

2013 International Conference on Control, Automation and Information Sciences (ICCAIS)

Following the success of **ICCAIS 2012**, the [Institute of Applied Mechanics and Informatics, Vietnam Academy of Science and Technology](#) is proud to host the Second International Conference on Control, Automation and Information Sciences (ICCAIS 2013) from November 25-28, 2013, co-organized by [University of Information Technology, Vietnam National University at Ho Chi Minh City](#). ICCAIS 2013 (**IEEE Conf. No. 31270**), technically co-sponsored by the **IEEE Vietnam Section**, will be held at the beautiful beach front city of Nha Trang (the most popular tourist destination in Vietnam), Vietnam. This conference provides a forum for regional and international researchers, engineers and practitioners to get together, discuss and present relevant achievements, challenges, innovation as well as future direction in control, automation and information sciences research and practice.



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A Wearable Assistive Device for the Blind Using Tongue-Placed Electrotactile Display: Design and Verification

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Abstract – Various assistive devices have been developed intensively in order to help and guide blind people. Thanks to the experimental paradigm of sensory substitution, the blind people are able to “sense” the environment by one of these devices which are called Tongue-Placed Electrotactile Display (TED). It plays a key role as a man-machine interface that brings the environment information to the brain in place of the deceased sense organ. In this paper, a proposed design of the TED which is located within the human mouth is introduced. Then the performance of the TED is validated via tests with ordinary people at the safety intensity of electrical voltage and current. The results show that such device can totally function inside the mouth and can be a potential wearable aid device. This research shows a promise of a new prosthetic which may result in the improvement in the living quality for the disabled community.

Index Terms—assistive devices; sensory substitution; man-machine interaction; blind mobility; wearable devices and systems

I. INTRODUCTION

According to the Global data recorded in 2010 by the World Health Organization (WHO), there have been 285 million visually-impaired people, in which 40 million people are totally blind [1]. The Vietnam Institute of Ophthalmology (VNIO) reported that in 2007 up to 380,000 people are blind whereas 1.6 million have vision problems [2]. The lack of sight causes a variety of problems in daily life such as mobility, navigation, environment accessibility and interaction.

Assistive technologies for the blind have been so far studied and developed extensively to compensate the deficit that the blind have to deal with and to increase their autonomy and quality of life. Some of the systems have been designed to help them navigate such as Guide Cane [3], Sonic Guide [4], GPS System [5] or Guide Robot Dog [6]. However, the above systems appear to be rather bulky and furthermore, they make use of other sense organs i.e. hands or ears while all these organs are necessary for the blind to

keep security and preferred to be used for other tasks. Hence, a demand for a compact, lightweight and wearable device or system is an interesting matter not only for the blind people, but also for all people with disabilities.

In 1972, Professor Paul Bach-y-Rita conducted an intensive study on the theory called “Brain plasticity” [7]. It is the ability of the central nervous system to reorganize its organization and functioning. For the handicapped people, it refers to adaptive capacity of the brain towards functional demand despite they have malfunctioned organisms. The definition of sensory substitution emerged due to the plasticity in the brain. This can happens across sensory systems (touch to sight) or in one sensory system (touch to touch). The most famous sensory substitution system is the Braille. Instead of reading, the content presented in words can be achieved via the fingertips. Since then, there have been multiple systems developed based on this principle to assist the disabled people.

For the blind, in place of perceiving image through the retina, man-machine interface devices and systems can act as an artificial receptor to couple the environment information to the brain. Typical examples can be taken into accounts are sound sensor systems, balance systems or skin sensor systems [8].

The wearable and lightweight characteristics draw most of our interest. Several parts of the body, i.e. back, abdomen, thigh, wrist, arm, finger or tongue have been researched to transmit the visual information to the blind [9]. In 1998, the Tongue Display Unit (TDU) was first introduced by the group of Bach-y-Rita [10]. It conveys the visual information by electrical stimulation on the tongue with an array of electrodes. Through the touch receptors on the tongue, a small current is passed to send optical translated signal to the brain via different paths. Finally, the blind user has to be trained to interpret the send touching signals. In the light of the TDU idea, a device called BrainPort Vision was developed to help blind people to navigate around obstacles [11]. Vuillerme et al. [12] at University of Joseph Fourier

(France) developed a matrix of 6x6 electrodes on the tongue for proprioception and balance improvement.

