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HUMAN MACHINE INTERFACING VIA PERIPHERAL SENSORY NEURON STIMULATION

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Abstract— Electronics Travels Aids (ETAs) are electronic devices that are created to help the blind navigate their environment. To help the visually impaired people to navigate the environment, this paper seeks to address the following goals:

- ***Detect object in path of travel***
- ***Detect motion of object***
- ***Detect horizontal***
- ***Detect vertical location of object***
- ***Detect shape of object***

Brail Vision consists of a belt of vibro-motor actuators which will be mounted to user's head, and an android phone as the processing unit and camera. The ETA was mainly developed to enable experimentation with the algorithm proposed which is described in detail in this paper. The proposed system managed to meet 80% of the targets.
The paper details how the proposed system was implemented and tested.

Keywords—Electronic Travel Aid (ETA), Tactual Feedback, Brail Vision, haptic feedback, binarization, brailing

I. INTRODUCTION

Computers are interfaced with the brain to achieve a number of the things but mainly to develop a system that allows disabled people to communicate with other persons and to interact with the external environments and in a number of ways. This can be a two-way communication between the brain and the computer or only one-way communication. In the case of devices that aid the blind, these devices are known as Electronic Travel Aids (ETAs). As stated in [1], "An Electronic Travel Aid (ETA) is a form of assistive technology having the purpose of enhancing mobility for the blind pedestrian. Perhaps the most widely known device is the Laser Cane, which is a regular long cane with a built-in laser ranging system".

This paper will produce an ETA that uses tactual feedback to educate the wearer of their environment. Tactual feedback can be categorized into the following:

Electro-tactile

According to [2], the concepts employed in electro-tactile stimulation for sensory substitution are complex but the general idea is to electrically stimulate the sense of touch to relay non- tactile information. Non-Tactile input sources such as microphone and camera send signals to the electrodes which in turn stimulate the user using small painless currents on specific locations on the skin following specific patterns.

These patterns are presented as they would have been in the non-functional sense. Dr. Kurt Kaczmarek stated that "After stimulation the electric field thus generated in subcutaneous tissue directly excites the afferent nerve fibers responsible for normal, mechanical touch sensations." Those neurons then relay their encoded sensory impulses to the brain's cerebral cortex, the parietal lobe.

One successful implementation of this methodology is in the BrainPort system. "BrainPort is a technology whereby sensory information can be sent to one's brain through an electrode array which sits atop the tongue." [3].

Haptic Feedback

Haptic feedback also known as Kinesthetic feedback uses the sense of touch and activates sensory neurons through vibrations, motions and forces applied to a certain body region [4]. The mechanical stimulation is used to augment virtual worlds and in the same manner used in ETAs to represent object in user's path.

The touch sense is related with three main types of systems which are to kinesthetic, haptic and cutaneous [5][6]. Tactual perception is all perceptions via cutaneous and/or kinesthetic. The sense of touch is either passive or active [7], and "haptic feedback" enables object recognition and communication through active touch [8]. One successful implementation of haptic feedback is in [9]. This project will use kinesthetic tactual feedback.

II. OBJECTIVES

The main objectives of this paper are:

- To develop an algorithm that will map real world data to an intermediate form used by hardware to stimulate sensory neurons which in turn will relay the data to the brain.
- To develop a device that will provide the blind with an "alternate vision".

Hypothesis

The proposition is to scan pictorial data line by line, top to bottom, mapping pixels that correspond to object in the current scan line to vibrations on a hardware device worn by a user on their head. Once the bottom of the pictorial data is reached, the scan will start over again from the top. The hardware has an array of haptic actuators which span across the forehead.

The assumptions are:

- User will be able to tell horizontal direction of object using the position of the active actuator.
- User will be able to tell the shape of object using activation patterns of the actuators.
- User will be able to detect motion of object from the change in actuator activation in a certain pattern.
- User will be able to tell vertical direction of object using the delay in between actuator activation in a certain pattern.

