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Fully Integrated Wireless Inductive Tongue Computer Interface for Disabled People

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Abstract—**This work describes a novel fully integrated inductive tongue computer interface for disabled people. The interface consists of an oral unit placed in the mouth, including inductive sensors, related electronics, a system for wireless transmission and a rechargeable battery. The system is activated using an activation unit placed on the tongue, and incorporates 18 inductive sensors, arranged in both a key area and a mouse-pad area. The system's functionality was demonstrated in a pilot experiment, where a typing rate of up to 70 characters/minute was obtained with an error rate of 3%. Future work will include tests with disabled subjects.**

I. Introduction

THE recent developments within IT-technologies and within automatic electronic devices, which can be centrally controlled using systems such as the X10 control system, opens up new possibilities for severely disabled people such as quadriplegics. An advanced interface to IT-technologies, smart house technologies and electronic assistive devices, e.g. electrical wheelchairs, can potentially increase both their social and vocational activities, and thereby significantly improve their quality of life.

In relation to computer interfaces for disabled people, aesthetics have a high priority [1], and discreet interfaces are therefore desirable. One way of implementing a discreet interface is to hide the major part of the interface inside the mouth [1, 2, 3]. Different interfacing methods have previously been attempted, such as electrical contacts [4], Hall elements [5] and pressure sensors [6], the later being the most successful method, resulting in a commercial product [6]. Still, having 9 sensors, this commercial system is far from utilizing the high selectivity of the tongue, which can easily pick out each of our 32 teeth. Further, talking and drinking alone is capable of generating tongue-palatal forces of up to 20-60% of the maximal obtainable force [7,8]. This motivates more research within other sensor technologies than those based on pressure. Recently, an inductive tongue computer interface was suggested [3], and shortly after, a tongue interface based on magnetic sensors was presented [2]. Nevertheless, none of these systems provide more sensors/commands than the commercial system from New Abilities, and none of the systems were fully integrated into the mouth. Therefore, this study presents a fully integrated wireless inductive tongue computer interface, incorporating 18 separate inductive sensors, distributed on a key area and a mouse-pad area.

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II. Methods

A. Device development

1) Sensor technology

The inductive sensors are based on the variable inductance method as described in [3]. Here, the inductance is changed by changing the magnetic permeability of the core material of the coil (Faradays law):

$$\epsilon = -L\frac{di}{dt} = -\mu_0\mu_r N^2 \frac{A}{l}\frac{di}{dt} \quad (1)$$

Where: L = inductance, N= number of turns, l = the average length of the magnetic flux path, μ_0 = vacuum permeability, and μ_r = relative magnetic permeability of the core material

The inductive sensors used in this study are coils with a core of printed circuit board (PCB) material, and the permeability of the core material is changed by moving a cylindrical activation unit, made of ferromagnetic material, close to the coil (Fig. 1). Thus, the tongue activates the sensors by placing the tongue-mounted activation unit at a coil.

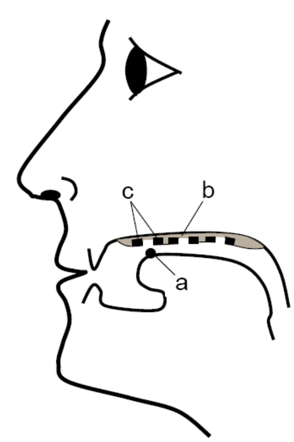

Fig. 1: From [3]: The principle of the Inductive tongue computer interface. a: The activation unit, b: The palatal plate, c: The inductors.

