

## **TONGUE DRIVE SYSTEM TO OPERATE COMPUTERS - A NEW TONGUE-OPERATED ASSISTIVE TECHNOLOGY**

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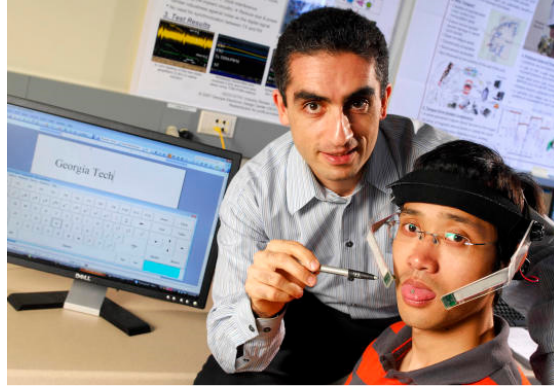
### **ABSTRACT**

The "**Tongue Drive**" is a wireless, noncontact tongue-operated assistive technology developed for people with severe disability for Computer Access and to control their environment such as wheelchairs and other devices simply by using their tongue. 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 magnet secured on the tongue. The sensor movements of a cursor on a computer screen or to operate a powered wheelchair, a phone, or other equipments. signals are transmitted across a wireless link and processed to control the mounted on a dental retainer on the outer side of the teeth to measure the magnetic field generated by a small permanent tiny magnet, size of a grain of rice, is attached to an individual's tongue using implantation, piercing or adhesive. This technology allows a disabled person to use tongue when moving a computer mouse or a powered wheel chair

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.

### **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.



*Fig 1: Georgia Tech assistant professor Maysam Ghovanloo (left) points to a tiny magnet pierced to a student's tongue that would help him control a computer cursor or power a wheelchair.*

A large group of assistive technology devices are available that are controlled by switches. 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. Tilt sensors and video based computer interfaces that can track a facial feature have also been implemented. 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 or not sitting in front of a computer.

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, or noninvasive, have been the subject of major research activities. BrainGate is an example of an invasive technology using intracortical electrodes, while Cyberlink is a noninvasive interface using electrodes attached to the forehead.

These technologies heavily rely on signal processing and complex computational algorithms, which can result in delays or significant costs. Think-a-Move Inner voice 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.

Up until now, very few assistive technologies have made a successful transition outside research laboratories and widely utilized by severely disabled. Many technical and psychological factors affect the acceptance rate of an assistive technology. Among the most important factors are the ease of use and convenience in control. Operating the assistive device must be easy to learn and require minimum effort on the user's 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



*Fig 2: The Tongue Drive system's technology was developed for individuals with paralysis caused by spinal cord injury, stroke or Lou Gehrig's disease.*

The Tongue Drive system is developed to recognize a wide array of tongue movements and to apply specific movements to certain commands, taking into account user's oral anatomy, abilities and lifestyle.

The ability to train our system with as many commands as an individual can comfortably remember is a significant advantage over the common sip-n-puff device that acts as a simple switch controlled by sucking or blowing through a straw," said Ghovanloo.

The Tongue Drive system is touch-free, wireless and non-invasive technology that needs no surgery for its operation. During the trials of the system, six able-bodied participants were trained to use tongue commands to control the computer mouse. The individuals repeated several motions left, right, up and down, single- and double-click to perform computer mouse tasks.

## **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. This is evident in their usefulness 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 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. 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 exo-skeletal 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 Tongue Touch Keypad, which is a switch based device.

Tongue-mouse 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 dental plate. Tongue point is another tongue operated device that adapts the IBM Track point pressure sensitive isometric joystick for use inside the mouth. The latter two devices have fairly large protruding objects inside the mouth, which can cause inconvenience during speaking or eating.

## WORKING OF TONGUE DRIVE AND ITS BLOCK DIAGRAM

In 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.

