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New Ergonomic Headset for Tongue-Drive System with Wireless Smartphone Interface

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***Abstract*— Tongue Drive System (TDS) is a wireless tongue-operated assistive technology (AT), developed for people with severe physical disabilities to control their environment using their tongue motion. We have developed a new ergonomic headset for the TDS with a user-friendly smartphone interface, through which users will be able to wirelessly control various devices, access computers, and drive wheelchairs. This headset design is expected to act as a flexible and multifunctional communication interface for the TDS and improve its usability, accessibility, aesthetics, and convenience for the end users.**

I. Introduction

Tongue Drive System (TDS) is a wireless assistive technology that enables its users to control their environments by utilizing their volitional tongue movements inside their mouth. This system can wirelessly detect the position of a small permanent magnetic tracer, secured on the tongue via adhesives or piercing, to translate different tongue positions and gestures into a set of specific user-defined tongue commands [1]. Reports on the TDS electronic hardware, signal processing, and effectiveness in controlling users' environments, accessing computers, and driving wheelchairs can be found in our previous publications [2]-[4].

We have successfully proven the TDS functionality in several experiments involving able-bodied subjects as well as clinical trials by people with high-level spinal cord injury (SCI) [3], [4]. We evaluated the system for accessing computers effectively in terms of its human factors [5]. TDS as a computer input device has several advantages compared to other assistive technologies, such as sip and puff, eye trackers, head pointers, electromyography (EMG) switches, and voice controllers [6]. However, we observed the need for improving the TDS in terms of its appearance, comfort, ease of don and doff, and its ergonomic factors for the people with disabilities in actual usage. Users were understandably not quite satisfied with the appearance of the early prototypes because they were either built on commercially available industrial safety headgears or large headphones (see Fig. 1). In fact, research shows that appearance is one of the important factors that affect the acceptability of the new ATs by their potential end users [7], [8]. In addition, the headphones were not quite stable on the head and the headgears were not comfortable enough either because the headband constantly applied pressure to or the size adjustment knob on the back hindered leaning the head against the wheelchair headrest.

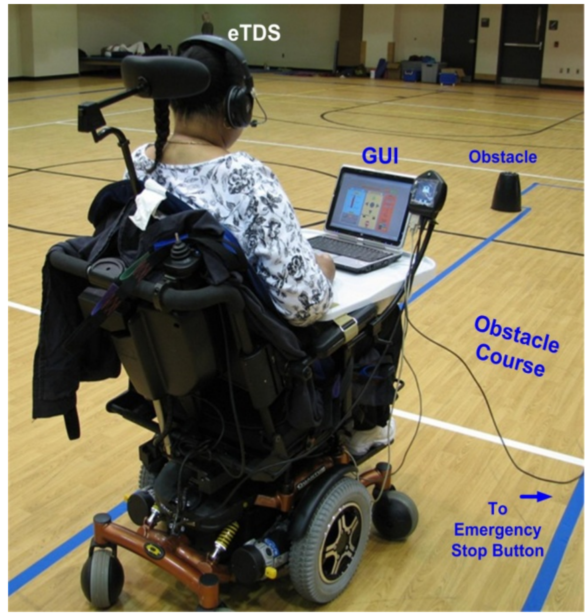

Fig. 1. A subject with SCI at C4 wearing the TDS prototype to navigate a wheelchair through an obstacle course [4].

TDS users also needed a smaller, lighter, and more portable platform than laptops on their wheelchairs. Previously, users needed to place the laptop, which was responsible for receiving the magnetic signals, processing them, and showing the selected tongue commands and other items on the special graphical user interface (GUI) on their lap tray. However, placing laptops with open lids in front of users while driving wheelchairs (see Fig. 1), can limit their field of view and partially block the path in front of them, causing potential safety issues in uncontrolled environments. In addition, the operation time of the TDS was limited by the capacity of the laptop battery to only a few hours, unless the wheelchair battery was tapped, which could create more hassle.

II. Design objective

To make the TDS more usable, we designed a fashionable outlook for the TDS headset such that the users willingly accept it as a daily tool. Also, we improved the mechanical design of the headset by adding to its adjustability as an ergonomic headset, which could enhance the user comfort while wearing it. Finally, we chose iPhone® as one of the most popular smartphone platforms and developed a user

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TABLE I
HEADSET DESIGN QUESTIONS AND ANSWERS

Criterion	Questions	Answers
Appearance	How to improve the headset appearance?	Hide all the electronics behind the ear, to look like an advanced audio headset
Comfort	How to make TDS comfortable to wear?	Adjustable headband, flexible arc, and U-shaped ear-rests
Performance	How to maximize TDS sensitivity to tongue motion?	Adjustable sensor positions and increasing their number from 2 to 4
Operating time	How to extend the headset operating time with a limited battery capacity?	Low-power microcontroller and wireless transceiver, duty-cycling the sensor operation
Assembly	How to connect signals in a narrow path and enable easy assembly?	Using 10-wire flat flexible cable (FFC) for signals and crimp-style 5-wire cable for supply

friendly interface to allow users to utilize their phones (or iPod touch) as an easily accessible device to control their environments. The new TDS will ease the burden of carrying a laptop and enable its users to employ the same AT (i.e. TDS) for a variety of different tasks.