It seems that the tongue has the most potential over the other parts of the skin firstly because it can be worn due to the advanced technology of the dentistry. The artificial jaw that is easily put on or taken off can be the base to locate the device. Secondly, the mouth has a liquid environment; in case of using electrical stimulation, the device does not need much energy to activate the stimulation. Thirdly, the device does not make use of the ear like in auditory sensory substitution systems. Consequently the ear is still available to use to get more information, especially in case of dealing with dangers.

Based on the idea on the TDU of Bach-y-Rita [10] and the device of Vuillerme et al. [12], the overall system of our project is displayed on Figure 1.

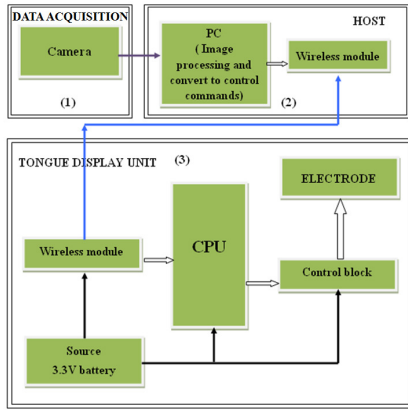


Figure 1. Schematic diagram of the overall TED system

The main idea of the TED system is to aid blind people by translating visual information into tactile display. The video information is recorded by a Bluetooth camera which is mounted on the glasses of the blind person and then sent to a host computer wirelessly. In the host computer, a computer program conducts the image processing to transform all video images into the understandable information for the blind. This converted information is, in the next step, sent wirelessly to the TED device which is placed inside the mouth and consists of the matrix of electrodes. In the TED device, the information received from the host computer is translated into the command to activate certain electrodes. At each electrode, an appropriate voltage is applied to tingle the tissue. As the blind users turn the camera when they move, different series of electrodes are activated to guide the blind. The test in this paper will show one example of how the electrodes are used to guide blindfolded people to different directions. As indicated in Figure 1, our system is composed of three distinct parts:

(1) Data acquisition: the user can wear a pair of sun-glasses which includes a camera capturing images from the environment. These images are sent continuously to the Host system.

(2) Host system: the computer translates sequences of images into a pattern of command and then sends wirelessly to the TDU.

(3) TED: Central Processing Unit (CPU) converts the command to electronic impulses that will be sent to an array

of electrodes placed in contact with the tongue. The TED contains five functioning blocks: (1) a battery providing energy to all the components, (2) a CPU processing the command signal into an encoded signal, (3) a control block processing the encoded signal to pulse to be sent to the electrodes and (4) the wireless module that receives the wireless signal from the camera; (5) an array of electrodes is around 2.5 square millimeters that stimulates the receptor cells on the surface of the tongue to the brain.

In this paper, a demonstrator of the device inside the mouth is designed with the research aim of evaluating the possibility and the feasibility of using a round-form matrix of electrode which has never been tried before. This round matrix of electrode was made to conform to the mouth. Such form of electrode will be later integrated into a future complete Tongue-Placed Electrotactile device which will be made to be a compact wireless device and worn like a dental orthodontic appliance. The design of the demonstrator will be described in more details in the second part of this paper.

Whatever the form of the matrix of electrodes is, the feeling of the tongue on the TED has to be clear. In order to verify the performance of this form of electrode matrix, a test with the tongue on the directions will be carried out. In this device demonstrator, the information about the direction which is given in advance is translated to tactile data. This tactile data is displayed by passing an electric current to the right spot on the surface of the tongue. The procedure and results of the test will be given in the third part.

The sensation of the device relies on all properties of the system such as electrode form and dimension, the current and voltage of stimulation and the stimulation waveform. In the fourth part, all these characteristics will be investigated thoroughly through the experimental results in order to have a complete understanding on the realistic interaction of the human tongue with the device. In the last part the future work and prospective will be drawn.

II. DESIGN OF THE TED DEVICE

In this paper, a demonstrator of the TED will be fabricated and verified. Because of the conductive characteristics of the saliva, the TDU requires an input voltage range from 5 to 15V [10]. Each electrode receives one pulse at a time. Due to such requirement, the block diagram of this TED device can be depicted in Figure 2.