III. LITERATURE REVIEW

Tactile Handle

It was developed at the University of New Jersey by Bouzit and co-workers [10]. It is supposed to help the visually impaired in navigating their environment whether familiar or not. It has resolution of 4x4 and each actuator matches one finger phalanx. It has 4 sonar sensors, which detect obstacles in the front, left, right, and bottom. The location of the feedback on the fingers represent direction of the obstacle. The intensity represents distance of objects from user. The timing of the feedback represents speed of self or object. Lab reviews with blind folded users show that excessive training is necessary. The lab reviews also showed that the device can perform as an obstacle detection system. One advantage is that the prototype does not block the user's hearing. However, requires the user to constantly scan and use one of his/her hand.

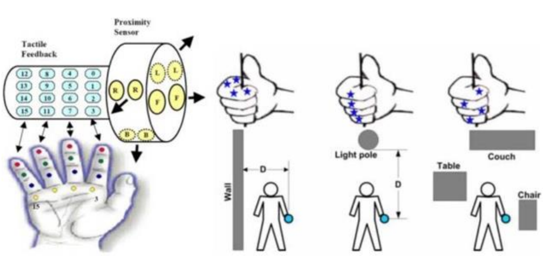

Fig. 1 : Visualization of the Tactile Hand

Tactile Vision System

Johnson and Higgins [11] had a vision of allowing blind people to navigate on their own without bumping into objects by creating an electronic travel aid that encoded visual input into a tactile signal. The system consists of portable computer, two web cameras and has a resolution of 14x1. Each of the 14 actuators is allocated a region in which the nearest object in the region is translated in a vibration as shown in (Fig. 3). Vibration frequency increases if object is clos. But very far and very close objects are ignored. The system video feed is 10 frames/s.

Advantages of TVS:

a) It is wearable
b) It gives user free hands
c) Does not block hearing
d) It operates in real time.

Disadvantages

a) It cannot differentiate between overhanging and ground obstacles.
b) No real experiments with visually impaired people have been performed

Fig.2 TVS prototype

Fig.3 Example of TVS operation: image from the two camera, disparity map, and the corresponding signals sent to the tactor belt.

University of Guelph Project

This is an inexpensive ETA made with off-the-shelf components. It was developed by Zele at the University of Guelph [12]. The prototype is made up of two stereo cameras, piezoelectric buzzers as the tactual actuators. It uses tactile or auditory feedback. As shown in Fig.4 each actuator is on a corresponding finger and there also is a portable controller computer. Each finger represents spatial direction as shown in Fig.4 bottom. For example, the middle finger corresponds to straight ahead. Each actuator corresponds to vertical splice in the depth image.

Advantages:

a) Low power
b) Wearable

Disadvantages:

a) The stereovision algorithm needs improvement

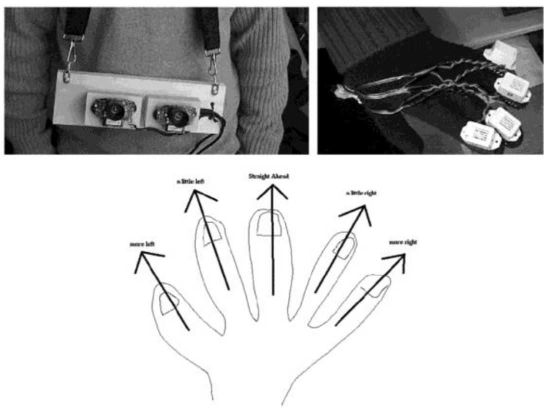

Fig.4 Prototype from the University of Guelph and the hand spatial correspondence

Summary

In Summary looking at all the above-mentioned implementations we can say they mainly provide object direction, distance from user and some environment details such as speed. The proposed system will also include all the functionality in the discussed implementations, and additional functions such as vertical displacement and object shape will be included. The system introduced in this paper will use a resolution of 40.

IV. DESIGN

The system has a modular approach. Two modules developed include

- **Image Processing Module**
- **Actuation Module**

Image Processing Module

a) Capture continuous image
b) Dynamically Binarize captured image
c) Scale the image to 40 x N
d) Turn image into multidimensional 'Brail array' (activation commands)
e) Relay data to Actuation module

Actuation Module

a) Uses data from the Image Processing module.
b) Activate the actuators mapping the multidimensional array in a line by line vertical tactual scan.

The modules mentioned above consist of Software and Hardware.

The Software

The software module was developed on top of the Android platform. It is in the form of an application that is installed on user's phone and communicates with the hardware via Bluetooth.

