34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

Alternative Design of Inductive Pointing Device for Oral Interface for Computers and Wheelchairs

Eugen R. Lontis, Lotte N. S. Andreasen Struijk

Abstract— **An inductive pointing device was designed and implemented successfully in a tongue controlled oral interface. Sensors were manufactured as an assembly of multilayer coils in the printed circuit board technology on two pads. The sensor pads were encapsulated together with electronics and battery in a mouthpiece, placed in the upper palate of the oral cavity. The PCB technology allowed surface activation of one or more sensors by gliding over the surface of the coils assembly of a small cylindrical unit attached to the tongue. The model consisted of 8 sensors and allowed real time proportional control of both speed and direction similar to a joystick. However, the size of the oral cavity, the number and geometry of the coil loops and characteristics of the activation unit impose limits in designing the sensors and call for an alternative layout design. Two alternative sensor designs are proposed in this paper, aiming to reduce the size of the sensor pad by one third, extending the target group, including children, and increasing the easiness of wear of the oral interface.**

I. Introduction

Injury of the sensory-motor system in humans at the cervical level of the spine induces a high degree of disability. The disabled person confined to a wheelchair requires daily assistance of a helper. Improve of quality of life of the disabled person has been the aim of several research teams in the last decades. Interfaces have been developed to compensate up to a degree the lost motor functions. Intact functionality of the brain, eyes, head, voice and tongue has been used to provide control of assistive devices for mobility and communication [1], [2], [3], [4]. The pointing device is most often referred as a mouse or a mouse pad in the case of a planar design, such the one analyzed in this paper.

A tongue controlled oral interface has been developed based on inductive sensors [5], [6]. The printed circuit board technology (PCB) has been chosen for manufacturing the sensors due to the ability to replicate electrical parameters with low tolerance, to form assembly of sensors and to easy the integration process with the driving electronics. The sensor consists of a sandwich structure by placing wire windings in interconnected parallel planes forming an air-cored coil [6]. A cylindrical activation unit activates the sensor (Fig. 1). The activation unit has to be attached to the tongue by gluing, for temporary use or test, or by piercing

*Research supported by Vanførefonden, TRYGfonden and Jaschafonden, Denmark

E. R. Lontis and L. N. S. Andreasen Struijk are with Center for Sensory Motor Interaction (SMI), Dept. of Health Science and Technology, Aalborg University, DK-9220 Aalborg, Denmark.

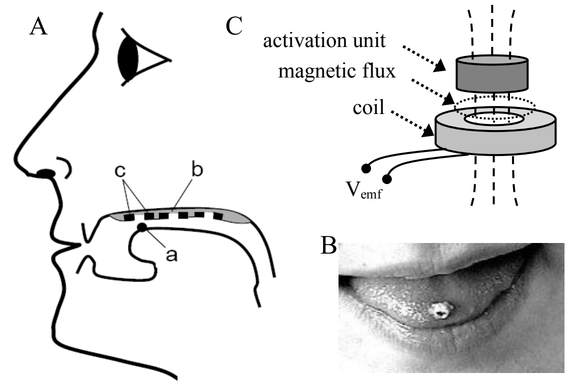

Figure 1. Tongue controlled oral interface. **A** Placement of inductive sensors on the palate of the oral cavity and the activation unit. **B** Activation unit, glued or pierced to the tongue. **C** Principle of activation. Modified from [5] with permission, © 2006 IEEE.

for regular use of the system. The activation unit is a soft ferromagnetic material that changes the inductance of the coil when gliding at the surface of the coil. This change is the result of the perturbation of the flux Φ of the magnetic field generated by an electric current i flowing through the coil. The coil inductance L is defined by the ratio of the magnetic flux to the current (1). The induced voltage U_{emf} in the coil changes with inductance according to Faraday's law (2).