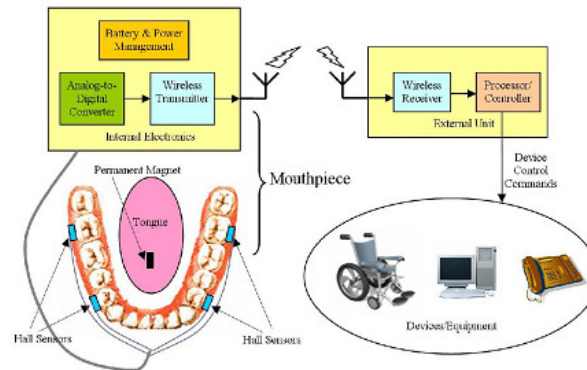


Figure 1. Simplified block diagram of the Tongue Drive system.

Fig 3: shows the Tongue Drive System block diagram with two major units:

- (1). Inside the mouth, the Mouthpiece, and
- (2). 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.

The magnetic field generated by the tracer inside and around the mouth varies as a result of the tongue movements. These variations are detected by an array of sensitive magnetic sensors mounted on a headset outside the mouth, similar to a head-worn microphone, or mounted on a dental retainer inside the mouth, similar to an orthodontic brace. The sensor outputs are wirelessly transmitted to a personal digital assistant (PDA) also worn by the user.

A sensor signal processing (SSP) algorithm running on the PDA classifies the sensor signals and converts them into user control commands that are then wirelessly communicated to the targeted devices in the user's environment.

The principal advantage of the TDS is that a few magnetic sensors and a small magnetic tracer can potentially capture a large number of tongue movements, each of which can represent a particular user command. A set of specific tongue movements can be tailored for each individual user and mapped onto a set of customized functions based on his or her abilities, oral anatomy, personal preferences and lifestyle. The user can also define a command to switch the TDS to standby mode when he or she wants to sleep, engage in a conversation, or eat.

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 control functions may then individual user. These customized control functions may then be used to operate a variety of devices and equipments including computers, phones, and powered wheelchairs.



Fig 4: Tongue Drive System component diagram and proof-of-concept prototype on dental model.

From above Fig 4:

ISM = industrial, scientific, and medical (radio frequency band);  
 PC = personal computer;  
 PDA = personal digital assistant; TV = television

## PROTOTYPE SYSTEM

### A. Mouthpiece:

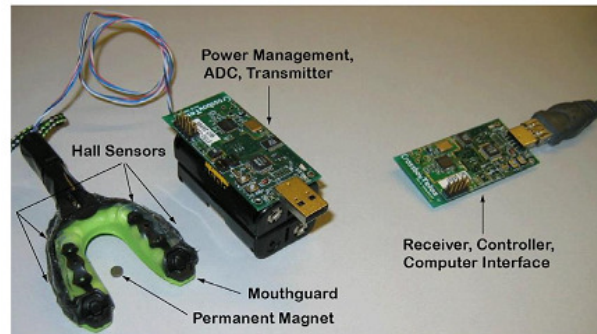


Figure 2. Off-the-shelf components of the prototype Tongue Drive system.

The main purpose of the prototype device was to move a cursor on computer screen based on the location of a permanent magnet relative to four Hall-effect magnetic sensors. 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.

### B. Control Hardware and Wireless Link

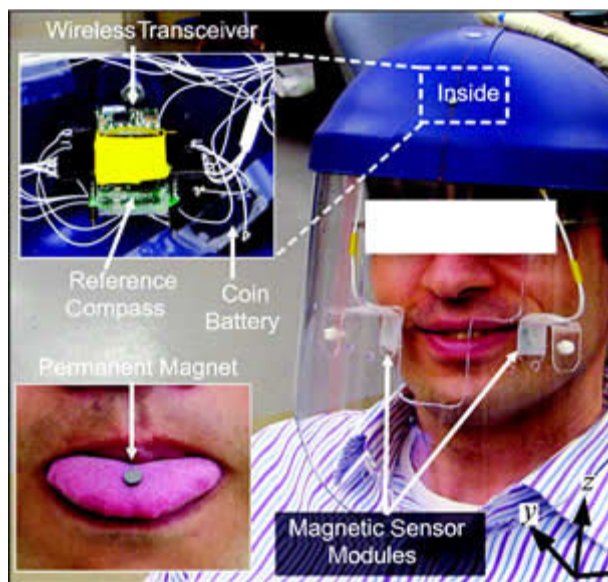
The ADC, control hardware, and wireless link were implemented. This platform provides a low-power microcontroller including an 8-channel ADC, and an IEEE