III. HEADSET DESIGN

In order to meet the requirements of a wearable and portable device, we considered these criteria in the new TDS headset design: 1) performance, 2) operating time, and 3) ease of assembly and repair, in addition to appearance and comfort, which were discussed earlier. Table 1 shows the questions we raised and the solutions we found in response to those questions for the new headset design.

Fig. 2 shows the resulting TDS headset, fabricated using stereo-lithography (SLA) rapid prototyping technology with Eden 250 (Objet, Billerica, MA) system. Building material was Fullcure 720™, which gave the headset a yellowish semi-transparent color. Trapezoid shaped enclosures hidden behind the ears on both sides contained electronics and a rechargeable battery.

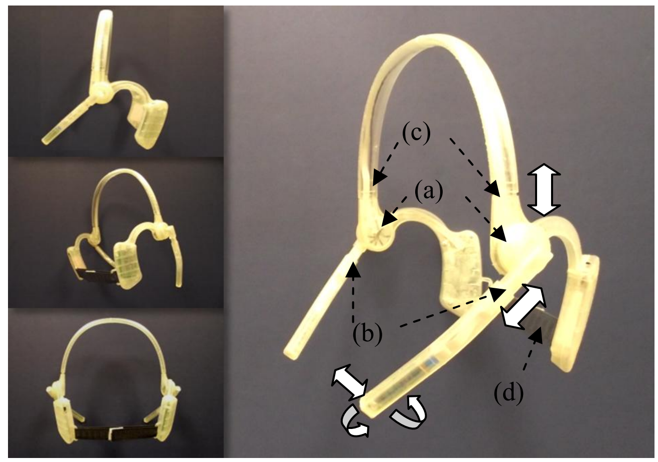

Fig. 2. Custom-designed TDS headset, build by rapid prototyping.

Fig. 3 shows detailed views of adjustable parts of the TDS headset. Fig. 3a is a ball and socket joint on top of the sensor poles allowing up to 60° rotation in all directions. Proper positioning of the poles and consequently the sensors is key in TDS performance as it affects the quality of the measured magnetic signal (SNR). Fig. 3b shows the structure which enables the pole length adjustment. Fig. 3c shows the part that adjusts the size of the arc over the head. Fig. 3d shows the adjustable headband which holds the headset from the backside of the head. Thanks to these flexibilities, one can adjust the position of the sensors to achieve the optimal performance from the TDS and also stabilize the headset on the user's head.

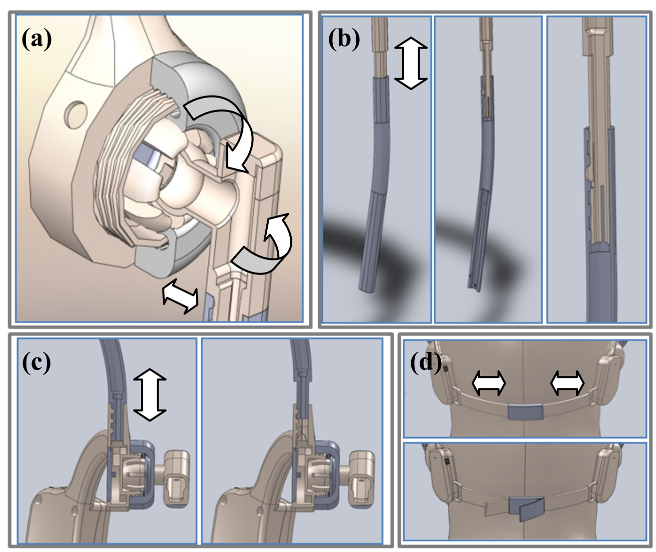

Fig. 3. 3-D rendering of the headset details.

Sensor boards, each containing two small 3-axial magnetic sensors and their signal conditioning circuitry, are placed at the tip of the two sensor poles and the rest of the electronics and battery are housed in the trapezoid enclosures. The wireless control unit is included in the right enclosure, and a 500 mAh, 3.7 V, Li-ion battery with charging and power management circuitry is placed in the left side. All of the electronic circuits were carefully designed in terms of their power consumption and the duty-cycling technique was employed to reduce the power consumption of the magnetic sensors. The average current consumption was about 5 mA, allowing the TDS headset to operate up to 100 hours with a fully charged battery.

