4**	3	**3**	7	**0**	5	**1**
3	**3**	4	**4**	4	**4**	6	**6**
7	**0**	8	**8**	1	**1**	1	**1**
2	**2**	6	**8**	6	**3**	4	**4**
5	**5**	5	**5**	3	**3**	5	**1**
8	**0**	1	**1**	2	**2**	2	**2**
4	**4**	2	**2**	4	**4**	3	**3**
1	**1**	3	**3**	6	**3**	8	**2**
2	**2**	5	**5**	5	**6**	5	**5**
5	**5**	6	**8**	4	**4**	4	**4**
7	**2**	4	**4**	7	**0**	3	**3**
3	**3**	1	**1**	8	**0**	7	**7**
6	**3**	2	**2**	3	**3**	2	**2**
1	**1**	6	**6**	4	**4**	6	**3**
3	**3**	3	**3**	1	**1**	4	**4**
8	**8**	4	**4**	2	**2**	5	**5**
2	**2**	5	**7**	3	**3**	8	**8**
4	**4**	6	**6**	8	**0**	1	**1**
6	**3**	7	**0**	6	**6**	7	**0**
7	**0**	8	**8**	4	**4**	3	**3**
5	**1**	5	**5**	5	**5**	5	**7**

In Table 2, the Input column shows the set values which were given arbitrarily to the participant. All the values from 1 to 8 stand for eight directions which are illustrated in Figure 7. The Output column recorded the responding values of the participant when the set values were given. All the numbers 0 to 8 correspond to the feeling on the dorsal part of the tongue: 0 means no feeling; 1, 2, 3, 4 means there is feeling on the front, rear, right and left region of the tongue; 5, 6, 7, 8 means there is feeling on the left rear, right rear, left front, right front region of the tongue.

A. Participant 1

The total time of training for this participant, a woman at the age of twenties, was two hours. For the first duration of forty five minutes, the participant receives one series of stimulation signal of all directions. After that, she could learn and know exactly the four main directions (1, 2, 3, and 4). After one hour and a half, the participant was given arbitrary instructions and was asked to tell the directions. The result demonstrates that the four main directions (straight forward, left, right, and backward) could be easily perceived but the other sub−directions (5, 6, 7, and 8) were mistaken with the main directions. The right part of the tongue could have much better feeling than the left one. Moreover, in the edge parts to the left, right and front, the sensation seemed much clearer than in the inner parts. At one side of the tongue (left or right), the perceived level of the tongue was decreasing as follows: 8 → 3 → 6. The direction 6 is not sensed properly and could be easily mistaken with the direction 3. The direction 7 could be hardly felt. The direction 5 could sometimes be perceived properly but in general it could be mistaken with direction 1 or 7. It was noted from participant 1 that at this intensity of voltage, it was extremely difficult to perceive all directions and to discriminate adjacent directions.

B. Participant 2

The total time of training was one hour and a half. This participant was a girl at the age of twenty. She felt that the voltage level was bearable. After half an hour of training, the four main directions (1, 2, 3 and 4) could be recognized precisely and differentiate between the directions 5 and 6; however, these two directions were mistaken with the directions 7 and 8. When the directions 7 and 8 were stimulated, the signal could be perceived very weakly. According to the result of the test for participant 2 in Table 1, the directions 1, 2, 3 and 4 were almost sensed exactly. Meanwhile the directions 5 and 6 were sensed correctly that they were in the left or right orientations but at times, these directions could be mistaken between the front and the rear orientations. The direction 7 was hardly felt. In the direction 8, the electrical pulse on the tongue was poorly received; only left and right orientations were sensed a bit more clearly. The half front part of the tongue gave stronger perception than the half rear one. It was proposed by this participant that the software program should be improved to gives better tactile sensation on the forward and backward orientations.