802.15.4 radio transceiver with up to 250 kB/s data rate across 130m. A TPR2400 mote and a TPR242OCA mote were used, either of which could be configured as a transmitter or receiver. In this prototype System the internal mouth piece 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 run 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.

## HUMAN TRIALS

One **prototype for human trials**, shown in below fig, was built on a face shield to facilitate positioning of the sensors for different subjects. The main function of this prototype was to directly emulate the mouse pointing and selection functions with the tongue movements.

Six commands were defined: left, right, up, and down pointer movements Q3 and single- and double-click movements. As long as the SSP algorithm was running in the background, no additional software or learning was needed if the user was familiar with the mouse operation and any piece of software that was operable by a mouse. Small, cylindrical, rare-earth permanent magnets were used as magnetic tracers. A pair of two-axis magnetic field sensor modules was mounted symmetrically at right angles on the face shield close to the user's cheeks. Each two-axis module contained a pair of orthogonal magneto-inductive sensors, shown in Figure.



**Figure 2.**

External Tongue Drive System prototype implemented on face for human trials. A pair of two-axis magnetic sensor mod mounted symmetrically at right angles. Hence, one sensor is x-axis, one along y-axis, and two along z-axis with respect to shield imaginary coordinates (lower right of figure). Top inset: Rel three-dimensional electronic compass. Bottom inset: Permanent m: tracer attached to user's tongue with tissue adhesives.

Hence, we had one sensor along the x-axis, one along the y-axis, and two along the z-axis with respect to the imaginary coordinates of the face shield. To minimize the effects of external magnetic field interference, including the earth magnetic field, we used a three-axis module as a reference electronic compass. The reference compass was placed on top of the face shield so as to

be far from the tongue magnet and to only measure the ambient magnetic field. The reference compass output was then used to predict and cancel out the interfering magnetic fields at the location of the main two-axis sensor modules. All seven sensor outputs, already in digital form, were sent serially to the ultralow-power MSP430 microcontroller that is the heart of the control unit.

The microcontroller took 11 samples/s from each sensor while activating only one module at a time to reduce power consumption. After reading all sensors, we arranged the samples in a data frame and wirelessly transmitted them to a personal computer (PC) across a 2.4 GHz wireless link established between two identical nRF2401 transceivers. The entire system was powered by a 3.3 V coin-sized battery, which together with the control unit and reference compass were hidden under the face shield cap (Figure 3 inset).

## SENSOR SIGNAL PROCESSING ALGORITHM

The SSP algorithm running on the PC operates in **two** phases: **training and testing**.

The training phase uses principal components analysis (PCA) to extract the most important features of the sensor output waveforms for each specific command. During a training session, the user repeats each of the six designated commands 10 times in 3-second intervals, while a total of 12 samples (3 per sensor) are recorded in 12-variable vectors for each repetition and labeled with the executed command. The PCA-based feature-extraction algorithm calculates the eigenvectors and Eigen values of the covariance matrix in a three-dimensional (3-D) space based on the 12-variable vectors offline. Three eigenvectors with the largest Eigen values are then chosen to set up the feature matrix [v1, v2, v3]. By multiplying the training vectors with the feature matrix, the SSP algorithm forms a cluster (class) of 10 data points from training for each specific command in the PCA virtual 3-D feature space.