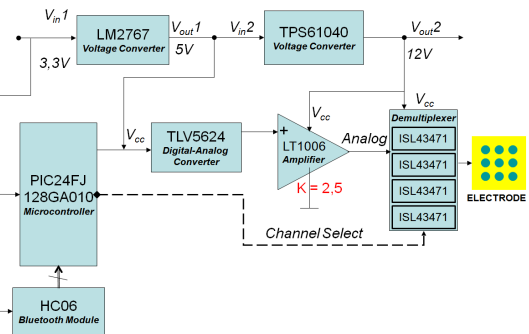


Figure 2. Schematic diagram of the TED device

In Figure 2, 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 [12] has ever made (Figure 3).

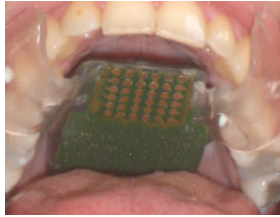


Figure 3. Prototype of a wireless 6x6 TDU in an orthodontic retainer [12]

In the following part, detailed descriptions of each block in the schematic diagram in Figure 2 will be indicated. In Figure 2, the names of all electronic components were indicated specifically.

a) Source (power supply)

For future design inside the mouth, the Lithium battery with diameter of 20mm and height of 3.2mm is used. A voltage of 3.3V and current of 135 mA is supplied.

b) Voltage Converter Circuits

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 12V. 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 4.

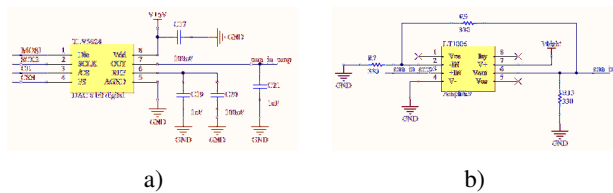


Figure 4. Schematic diagrams of: a) DAC block and b) Amplifier block

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. The detailed schematic diagram can be easily found in the datasheet of these two ICs. Besides these two converters, in order to have a range of 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.

c) 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 5).

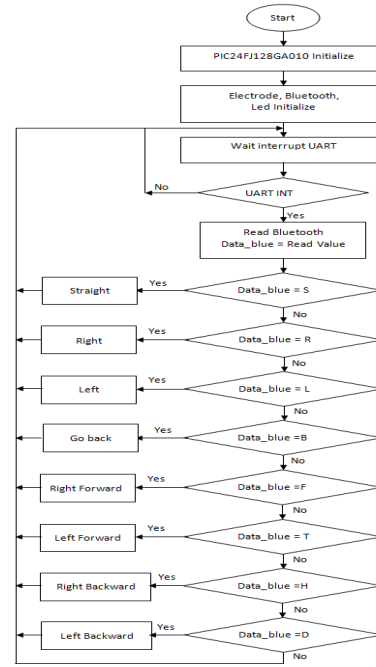


Figure 5. Flow chart of controlling algorithm for matrix of electrodes

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 Intersil 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.

d) Wireless communication block

From the host computer, the signal will be sent wirelessly to the tongue display unit. In order to make such wireless communication device, a Bluetooth module was created using 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 6 shows the antenna that was made in our group, which has recently been published in the Proceedings of European Conference on Antenna and Propagation [13].

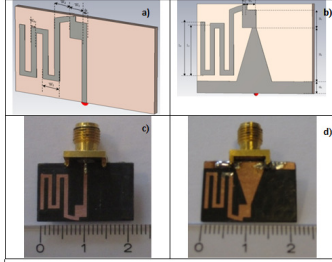


Figure 6. Dipole antenna for tongue-placed electro-tactile device: Design model for the antenna at the a) front and b) back; Fabricated antenna at the c) front and d) back

e) Matrix of electrodes

Based on the idea of groups of Professor Bach-y-Rita, Doctor Vuillermé, the electrode is worn on the dorsal part of the tongue. The number of electrode can be varied depending on the purpose of the usage, however, all matrix of electrodes were recorded to deposit on a squared plate while almost all applications are to provide information on direction/ motion. As a result, our group proposed a new design for the matrix of electrode - the round form in which electrodes are divided into different directions but not in the array like in square plate. In this way, navigation is easier since the direction information is translated directly to the tongue. Figure 7 shows the idea of our electrode design.