Solution Software Implementation

The system architecture components mentioned in the previous chapter be will explained below:

Binarization

The stage uses a modified Otsu binarization which has a user defined static bias added to the dynamic threshold deduced by the algorithm. Figures that follow shows the application actively binarizing an image stream.

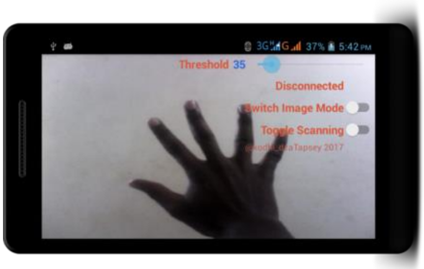

Fig. 5 Application User interface with camera viewport showing image

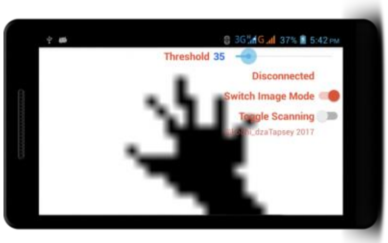

Fig. 6 Application User interface with camera viewport showing binarized image.

Brailing

From the binarized image each pixel is classified into either a timed activate command or a do-nothing command as shown below:

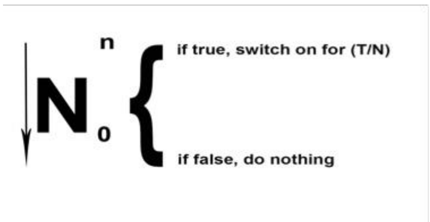

Fig. 7 Command Status

T=0.2 seconds N=number of horizontal lines in image

Actuation command streaming

The proposition is to scan pictorial data line by line, top to bottom, mapping pixels that correspond to object in the current scan line to vibrations on a hardware device worn by a user on their head. Once the bottom of the pictorial data is reached the scan will start over again from the top. The steps of the algorithm are as follows:

The algorithm takes in an N by L multi-dimension array of actuation commands. The hardware which works with the algorithm has an array of field actuators and one or two indicator actuators.

The Actuation algorithm

Steps:

1. Initialize I (row position) to 1.
2. Initialize N (number of rows) to input array height.
3. Compute M (mean switching time) using 0.2 seconds divided by N.
4. Scan out row I from the input array to the field actuators.
5. Wait for mean time M.
6. Increment I by 1.
7. Check if I is equal to N.
8. Repeat 4 to 7 until I is equal to N.
9. Scan out an activation command to indicator actuators.
10. Wait for mean time M.
11. Set I to 1.
12. Start all over from 4.

The pseudo code

Steps:

Begin

1.INT I = 1;

2.INT N = commands_length;

3.DECIMAL M = N/0.2;

4.**While** I !=N **do**

5.Scan_out_* field(commnds[]);*

6.sleep_for(M);

7.I= I+1;

8.*END WHILE;*

9.*Send_Results(Cp)*;

10. End While

11. Scan_out_* indicator(commnds[]);*

12. sleep_for(M);

13. I=1;

14. **Go to 5**

The Hardware

Here on we will do an in-depth analysis of hardware implementation. The hardware core components are briefly summarized below.

Android mobile device

Android device API 17 was used.

Coin Vibration Motors

These are a special type of eccentric rotating mass (ERM) vibration motor. They integrate into many designs because they have no external moving parts. These were used as the actuators in the system.

Fig. 8 Coin Vibration Motors

IOIO-OTG

This PCB board allows input and output from an android device or computer java programs. It is used to output signal from the android device.

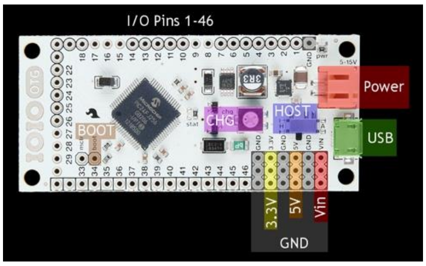

Fig. 9 IOIO-OTG board

Partial Circuit

The common emitter configuration was used in the switching layer in the hardware.