$$L = \frac{\Phi}{i} \quad (1) \qquad U_{emf} = -L\frac{di}{dt} \quad (2)$$

Geometry of the sensor in relation to the size and electrical properties of the activation unit may extend the functionality of the sensor from a switch type for text input to a proportional type for movement or position detection in real time [6]. Sensors have been designed to yield a minimal functionality and to occupy a maximal volume (i.e. minimal size of an adult oral cavity). A full alphabet keyboard based on a 10 sensors pad, similar to a mobile phone keypad, and a proportional mouse based on 8 sensors pad with control of direction and speed, similar to a joystick, have been implemented. Previous experimental results obtained with this oral interface have been reported [6], [7]. [8], [9]. Constraints are imposed on sensors design by the size of the oral cavity, the number and geometry of the coil loops forming the sensors, characteristics of the activation unit, complexity of the functionality of interface, and nevertheless by the limitations of the PCB technology. The paper presents two alternative designs of a mouse pad of smaller size with a reduced number of sensors for proportional detection of movement or position in real time. The solutions proposed

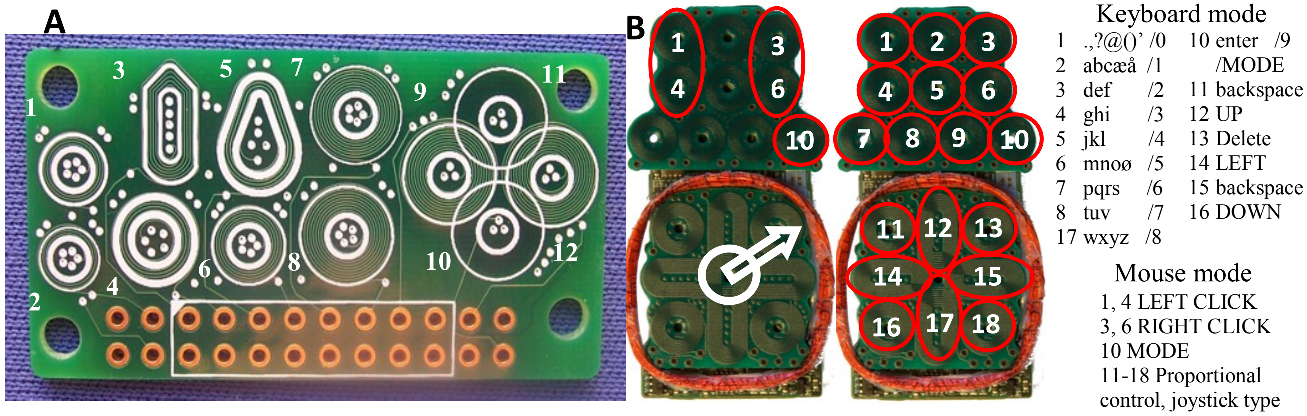

Figure 2. **A** Test board for test of the geometry(1)-(8) and of the interlaced relative positioning (9)-(12) of inductive sensors manufactured in PCB technology. Reprinted from [6] with permission, © 2010 Informa Ltd. United Kingdom. **B** Sensors layout and functionality associated for the tongue controlled oral interface. Layout manufactured on two pads, interconnected through a flex print. Mouse Mode for proportional control of speed and direction (left panel). Activation unit of 4 mm diameter illustrated in the center of the mouse pad. Keyboard Mode for full alphabet text input (right panel). Selection of characters from the list associated to each sensor performed by activating the sensor for a certain time (user defined *dwell time* for list scroll). Switch between Keyboard and Mouse modes performed by activating sensor number 10 for a certain time (user defined *mode time*).

may be used in designing of an oral interface for persons with a reduced volume of the oral cavity, including children. Furthermore, the easiness to wear may be increased by a reduced volume of the interface occupied in the oral cavity, providing a better comfort for the user.

II. Theoretical Background

A. PCB sensors for tongue controlled oral interface

Test sensors were designed in round and oval geometries in 10 layers PCB technology, the width of the copper wire having 120 and 100 μm (test board Fig. 2) [6]. The thickness of the test board was 1.2 mm. An activation unit of 4 mm diameter and 2.5 mm height made of stainless steel SUS447J1 (μ_r of 1500 and σ of 10^2 S/m) was used to evaluate activation signals measured with an RLC meter (Radiometer Copenhagen). Round and oval sensors of the most recent version of the tongue controlled oral interface were manufactured in the PCB technology with 10 layers, 75 μm width of copper wire, and a PCB board thickness of 0.8 mm (layout and functionality showed in Fig. 2B) [8].

