Tongue Drive: A Tongue Operated Magnetic Sensor Based Wireless Assistive Technology for People with Severe Disabilities

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Abstract— **The "Tongue Drive" system is a tongue-operated assistive technology developed for people with severe disability to control their environment. The tongue is considered an excellent appendage in severely disabled people for operating an assistive device. Tongue Drive consists of an array of Hall-effect magnetic sensors mounted on a dental retainer on the outer side of the teeth to measure the magnetic field generated by a small permanent magnet secured on the tongue. The sensor signals are transmitted across a wireless link and processed to control the movements of a cursor on a computer screen or to operate a powered wheelchair, a phone, or other equipments. The principal advantage of this technology is the possibility of capturing a large variety of tongue movements by processing a combination of sensor outputs. This would provide the user with a smooth proportional control as opposed to a switch based on/off control that is the basis of most existing technologies. We modeled the effects of position and orientation of the permanent magnet on the sensors in FEMLAB and experimentally measured them. We built a prototype system using off-the-shelf components and tested it successfully by developing a graphical user interface (GUI) in LabVIEW environment. A small battery powered wireless mouthpiece with no external component is under development.**

I. INTRODUCTION

Assistive technologies are critical for people with severe disabilities to lead a self-supportive independent life. Persons severely disabled as a result of causes ranging from traumatic brain and spinal cord injuries to stroke generally find it extremely difficult to carry out everyday tasks without continuous help. Assistive technologies that would help them communicate their intentions and effectively control their environment, especially to operate a computer, would greatly improve the quality of life for this group of people and may even help them to be employed.

A large group of assistive technology devices are available that are controlled by switches [1]. The switch integrated hand splint, blow-n-suck (sip-n-puff) device, chin control system, and electromyography (EMG) switch are all switch based systems and provide the user with limited degrees of freedom. A group of head-mounted assistive devices has been developed that emulate a computer mouse with head movements. Cursor movements in these devices are controlled by tracking an infrared beam emitted or reflected from a transmitter or reflector attached to the user's glasses, cap, or headband [2]-[4]. Tilt sensors and video-based computer interfaces that can track a facial feature have also been implemented [5], [6]. One limitation of these devices is that only those people whose head movement is not inhibited may avail of the technology. Another limitation is that the user's head should always be in positions within the range of the device sensors. For example the controller may not be accessible when the user is lying in bed or not sitting in front of a computer.

Another category of computer access systems operate by tracking eye movements from corneal reflections [7] and pupil position. Electro-oculographic (EOG) potential measurements [8], [9] have also been used for detecting the eye movements. A major limitation of these devices is that they affect the users' eyesight by requiring extra eye movements that can interfere with users' normal visual activities such as reading, writing, and watching.

The needs of persons with severe motor disabilities who cannot benefit from mechanical movements of any body organs are addressed by utilizing electric signals originated from brain waves or muscle twitches. Such brain computer interfaces, either invasive [10], or noninvasive [11], [12] have been the subject of major research activities. BrainGate [13] is an example of an invasive technology using intracortical electrodes, while Cyberlink [14] is a noninvasive interface using electrodes attached to the forehead. These technologies heavily rely on signal processing and complex computational algorithms, which can results in delays or significant costs. Think-a-Move Innervoice [15] is yet another interface technology platform that banks on the capabilities of the ear as an output device. A small earpiece picks up changes in air pressure in the ear canal caused by tongue movements, speech, or thoughts. Signal processing is used to translate these changes into device control commands.

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Up until now, very few assistive technologies have made a successful transition outside research laboratories and widely utilized by severely disabled. Many technical and psychophysical factors affect the acceptance rate of an assistive technology. Among the most important factors are the ease of usage and convenience in control. Operating the assistive device must be easy to learn and require minimum effort on the users' part. The device should be small, unobtrusive, low cost, and non- or minimally invasive. Finally, a factor that is often neglected is that the device should be cosmetically acceptable. The last thing a disabled person wants is to look different from an intact person.