Fig. 4 shows the headset assembly process. We used

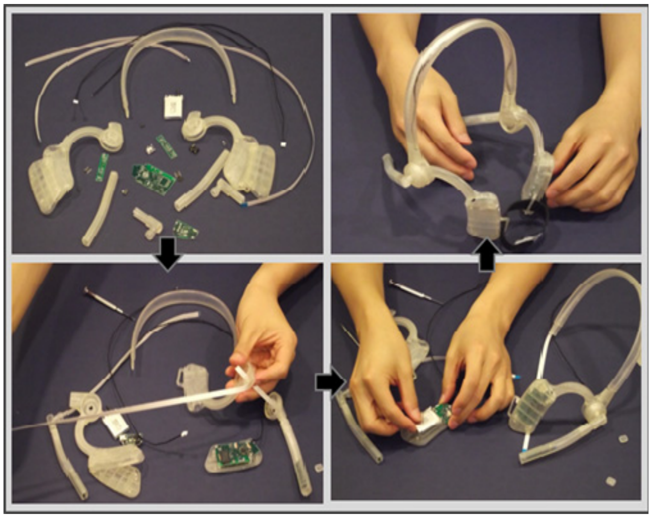

Fig. 4. Assembly process of the TDS headset

10-wire flat flexible cables (FFC) and crimp-style 5-wire cables to connect the sensors to the control unit and power management boards on the two sides of the headset. These types of cables are thin enough to pass through the poles and the arc on top of the TDS headset.

IV. TDS HEADSET FUNCTIONS AND APPLICATIONS

The TDS headset function is sensing and wirelessly transmitting the magnetic signals from around the mouth, where they change based on the tongue position. Fig. 5 shows the electronic modules inside the headset. TDS electronics are divided into three parts according to their functions: 1) control, 2) supply, and 3) sensor, and implemented on separate board. The control board controls every function in the headset. It manages the control of magnetic sensors including duty cycling, amplifies and digitizes the analog sensor signals, generates the data packet, and wirelessly transmits the data to the receiver. The supply board mainly deals with power management. It includes a battery charger, a low-battery monitor, and a regulator to provide a constant 3V supply to the other boards.

Each sensor board, placed inside the left and right pole has two 3-axial anisotropic magneto-resistive (AMR) sensors HMC1043 (Honeywell, Morristown, NJ). These two magnetic sensors are positioned at two edges of the sensor boards to sense the magnetic tracer's field at different angles and distances. The number of magnetic sensors was increased from 2 to 4 compared with the previous TDS headset in order to increase the dimensions of the acquired data set and track the tongue position more accurately [9]. This change can potentially enhance the TDS performance by allowing users to define more tongue commands.

In addition, we intend to include Bluetooth and audio functions in the new TDS headset to provide a bidirectional wireless voice transmission similar to a wireless headphone. As a result, TDS can be incorporated with speech recognition software, such as Dragon, and used as a multimodal tongue and voice controller [9]. Users will be able to select one of these two mechanisms for control depending on the task at hand and the environmental conditions.

Recently developed TDS-smartphone interface transfers the incoming signals from the headset to an iPhone through a wireless receiver dongle for further processing. This interface provides easy access to the smartphone itself as well as most applications that run on it [11]. Fig. 6 shows the new TDS headset and its smartphone interface connected to the powered wheelchair (PWC). The TDS-smartphone interface wirelessly acquires data from the magnetic sensors. In addition to processing the sensor signals, the iPhone software also provides a GUI for the user to easily perform various functions, such as making a phone call, sending a text message, playing a game, driving the PWC, and controlling networked home appliances.