C. Participant 3

The training was designated to a man at the age of twenties. It took also one and a half hour for the training and test. After ten minutes of trying all the directions from 1 to 8, the user could know that there were different directions on the tongue but could not figure out which direction was. After twenty minutes, he started to feel the four main directions 1, 2, 3 and 4 but not so sharply. After thirty minutes, all these main directions were perceived clearly and correctly. After one and a half hour of training, he feels that the half front part gave the stronger feeling than the half rear part. Directions 7 and 8 were difficult to distinguish; besides, the pulse was very weak. Direction 5 was frequently recognized, only a few times it was confused with direction 4. For the tester, direction 6 was sometimes mistaken with direction 3. In general, for all diagonal directions, the left and the right directions were realized. For all the diagonal directions, the forward and backward orientations were hard to achieve. After long time of continuous testing, the tongue could not feel the impulses as clearly as the first duration. The strongest feelings seemed to emerge after thirty minutes of training.

D. Participant 4

The last participant was a man over thirty years old. The test last for one hour and a half. During the first twenty minutes, user was trained with the automatic program to learn and remember all directions from 1 to 8. The next ten minutes was the time for him to learn again and perceive. After one and a half hour of training, the user was tested with arbitrary directions. The result is given in Table 1. It shows that the participant could realize left and right orientations of the main and diagonal directions whereas the forward and backward orientation was hard to recognize. Moreover, the front part of the tongue was more sensitive than the rear one.

The mistakes were made between directions 5, 6 and direction 1, between directions 7, 8 and direction 2.

At 3.3V stimulation pulses, the signal on the rear inner part was less well perceived. It was proposed by the participant that the voltage should be raised to 5V. The distance between electrodes was too small that sporadically the first and last impulses of one series of electrode impulses were perceived but the others were not.

V. DISCUSSION

All the participants had positive feedback on the test and they believe in the promise of a complete system which can function well for assisting the blind. All the testers were very eager to take part in the test and found that the system was very helpful and enjoyable. Excluding participant 1, the average training and testing time is one hour and a half. After this continuous training, one of them felt that the feeling on the tongue is decreasing. That can result in a problem of usage time limit which is the longest duration that human tongue can endure. All of the testers, after a short time of training (thirty to forty five minutes), can recognize correctly the four main directions (1, 2, 3 and 4). The edge of the tongue seems to be the more effective parts than the inner part of the tongue. However, the size of the edge surface that can generate good perception is unknown. This should be calculated and tested to design the form and size of the circuit electrode in a way that gives the most efficiency. Most notably, each participant has different feelings on the diagonal directions. Figure 11 shows the ratio of recognition on each direction in total stimulation on the tongue. All main directions (1, 2, 3, and 4) get 100% of recognition. Direction 7 is hard to feel, with only 10% of right realization. All three directions (5, 6, and 8) only can get approximately 50% of right recognition.

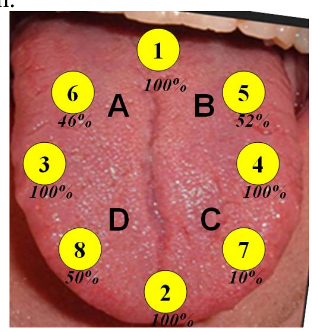


Figure 11. Percentage of feeling of all directions on the tongue

VI. CONCLUSION AND FUTURE WORK

A proposed electrotactile display with new form of electrode grid was presented in this paper. A demonstrator of it was successfully designed and fabricated. The sensitivity of human tongue on the period of burst and pulse was carefully tested. A set of tests on sighted people was conducted in order to investigate the perception of different directions. To some extent, the testers can distinguish most of them. However, the voltage level is not high enough to have proper stimulation; therefore, it is strongly appreciated by the testers to have various voltage levels for all users to be adapted. In a future study, the voltage range has to be first modifiable for the users. Then packaging such device for comfortable usage is necessary. Furthermore, the wireless communication has to be enhanced for using such device in all environments. An effort to make the system rechargeable is highly recommended. Besides, the image processing part that converts images into command has to be completed in the future. In the long run, the tests with real blind users should be conducted step by step to make the device really applicable.

VII. ACKNOWLEDGEMENT

The authors are very grateful to Antoine Gachone and Jean Marc Duchamp of IMEP-LAHC laboratory for successful fabrication of the circuit and useful comments in their practical experiment. The experiment would not be fully finished without the very kind and enthusiastic help of members of International Research Center MICA.

REFERENCES

[1] "WHO | Visual impairment and blindness." [Online]. Available: http://www.who.int/mediacentre/factsheets/fs282/en/.