II. USE OF TONGUE FOR MANIPULATION

Since the tongue and the mouth occupy an amount of sensory and motor cortex that rivals that of the fingers and the hand, they are inherently capable of sophisticated motor control and manipulation tasks [16]. This is evident in their usefulness in vocalization and ingestion [17]. The tongue is connected to the brain by the cranial nerve, which generally escapes severe damage in spinal cord injuries. It is also the last to be affected in most neuromuscular degenerative disorders. The tongue can move very fast and accurately within the mouth cavity. It is thus a suitable organ for manipulating assistive devices. The tongue muscle is similar to the heart muscle in that it does not fatigue easily. Therefore, a tongue operated device has a very low rate of perceived exertion [18].

An oral device involving the tongue is mostly hidden from sight, thus it is cosmetically inconspicuous and offers a degree of privacy for the user. The tongue muscle is not afflicted by repetitive motion disorders that can arise when a few exoskeletal muscles and tendons are regularly used. The tongue is not influenced by the position of the rest of the body, which may be adjusted for maximum user comfort. The tongue can function during random or involuntary neurological activities such as muscular spasms. Also noninvasive access to the tongue movements is possible.

The above reasons have resulted in development of tongue operated assistive devices such as the TongueTouch Keypad (TTK) [19], which is a switch based device. Tonguemouse [20] is another device that has an array of piezoelectric ceramic sensors, which elements can detect strength and position of a touch by the tongue. The sensor module is fitted within the oral cavity as a dental plate. Tonguepoint is another tongue operated device that adapts the IBM Trackpoint pressure sensitive isometric joystick for use inside the mouth [17]. The latter two devices have fairly large protruding objects inside the mouth, which can cause inconvenience during speaking or eating.

A. Tongue Drive System Overview

In the Tongue Drive system, the motion of the tongue is traced by an array of Hall-effect magnetic sensors, which measure the magnetic field generated by a small permanent magnet that is contained within a nonmagnetic fixture and pierced on the tongue. The magnetic sensors are mounted on a dental retainer and attached on the outside of the teeth to measure the magnetic field from different angles and provide continuous real-time analog outputs. Fig. 1 shows the Tongue Drive system block diagram with two major units: one inside the mouth, the mouthpiece, and the other outside, a portable body worn controller. Small batteries such as hearing aid button-sized cells are intended to power the mouthpiece for extended durations up to a month. The power management circuitry scans through the sensors and turns them on one at a time to save power. The time division multiplexed (TDM) analog outputs are then digitized, modulated, and transmitted to the external controller unit across a wireless link.

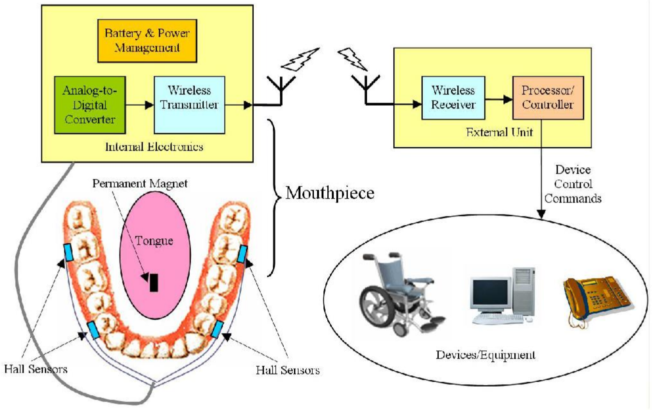


Figure 1. Simplified block diagram of the Tongue Drive system.

The signals received by the external controller unit are demodulated and demultiplexed to extract the individual sensor outputs. By processing these outputs, the motion of the permanent magnet and consequently the tongue within the oral cavity is determined. Assigning a certain control function to each particular tongue movement is done in software and can be easily customized for each individual user. These customized control functions may then be used to operate a variety of devices and equipments including computers, phones, and powered wheelchairs.

B. Tongue Drive System Advantages

The signals from the magnetic sensors are linear functions the magnetic field, which is a continuous position-dependent property. Thus a few sensors are able to capture a wide variety of tongue movements [21]. This would provide a tremendous advantage over switch based devices in that the user has the options of proportional, fuzzy, or adaptive control over the environment. These would offer smoother, faster, and more natural controls as the user is saved the trouble of multiple on/off switch operations. Alternative assistive technologies that emulate a computer mouse use an additional input device such as a switch for the mouse button clicks besides the primary method for moving the pointer. In the Tongue Drive system on the other hand, the additional switches are unnecessary since a specific tongue movement can be assigned to the button press.