Once a cluster is formed for each command, the testing phase can be executed, during which a three-sample window is slid over the incoming sensor signals to reflect them onto the 3-D feature space as new data points by using the aforementioned feature matrix. The k-nearest neighbor (kNN) classifier is then used in real time to evaluate the proximity of the incoming data points to the clusters formed earlier in the training phase. The kNN starts at the incoming new data point and inflates an imaginary sphere around that data point until it contains a certain number (k) of the nearest training data points. Then, it associates the new data point to the command that has the majority of the training data points inside that spherical region. In the current version, we chose  $k = 6$ . After finding the intended user command, the mouse pointer starts moving slowly in the selected direction to give the user fine control.

However, for faster access to different regions of the computer screen, the user can hold his or her tongue in the position of the issued command and the pointer will gradually accelerate until it reaches a certain maximum velocity.

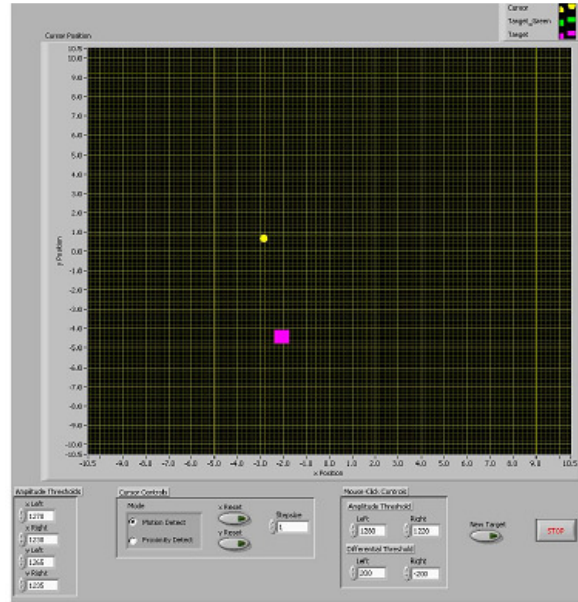


Figure 3. The GUI developed in LabVIEW environment for the prototype Tongue Drive system.

The LabVIEW GUI developed for the prototype Tongue Drive system is shown in Fig.4. It displays a large 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 large step-size) the cursor 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 dead zone, 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.

## TESTING

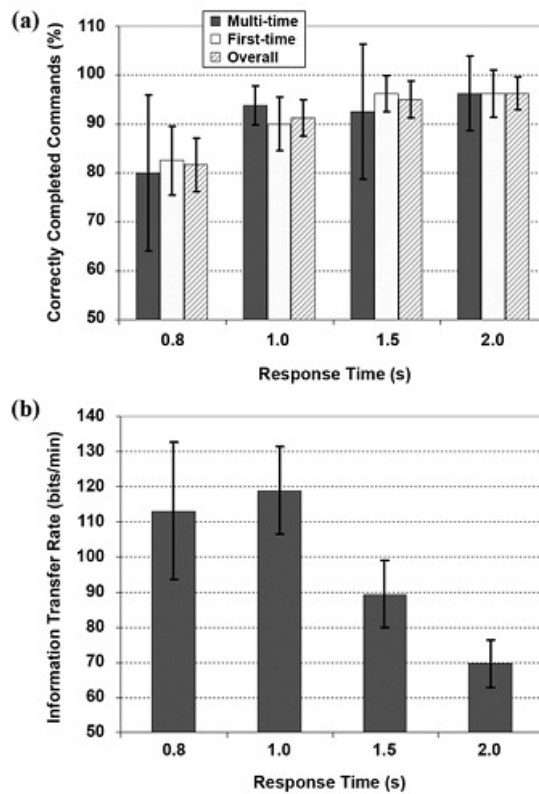
### Experiment I: Percentage of Correctly Completed: *Commands versus Response*

Experiment designed to provide a quantitative measure of the TDS performance by measuring how quickly a command is given to the computer from the time it is intended by the user. This time, the TDS response time includes thinking about the command and its associated tongue movement; the tongue movement transients; and any delays associated with hardware sampling, wireless transmission, and SSP computations. Obviously, the shorter the response time, the better. However, the accuracy of intending and performing tongue movements by the user and the discerning of those intended commands by the SSP algorithm are also affected by the response time. In other words, it is important not only to issue commands quickly but also to detect them correctly. Therefore, we considered the percentage of correctly completed commands (CCC %) as an additional parameter along with the response time.