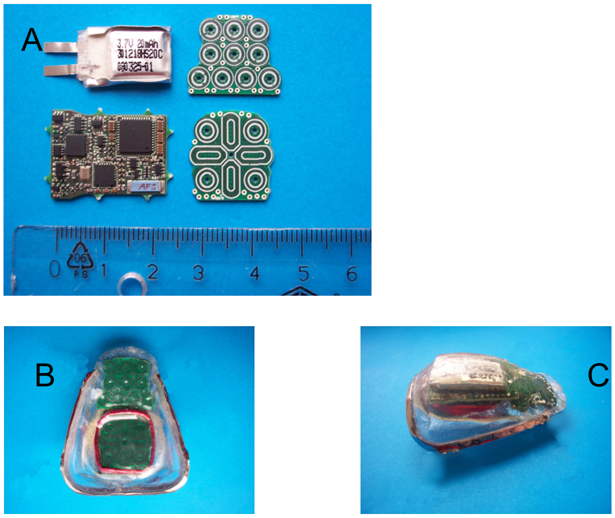

Fig. 2: A: Left: The battery and the electronics PCB. Right: The coil PCBs with 10 coils for the key area and 8 coils for the mouse area: Top; the key area. Bottom; the mouse area. The scale is in centimeters. B and C: The fully integrated wireless tongue interface. It can be attached to the teeth using clamps. The key area is placed in front of the mouth, and the mouse-pad area is placed in the back of the mouth.

2) Tongue Interface:

The tongue interface consists of:

1. Two PCBs with inductive sensors
2. A signal processing system
3. A wireless transmitter
4. A rechargeable battery
5. Connecting flexible PCBs
6. Encapsulation
7. An activation unit

1: The coils are produced as 10 layers PCBs [9]. Two separate coil PCBs are designed – one to be used as a key pad and one to be used as a mouse-pad (Fig. 2)

2: The signal processing system in the tongue interface (Fig. 3) provides the sensors with a 57 kHz current. The sensor signals are in the range of 1 mV and decreases due to activation in the range of 1-15%. The sensors are multiplexed, and the analog sensor signal is amplified, rectified and low pass filtered. The microprocessor samples the signal and feeds it to the transmitter.

3: The transmitter transmits the signal within the 2.4 GHz frequency band, and transmission is done every 0.033 sec. The transmitted signal includes amplitude information for each of the 18 sensor coils.

4: The battery is a 20 mAh rechargeable lithium polymer battery, which can supply the system for 15 hours of use before recharging (Fig. 2 A).

5: Two connecting flex-PCBs connects the coil PCB and the electronic PCB

6: The System is encapsulated in a dental retainer using standard dental materials (Fig. 2 B, C).

7: The activation unit is made of a dental stainless steel alloy Dyna©. It is shaped as a cylinder with a height of 2 mm and a diameter of 4.5 mm.

B. Experimental methods

1) Data acquisition

Using a USB interface for the PC COM-port, the signals are fed into a PC which is running MATLAB© Data acquisition toolbox. The MATLAB program performs thresholding of the signals from the coils PCBs in order to decide whether the sensor is activated.

The MATLAB© program provides the possibility of using an on-screen keyboard by activating the mouse-pad area of the Tongue Interface. Selections (mouse clicks) are made by activating either one of the six most frontal sensors of the key area (Fig. 2). The cursor control is established by combining signals from the 8 mouse-pad coils using fuzzy logic, to obtain movement in multiple directions and with variable velocity, so that the velocity close to the center of the mouse area is smallest.

Further, the MATLAB© program provides a visual feedback for the coils in the key area of the Tongue Interface, showing the related characters (Fig. 4). Using the key area, the currently activated sensor is marked with red, unless it is the character, that the subject is requested to type. When the requested sensor is activated, the color of the sensor on the visual feedback changes to green.

2) Subject

One 38 year old healthy male was used for demonstrating the functionality of the system. The subject is part of the project group and was therefore familiar with the topic of tongue interfaces. He had less than 10 hours experience with a similar system, but with no encapsulated electronics except from the coil PCBs. Instead wires were filling up and coming out of the mouth. The subject had approximately 30 min experience with wearing this new wireless device before the experiment.

3) Experimental procedure

At the beginning of the experiment the activation unit was glued to the tongue of the subject using tissue glue Histoacryl©. The activation unit was remounted once during

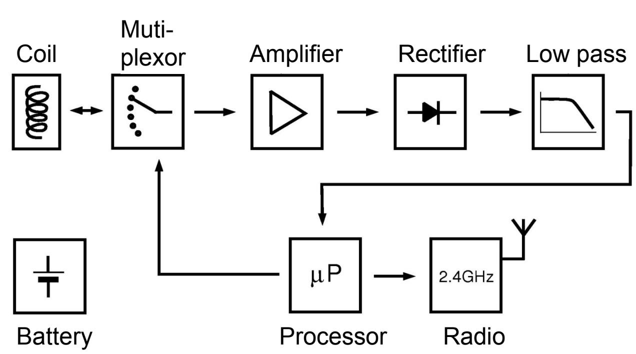

Fig. 3. The signal processing system embedded in the mouth.