[2] "Seeing the Facts about Blindness in Vietnam · Vietnam Talking Points." [Online]. Available: http://talk.onevietnam.org/seeing-the-facts-about-blindness-in-vietnam/.

[3] J. Faria, S. Lopes, H. Fernandes, P. Martins, and J. Barroso, "Electronic white cane for blind people navigation assistance," *World Automation Congress (WAC), 2010*, pp. 1–7, 19.

[4] A. Heyes, "A polaroid ultrasonic travel aid for the blind," *Journal of Visual Impairment and Blindness*, vol. 76, pp. 199–201, 1982.

[5] A. Kumar, R. Patra, M. Manjunatha, J. Mukhopadhyay, and A. K. Majumdar, "An electronic travel aid for navigation of visually impaired persons," *Communication Systems and Networks (COMSNETS), 2011 Third International Conference on*, pp. 1–5, 4.

[6] A. Marsh, M. May, and M. Saarelainen, "Pharos: coupling GSM and GPS-TALK technologies to provide orientation, navigation and location-based services for the blind," *Information Technology Applications in Biomedicine, 2000. Proceedings. 2000 IEEE EMBS International Conference on*, pp. 38–43, 2000.

[7] J. Wilson, B. N. Walker, J. Lindsay, C. Cambias, and F. Dellaert, "SWAN: System for Wearable Audio Navigation," *Wearable Computers, 2007 11th IEEE International Symposium on*, pp. 91–98, 11.

[8] H. Makino, I. Ishii, and M. Nakashizuka, "Development of navigation system for the blind using GPS and mobile phone combination," *Engineering in Medicine and Biology Society, 1996. Bridging Disciplines for Biomedicine. Proceedings of the 18th Annual International Conference of the IEEE*, vol. 2, pp. 506–507 vol.2, 31.

[9] H. Mori and M. Sano, "A guide dog robot Harunobu-5-following a person," *Intelligent Robots and Systems '91. 'Intelligence for Mechanical Systems, Proceedings IROS '91. IEEE/RSJ International Workshop on*, pp. 397–402 vol.1, 3.

[10] P. Bach-y-Rita, *Brain mechanisms in sensory substitution.* New York: Academic Press, 1972.

[11] P. Bach-y-Rita and K. A. Kaczmarek, "Tongue-Placed Tactile Output Device," 6430450.

[12] P. Bach-y-Rita, "Neurophysiological Basis of a Tactile Vision-Substitution System," *Man-Machine Systems, IEEE Transactions on*, vol. 11, no. 1, pp. 108–110, Mar. 1970.

[13] P. Bach-y-Rita, K. A. Kaczmarek, M. E. Tyler, and J. Garcia-Lara, "Form perception with a 49-point electrotactile stimulus array on the tongue: a technical note," *J Rehabil Res Dev*, vol. 35, no. 4, pp. 427–430, Oct. 1998.

[14] N. Vuillerme, N. Pinsault, O. Chenu, A. Fleury, Y. Payan, and J. Demongeot, "A wireless embedded tongue tactile biofeedback system for balance control," *Pervasive and Mobile Computing*, vol. 5, no. 3, pp. 268–275, Jun. 2009.

[15] F. Robineau, N. Vuillerme, O. Jean-Pierre, and P. Yohan, "Tongue Liminary Threshold Identification to Electrotactile Stimulation," in *4th International Conference on Enactive Interfaces ENACTIVE'07*, Grenoble, France, 2007, pp. 233–236.

[16] N. Vuillerme, O. Chenu, N. Pinsault, A. Moreau-Gaudry, A. Fleury, J. Demongeot, and Y. Payan, "Pressure sensor-based tongue-placed electrotactile biofeedback for balance improvement - Biomedical application to prevent pressure sores formation and falls," *Engineering in Medicine and Biology Society, 2007. EMBS 2007. 29th Annual International Conference of the IEEE*, pp. 6113–6116, 22.

[17] T. H. Nguyen, T. L. Le, T. T. H. Tran, N. Vuillerme, and T. P. Vuong, "Antenna Design for Tongue electrotactile assistive device for the blind and visually-impaired," *Antennas and Propagation (EuCAP), 2013 7th European Conference on*, pp. 1183–1186, 8.