One of these measures, known as information transfer rate (ITR), shows how much useful information the BCI can transfer from brain to computer within a certain period of time. Various researchers have defined the ITR differently. We have calculated the ITR using Wol paw et al.’s



definition: Where,  $N$  is the number of individual commands that the system can issue,  $P$  is the system accuracy ( $P = CCC \%$ ), and  $T$  is the BCI system response time.



**Figure 3.** (a) Percentage of correctly completed commands vs Tongue Drive System (TDS) response time in six human trials. Results of first-time subjects and multi-time subjects (i.e., familiar with TDS) are compared. (b) TDS information transfer rate vs response time, calculated with Equation 1 (see main text).

*Time*

### Experiment II: Maze Navigation:

The purpose of Experiment II was to examine the TDS performance in navigation tasks, such as controlling a PWC, on a computer. The subject navigated the mouse pointer within a track shown on the screen, moving the pointer from a starting point by issuing a double-click (start command) to a stopping point by issuing a single-click (stop command); meanwhile, the GUI recorded the pointer path and measured the elapsed time (ET) between the start and stop commands. The track was designed such that all six commands had to be used during the test. When the pointer moved out of the track, the subject was not allowed to move forward unless he led it back onto the track. Therefore, the subject had to move the cursor within the track very carefully, accurately, and as quickly as possible to minimize the ET. Each subject was instructed to repeat the maze task three times to conclude the trial.

## **Flexibility**

The user is free to associate any specific tongue movement with any one of the six commands defined in the system based on his or her preference, abilities, and lifestyle. These tongue movements should be unique and far from other tongue movements that are either associated with other TDS commands or are natural tongue movements used during speaking, swallowing, coughing, sneezing, etc. Fortunately, most of these voluntary or involuntary movements are back and forth movements in the sagittal plane. Therefore, to define their TDS commands by moving their tongue from its resting position to the sides or by curling their tongue up or down, movements that do not usually occur in other tongue activities.

## **Native Language**

Another expected observation from human trials was that the individual's performance when using the TDS was independent of his native language. In fact, our six human subjects had four different native languages, and we did not observe any correlation between their native language and their performance. This result contrasts with those found with the voice-activated or speech-recognition-based ATs that are popular mainly among users who speak English well.

## **ADVANTAGES**

- (1). 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.
- (2). 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.
- (3). These would offer smoother, faster, and more natural controls as the user is saved the trouble of multiple on/off switch operations.
- (4). 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.
- (5). In Tongue Drive system on the other hand, the additional switches are unnecessary since a specific tongue movement can be assigned to the button press.
- (6). 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 circuit (AISC). The AISC 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.
- (7). 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.

Therefore, the Tongue Drive system can serve as a platform to address a variety of needs of different individuals.

The results of the trials showed **100 percent of commands were accurate** with the response time less than one second, which equals to an information transfer rate of approximately 150 bits per minute.

## LIMITATIONS

- (1). Implementation is slightly harder.
- (2). Slightly Expensive.

## CONCLUSION & FUTURE AIM

The Ultimate goal in developing tongue operated magnetic sensor based wireless assistive technology is to serve people with severe disabilities to lead a self-supportive independent life enabling them to control their environment using their tongue. The system uses an array of magnetic sensors to wirelessly track tongue movements by detecting the position and orientation of a permanent magnetic tracer secured on the tongue. The tongue movements can then be translated into various commands for computer access, navigation, or environment control.

The next step of the research is to **develop software to connect the Tongue Drive system to great number of devices** such as text generators, speech synthesizers and readers. Also the researchers plan to upgrade the system by introducing the standby mode to allow the individual to eat, sleep or talk, while prolonging the battery life.

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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