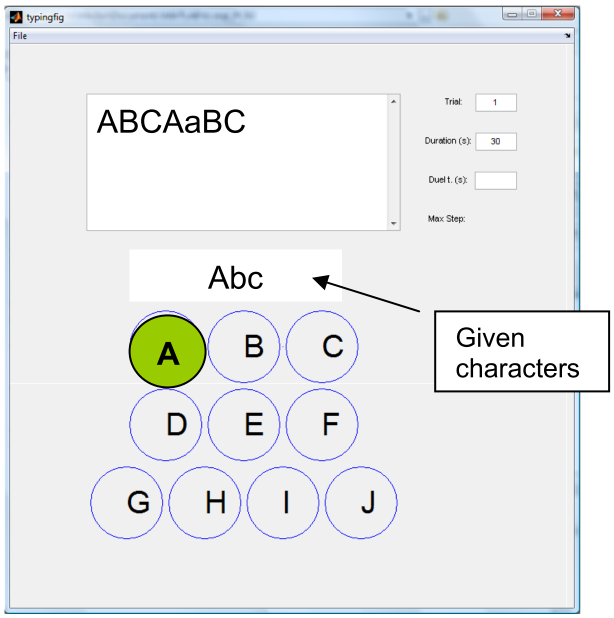

Fig. 4: The visual feedback used for experiments. The given characters are shown with the currently desired character in capital. In the text field above the given characters, the characters typed by the subject are shown – correct characters in capital. Below the given characters is a figure showing the placement of the characters in the tongue interface. As long as the activation unit is placed near an incorrect character, the circle around that character will have a red color, and it is temporarily typed in the text field. When the desired character/sensor is activated and the activation has been sustained for 0.4 -0.7 sec. (to be chosen by the subject) the color turns green, the character is typed in the text field and the cursor moves one step forward to show the next character, that is activated by the subject.

the experiment. Then the wireless tongue interface was placed in the mouth.

The subject was presented to a visual display as shown in Fig. 4. The subject performed 66 typing tests with a total typing duration of 33 min, typing a given sequence of characters. Usually, the given sequence consisted of 3 characters related to coils, which were arranged in rows or columns. Further, for all characters (a, b, c-j) trials were performed where only a single character was repeated. A test sequence including all possible characters: "eaicgfbhdj" were used in trial: 1,2b,9,10,21,22,29n,30n,31n,32n, 39,40,51,51,59n-66n, (where n means no visual feedback of the character placement) in order to have a measure of improvement.

After the typing test, an on-screen keyboard was used for typing, using the coils of the mouse-pad area. Each trial for the on-screen keyboard lasted 30 sec. and 14 trials were performed. The size of the keys of the on-screen keyboard was approximately: Width 11 mm, height: 8 mm.

III. Results

The results of the tongue typing tasks are shown in Fig. 5. The mean typing rate was 50 characters per minute, or a response time of 1.2 sec. for activation. The mean error rate was 16%. The maximum number of correctly typed characters is 35 with one error, which gives an activation

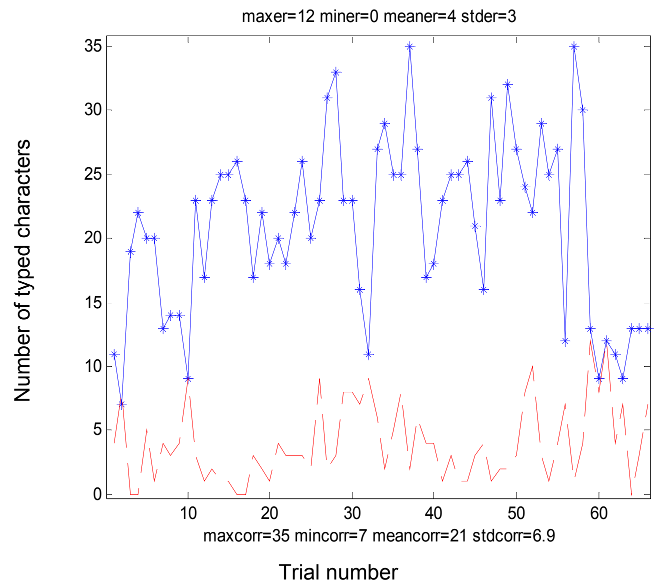

Fig. 5: Bold: The number of correctly typed characters. Punctured: The number of incorrect activations.