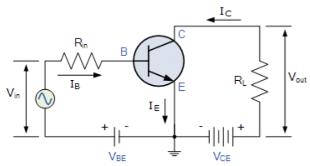

Fig. 10 Common Emitter Amplifier circuit

Solution Hardware Implementation

The Control Unit

It consists of an android phone and an IOIO-otg board. The android phone captures the input images and pre-processes them as described before into commands sent to the IOIO-OTG which then produces a signal as the output of the switching layer.

The Switching Layer

It consists of an array of transistors in common-emitter configuration (switching mode) which amplify the input signal and send actuation power to the actuators in the actuation layer.

The Actuation Layer

Consists of an array of actuators which will turn on and off corresponding to the actuation signal. Following is an image of annotated headset:

Fig. 11 Annotated headset, part the control unit is a circuit behind the phone

V. TESTING AND RESULTS

TABLE I
NARRATION OF TEST CONDUCTED

Test	Narration of Blinded candidate responses	Narration of Control candidate responses
Introduce an object into the field of vision and ask the candidates if they feel anything was introduced into the field of vision	100% where able to identify the introduction of an object into the field	correctly identified the introduction of an object into the field 100% of the times
Ask the candidates point at the object's direction, evaluate horizontal correctness	98% correctly pointed in the correct horizontal direction	correctly pointed in the correct horizontal direction 100% of the times
Move object horizontally through the field of vision and ask the candidates to track it by continuously turning their heads horizontally to face it.	96% correctly tracked the object.	correctly tracked the object 100% of the times
Ask the candidates point at the object's direction, evaluate vertical correctness	30% correctly pointed in the correct vertical direction	correctly pointed in the correct vertical direction 100% of the times
Move object vertically through the field of vision and ask the candidates to track it by continuously turning their heads horizontally to face it.	10% correctly tracked the object.	correctly tracked the object 100% of the times
Introduce big objects of different shapes in turn tell the candidates their names. Now repeat the introduction of the objects in turn asking the candidates to tell you their names.	27% correctly identified and differentiated among two shapes.	correctly identified and differentiated among two shapes 100% of the times

As shown above there is solid success in some aspects of the algorithm, but these are already effectively done well by other algorithms. The dimensions of data the algorithm is trying to introduce show low partial success.

Analysis of proposed system.

The proposed Brail Vision was supposed to meet the following targets:

1. Object detection
2. Real time object motion tracking
3. Vertical object positioning
4. Horizontal object positioning
5. Object shape details

However, it managed to meet 1,2 and 4 fully and 3 and 5 partially. Which is roughly 80% success. The limitation of the results is mainly due to the imprecision of the actuators used. The market simply does not have affordable actuators with required precision. The partial success by the developed implementation of the hypothesised algorithm show a chance that the algorithm actually works, the researcher highlights improvement on hardware implementation rather than the algorithm. Tactual ETAs are amongst the cheapest ETAs and this research showed promise in adding depth (vertical displacement information and shape of object) to the feedback they give to the user which is very valuable to the field and novel.

This research brings the possibility of high resolutions tactual ETAs as long as the actuators allow the resolution can be increased maybe to the thousands and limitless feedback dimensions as feedback is represented in an abstract manner, e.g direction is not represented by a specific actuator but rather by the general behaviour of all actuators and it is the user who is left to make the conclusion. However, the research is high dependant on the actuators used with the system which limits effective results.

Besides being applied to actual ETAs for the blind the representation generated by the algorithm can be used internal representation of the environment by self-navigating robots.

VI. FUTURE WORK

When designing a Kinaesthetic Electronic Travel Aid the actuators are a key component, great care must be taken to choose the right ones.

- There is need for development of specialized actuators as off the shelf actuators fail to deliver because they have slow switching and generate excessive but not precise vibrations.
- More research effort should be made on making electro tactual actuators cheaper and easily applicable to exo-skin, as these are more precise.
- Actuators need to be in Nano dimension hence the need for continued research into piezo- actuators.

This experiment carried out with the device developed in this paper must be carried out again in the futures with more precise actuators and the results compared with the ones produced above to better evaluate the algorithm.

VII. CONCLUSION

The experimental results in this paper showed that not only do the success of an ETA depend on a good algorithm but also specialized hardware. Although the research managed to have an 80% success rate it could improve in accuracy if better and improved actuators had been used.

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