B. Activation of inductive sensors and the path of maximal activation

Distribution of the magnetic field generated by the coil depends on the coil geometry. Perturbation of the magnetic field by the activation unit can be evaluated by measuring the voltage induced in the coil according to Eq. (1) and (2). Consequently, the position of the activation unit relative to the coil can be estimated. The path of maximal activation is defined by the segment between the edge and the center of the coil that corresponds to the longest displacement of the activation unit when gliding over the surface of the coil that generates a variable signal increasing from zero to a maximum (Fig. 3A). The variable signal generated when the activation unit moves along this path may uniquely characterize the position of the activation unit or may be used in conjunction with signals from neighbor coils to establish the position of the activation unit. A zero signal is obtained when the activation unit is placed edge-to-edge relative to the coil and increases as the center of the activation unit approaches the center of the sensor. Further move of the activation unit along the same direction would generate a decreasing variable signal, losing the ability to uniquely determinate the position of the activation unit in the absence of signals from neighbor sensors. A fuzzy inference system for detecting the position of the activation unit based on variable signals from neighbor coils has been described [10].

Measurements of activation signals (Fig. 3B, 3C, 3D) show that the larger the loop and the number of loops of the sensor the higher the activation signal. Furthermore, elongated geometries of the loop determine a decrease of the maximal activation, however with the benefit of a longer path of maximal activation.

III. Alternative Layout Design

Fig. 4 shows a comparison of the two layout designs proposed in this paper with the design of the mouse pad of the system already developed [6-15]. Proportional control allows a fine tuning in real time of values of a variable, such as the length or direction of a vector. The implemented mouse pad (Fig. 4A) has been designed to combine variable signals generated by sensors when the activation unit moves along a direction relative to the center of the mouse pad. Consequently, the pointer moves on the screen along that direction, having a speed proportional to the distance between the current position of the activation unit and the center of the sensor, resembling the output of a standard joystick. Eight adjacent sensors have been used to extend the range of motion that permits a lower spatial sensitivity allowing the user a less strict control of the tongue movements. To reduce the number of the sensors and the size of the sensor pad the following two layout designs that still provide a proportional control of both speed and direction are proposed.

A. *Interlaced 4 sensors layout design*

Fig. 4B shows an example of interlaced sensors design implemented on 10 layers with the width of the copper wire of 100 µm and pad thickness of 1.2 mm. Practice shows that this design may be implemented using a space and a copper wire of 75 µm width, reducing the radius of the pad by approximately 30% as compared to the mouse pad size shown in Fig. 4A. Furthermore, the pad thickness may be decreased to 0.8 mm, increasing the amplitude of the generated signals. Interlacing provides better signals from neighbor sensors as compared to adjacent sensors, however having a lower range of motion of the activation unit. Oval sensors such as sensor number 5 in Fig. 2A may be used for optimizing the output of this type of layout.

B. *Two sensors layout design*

Fig. 4C shows an example of a two sensors layout. The drastic reduction in the number of sensor can no longer ensure a direct 2D control of direction and speed. However by using a state machine the user can switch between linear translation and linear rotation. The upper sensor may be used as the active sensor whereas the lower sensor may be used as a state shift. Introduction of an interlaced switch type of sensor (i.e. round) may be a compromise to increase easiness of use. However, the use of the lower sensor as an active sensor for rotation or linear translation may be seen by some users as unnatural. Oval sensors such as sensor number 5 in Fig. 2A may be used interlaced for optimizing the output of this layout design as well.

IV. Discussion

Theoretical background and alternative design of an inductive pointing device (i.e. a mouse pad) have been presented. The actual implementation of the tongue control system was primarily a compromise between the technology available and the maximal volume that the system was allowed to occupy in the oral cavity.