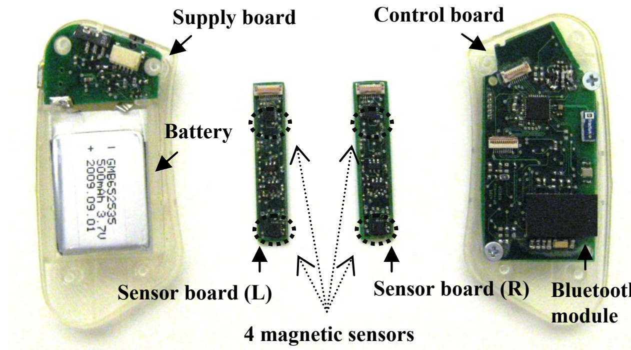

Fig. 5. Electronic circuits installed inside the TDS headset

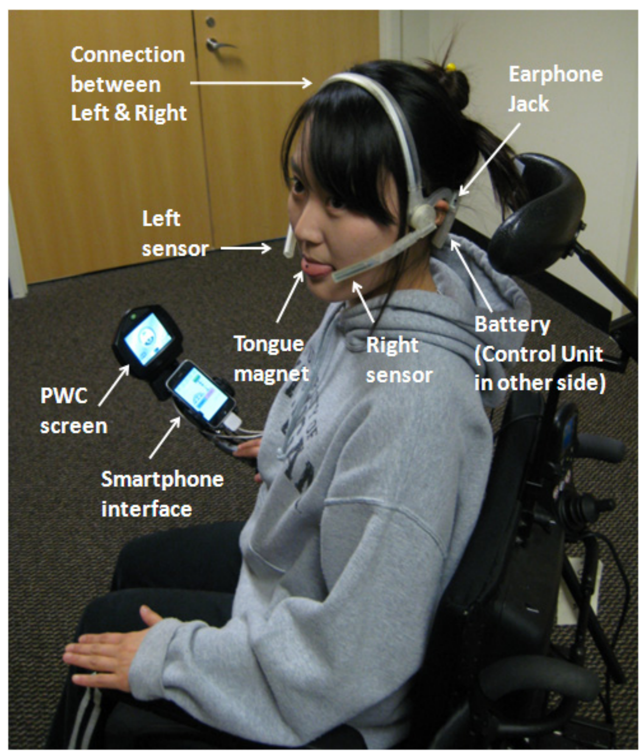

Fig. 6. TDS setup with iPhone for PWC control application.

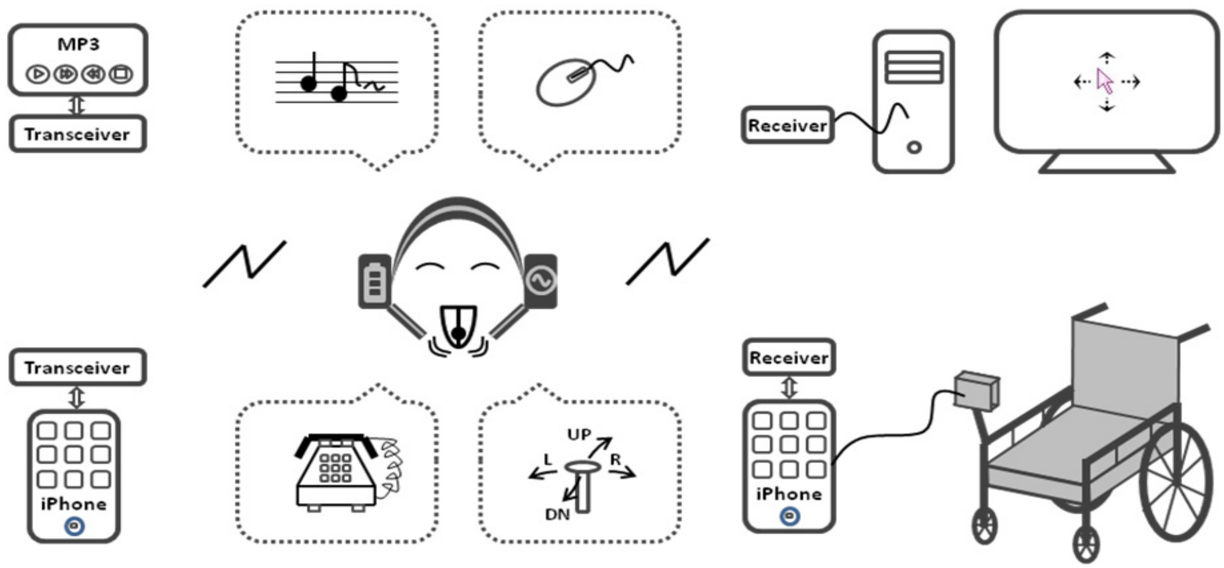

Fig. 7. Graphical depiction of various TDS applications.

The TDS-iPhone application has been developed in X-Code version 3.2.5 provided in the iPhone software development kit (SDK, Apple Inc, Cupertino, CA).

With the new headset and iPhone interface, TDS has become a truly wearable AT without imposing the burden of carrying a laptop on its end users. This should be an attractive feature because users can not only access every iPhone application, but also interact with any other device that can communicate with or controlled by the iPhone. Fig. 7 shows some of the possible applications of TDS from the computer mouse control to the wheelchair navigation. Unlike most other existing technologies, which are dedicated to one task or another, TDS users can perform several tasks without switching to different ATs.

V. Conclusion

We have improved the TDS appearance, comfort, and functionality by designing a new customized ergonomic headset. Moreover, we have developed a TDS-smartphone interface, which removes the burden of carrying a laptop to use TDS, and enables users to do conduct multiple tasks without switching from one AT to another.

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