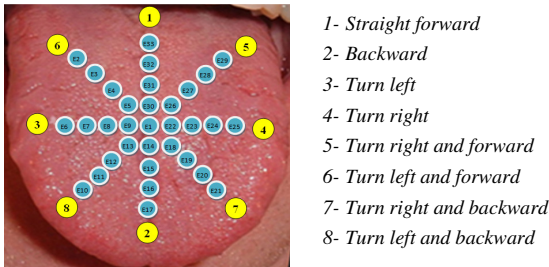


Figure 7. The representation of the directions of the matrix of electrodes on the tongue

When the matrix of electrodes was made, some characteristic parameter needs to be taken into account, i.e. the two-point discrimination threshold. It is the minimum distance which two adjacent stimuli can be distinguished. For the tongue, it was recorded that 4mm is the smallest value. Figure 8 shows the design and real image of the fabricated electrode plate.

In order to check whether the design of electrode is suitable for the TED device, a simple fabrication was made using copper. In our real component, 3mm-diameter copper electrodes were made on a round matrix. The insulator gap is 1mm around each. With the tongue have the dimension of 4x4cm; a round matrix of 33 electrodes can be made.

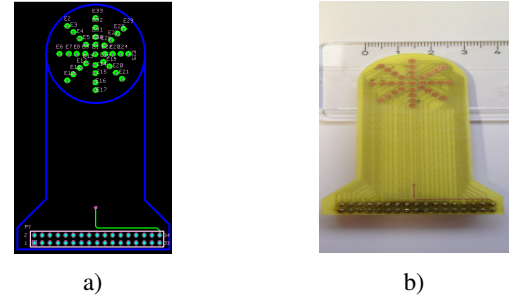


Figure 8. Round matrix of electrodes: a) in design; and b) in reality

In the long run, in our group, study on the material of the electrode is conducted in order to find the safe material for long term and practical use. Copper electrode after test was oxidized and could not have good stimulation and was toxic as well.

III. 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.

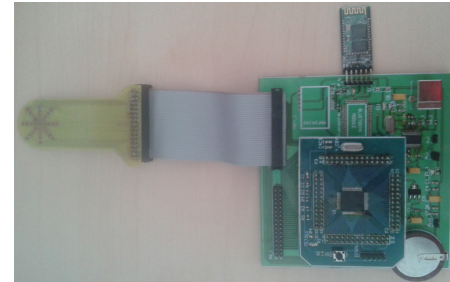


Figure 9. The control circuit of the TDU

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.

Four young healthy individuals voluntarily participate in the training within two hours. The training session consists of two steps: first step was to learn preset directions in order to know which places on the tongue corresponds to which direction; and the second 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 1.

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

Participant							
One		Two		Three		Four	
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		
1	1	6	6	4	4		
3	3	3	3	1	1		
8	8	4	4	2	2		
2	2	5	7	3	3		
4	4	6	6				
6	3	7	0				
7	0	8	8				
5	1						

In Table 1, 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 forty five minutes of training, this user 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 she perceived according to the above instruction. According to the description of the participant 1 in Table 1, the result turns out that the four main directions (straight forward, left, right, backward) could be easily perceived but the other sub-directions (5, 6, 7, 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 of the tongue in the left, right and front, the sensation seemed to be 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 could not be 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 for this user 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. After one hour of learning, the participant could differentiate between the directions 5 and 6, specifically the direction 5 was on the right orientation and the direction 6 was on the left orientation; 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 back 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. A conclusion of this participant was that 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, the test was finished and the result of participant 3 is shown in Table 1. Mostly, it was said by the participant 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. On the contrary, for all the diagonal directions, the forward and backward orientations were hard to achieve. After long time of continuous testing, due to the nonstop impact, 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 at the edge of the tongue was very well perceived while 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.

IV. 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 perhaps 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 10 shows the percentage of total recognition on each direction in total stimulation pulse on the tongue.

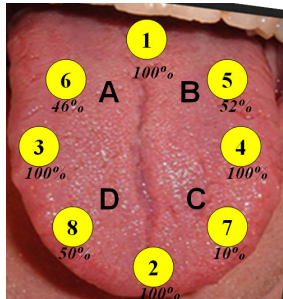


Figure 10. Percentage of feeling of all directions on the tongue

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.

V. CONCLUSION AND FUTURE WORK

A proposed electrotactile display device on the tongue was presented in this paper. A demonstrator of it was successfully designed and fabricated. The relationship between the electrical pulses and the human tongue was carefully tested. A set of tests on ordinary people was implemented in order to investigate how they can be trained to use the TED. To some extent, the testers can distinguish most of the directions. 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.

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