The permanent magnet which generates the magnetic field is a small, passive, and inherently wireless component leading to user convenience and additional power saving. The mouthpiece electronics can be integrated on an application specific integrated circuit (ASIC). The ASIC along with the transmitter antenna can be incorporated into a miniaturized package that may be fitted under the tongue as part of the dental retainer. Due to the proximity of the magnet and Hall-effect sensors in the oral cavity, the Tongue Drive system is expected to be more robust against noise, interference, and involuntary movements compared to alternative technologies. Many aspects of the system can be customized and fine tuned through software for a particular individual's oral anatomy, requirements, and disabilities. Therefore, the Tongue Drive system can serve as a platform to address a variety of needs of different individuals.

III. PROTOTYPE SYSTEM

A. Mouthpiece

We devised a prototype Tongue Drive system, shown in Fig. 2, using off-the-shelf commercially available components to evaluate the feasibility and performance of this approach in developing assistive devices. The main purpose of the prototype device was to move a cursor on computer screen based on the location of a permanent magnet (see Table 1) relative to four Hall-effect magnetic sensors [22]. Four Allegro A1321 ratiometric linear Hall-effect sensors with 5 mV/G sensitivity were installed along with 0.1 µF surface mount (SMD) decoupling capacitors in cavities created in a Shock Doctor Max mouth guard [23]. The sensors readily provide temperature compensated linear voltage output proportional to the vertical magnetic field. The front two sensor outputs were used to control the cursor movements along the X direction and the rear two, movement along the Y direction. The arrangement of sensors was at the corners of a parallelogram, as would be in a real setting. A set of 6 wires was needed for supply and sensor output connections.

B. Control Hardware and Wireless Link

The ADC, control hardware, and wireless link were implemented using the Crossbow Telos Research Platform [24]. This platform provides a low-power microcontroller (TI MSP430) including an 8-channel ADC, and an IEEE 802.15.4 radio transceiver with up to 250 kB/s data rate across 30 m indoor range for transmission and reception of the digitized sensor array data and adjustment/calibration commands. A TPR2400 mote and a TPR2420CA mote were used, either of which could be configured as a transmitter or receiver. In the prototype system (Fig. 2), the internal mouthpiece only incorporates the Hall sensors, which are hardwired to the transmitter mote and powered by 4 size-AA battery pack that may be carried in a shirt pocket. The receiver mote sits in the USB port of a personal computer, which runs the Tongue Drive system software in LabVIEW, and derives power directly from that port. The motes run the open-source TinyOS operating system, code for which is written in the NesC language.

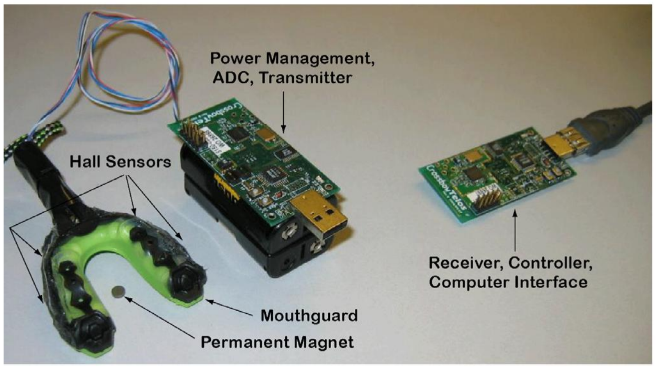


Figure 2. Off-the-shelf components of the prototype Tongue Drive system.