time of 0.83 sec., with 3% errors. This was for the sequence CBA. For the test sequence, the best result was 20 correct characters and 4 errors, or 1.25 sec. pr. activation with 17 % errors. Without a display showing the characters position, the best result while typing the test sequence was 13 correct characters with 0 errors, or a typing rate of: 2.3 Sec. (trial number 66 in Fig. 6).

An example of the normalized coil signals is shown in Fig. 6 for the sequence: ABC. The results for the on-Screen typing are shown in Fig. 7.

The best result was 8 corrects characters with 1 error, which corresponds to an activation time of 3.3 sec. and an error rate of 11%. The mean activation time was 5.5 sec.

IV. Discussion

This paper presents a fully integrated wireless inductive tongue interface. The interface fits into the mouth and can be activated using a small activation unit on the tongue. The system presents a novel design incorporating both at key-area and a mouse area. Further, having 18 separate sensors, the system incorporates more sensors/commands than previously reported implemented for tongue control systems, and thereby allows for many different user commands. The preliminary results shown in this study indicates, that despite

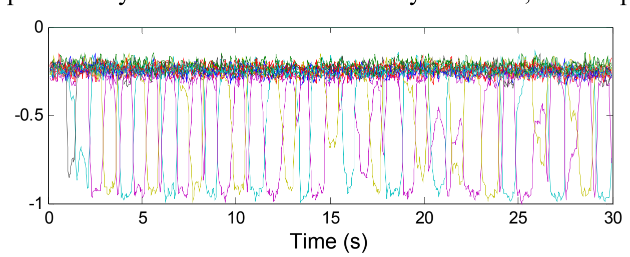

Fig. 6: The normalized processed sensor signals for the sequence ABC. The typed characters were: "dABCABCABCABCABCABCABCABCAcB CABCABCAB".

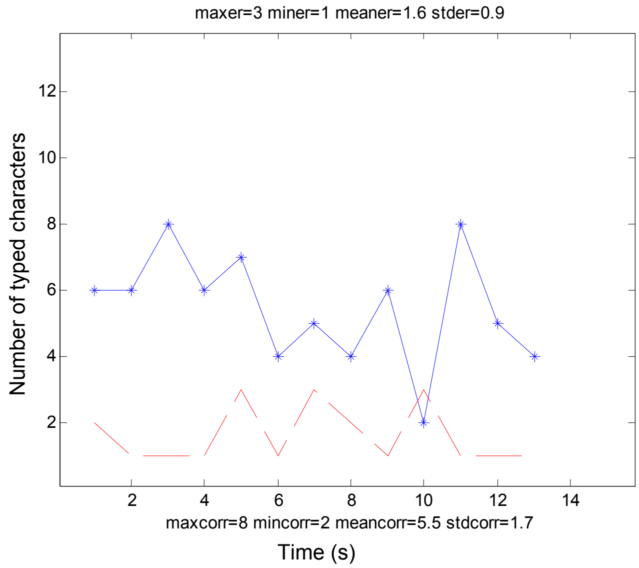

Fig. 7: The results of the on-screen typing. Bold: The number of correctly typed characters. Punctured: The number of incorrect typings.

having 10 typing keys, and 8 keys for a mouse area, the system can produce a similar response time: 1.2 sec. with 84% correct characters as a system with only 6 command possibilities, resulting in a response time of 0.8 sec. with 87% correct characters [2]. Still, practicing is necessary in order to obtain a consistent high typing rate, since there was great variability on the number of correctly typed characters in this preliminary study. We believe that the results encourages for further studies with disabled individuals.

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