TABLE 1. RADIOSHACK 64-1895 1/8" RARE EARTH SUPER MAGNET SPECIFICATIONS

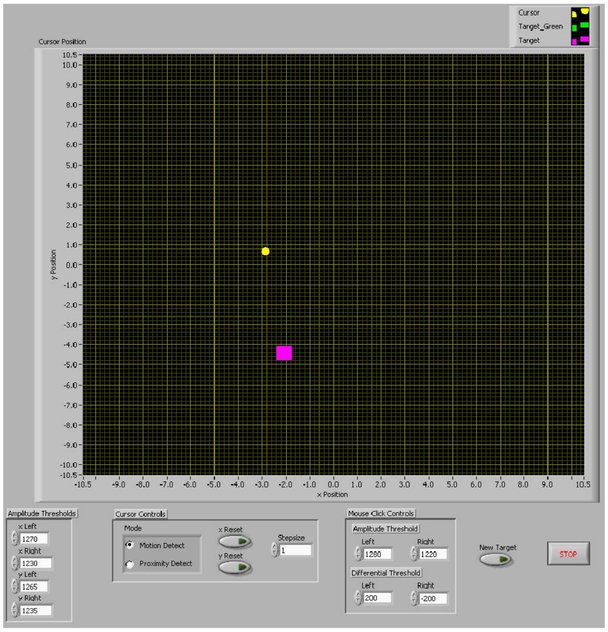
Material	Neodymium-Iron-Boron
Residual Induction (B_r)	10,800 Gauss
Coercive Force (H_C)	9,600 Oersted
Peak Energy Density (BH_{max})	30 MGO
Magnetizing Force (H_S)	35,000 Oersted
Curie Temperature	310 °C
Density	7.4 g/cm^3
Diameter	4.7 mm
Thickness	1.2 mm

C. Software

The transmitter mote scans through an array of 4 ADC channels in a round robin fashion. The data is organized into packets and transmitted wirelessly to the receiver. A radio-to-serial link program running on the receiver mote sends the packets containing sensor readings to the USB port. The code for Telos-B/LabVIEW interfacing has been written by making use of the LabVIEW serial port access resources. The packet data is deciphered to interpret the sensor readings contained therein before being passed to the cursor control GUI code.

The GUI has 2 modes of operation: (1) Proximity Detection (PD) Mode: The cursor movement is controlled by the sensor closest to the magnet, with a "deadzone" for the resting position of the tongue in which none of the sensors have control over the cursor. For example, if the magnet is within a certain range of the front left sensor as set by a software threshold, the cursor moves to the left. (2) Motion Detection (MD) Mode: In addition to the proximity requirement, there is a need for the magnet to be in motion, i.e. the system looks for movement of the magnet in addition to its position relative to the sensors. The cursor will not move no matter how close the magnet may be to the sensor if the magnet is held steady. This mode is provided for better control over cursor movement, for instance when it has to be moved in small increments at a time. Motion detection is performed by comparing the derivative of each sensor output to a threshold.

The LabVIEW GUI developed for the prototype Tongue Drive system is shown in Fig. 3. It displays a large



Amplitude Thresholds
x Left 1270
x Right 1230
y Left 1265
y Right 1235

Cursor Controls
Mode
● Motion Detect
○ Proximity Detect
Stepsize 1

Mouse Click Controls
Amplitude Threshold
Left 1280
Right 1220
Differential Threshold
Left 200
Right -200

Figure 3. The GUI developed in LabVIEW environment for the prototype Tongue Drive system.

rectangular pink marker as a target in a random position for tracking by a smaller circular yellow cursor. Proportional control is incorporated in the system by accelerating the cursor (moving by a larger step-size) the closer the magnet is held to a sensor. The marker disappears and reappears at a different location when the user reaches it with the cursor and executes a "tongue click". Left and right mouse-clicks are available in this system using the tongue movement. If the user quickly flicks the magnet towards one of the front sensors starting from the deadzone, it is considered a tongue click. These special tongue movements allow the user to "select" and "drag" an icon on screen represented by a target marker. The GUI software has tuning controls in the form of amplitude thresholds for PD mode, differential thresholds for MD mode, and thresholds for sensing tongue clicks.

IV. CONCLUSION

A tongue operated magnetic sensor based wireless assistive technology has been developed for people with severe disabilities to lead a self-supportive independent life by enabling them to control their environment using their tongue. This technology works by tracking the movements of a permanent magnet, secured on the tongue, utilizing an array of linear Hall-effect sensors. The sensor outputs are a function of the position-dependent magnetic field generated by the permanent magnet. This allows a small array of sensors to capture a large number of tongue movements. Thus, providing quicker, smoother, and more convenient proportional control compared to many existing assistive technologies. Other advantages of the Tongue Drive system are being unobtrusive, low cost, minimally invasive, flexible, and easy to operate. A more advanced version with custom designed low-power electronics that entirely fit within the mouthpiece is currently under development.

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