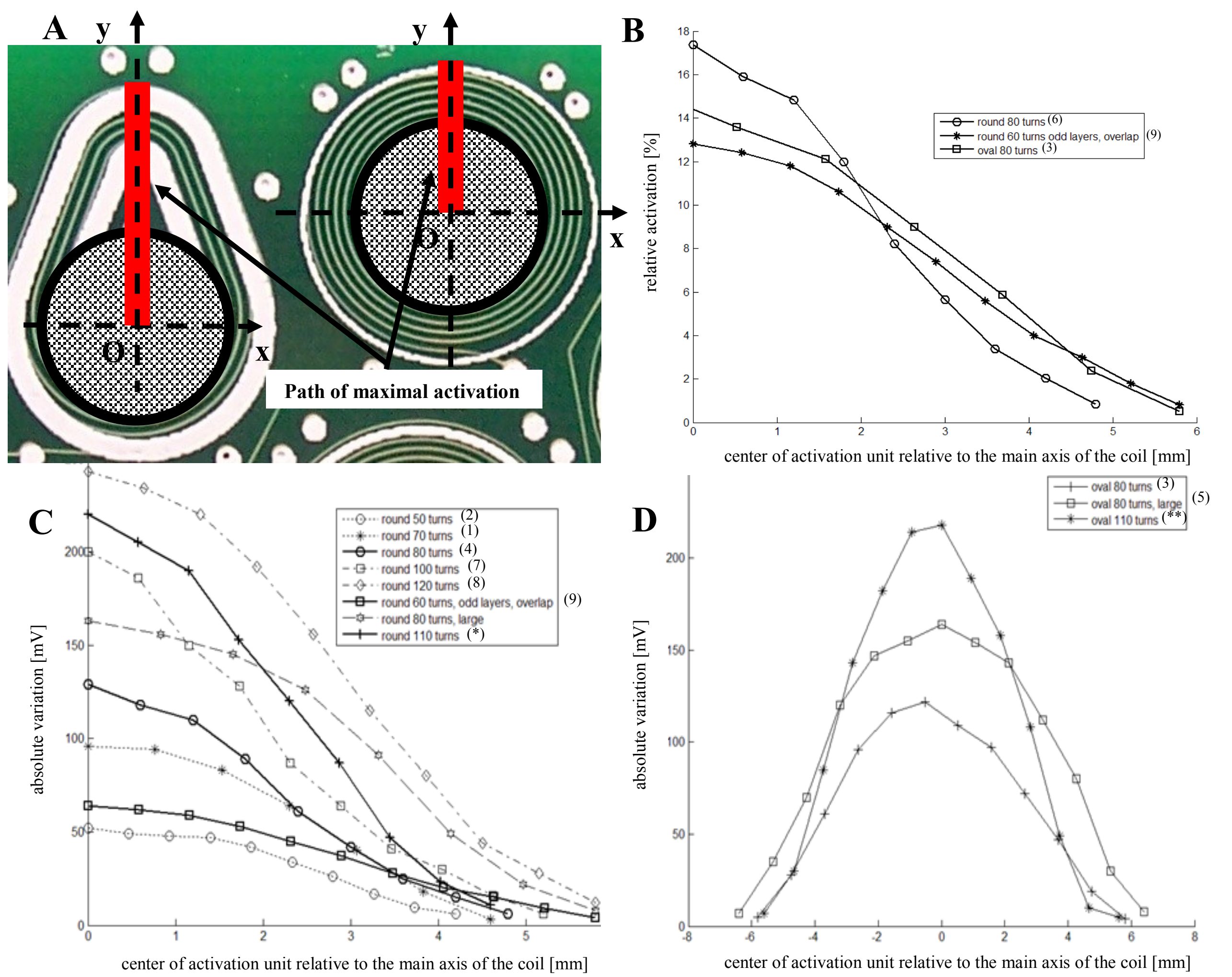

Figure 3. Characterization of activation of test sensors (sensor number as in Fig. 2A) and sensors of the tongue control system (round (*) and oval (**) sensors from Fig. 2B). **A** Round (7) and oval (5) coil design, showing the path of maximal activation. The activation unit is illustrated in a position generating a maximal signal. Evaluation of the path of maximal activation starts from edge-to edge position of the activation unit relative to the sensor. **B** Relative activation, expressed as $100{*}U_{emf\text{-}ACTIVE} / U_{emf}$ for the round coils (6), (9) and oval coil (3) from coil center to edge-to-edge position of the activation unit relative to the coil (x1000 gain). **C** Absolute variation of the induced voltage for activation of the round coils from coil center to edge-to-edge position of the activation unit relative to the coil (x1000 gain). **D** Absolute variation of the induced voltage for activation of the oval coils from edge-to-edge to edge-to-edge position of the activation unit relative to the coil along the main axis (x1000 gain).

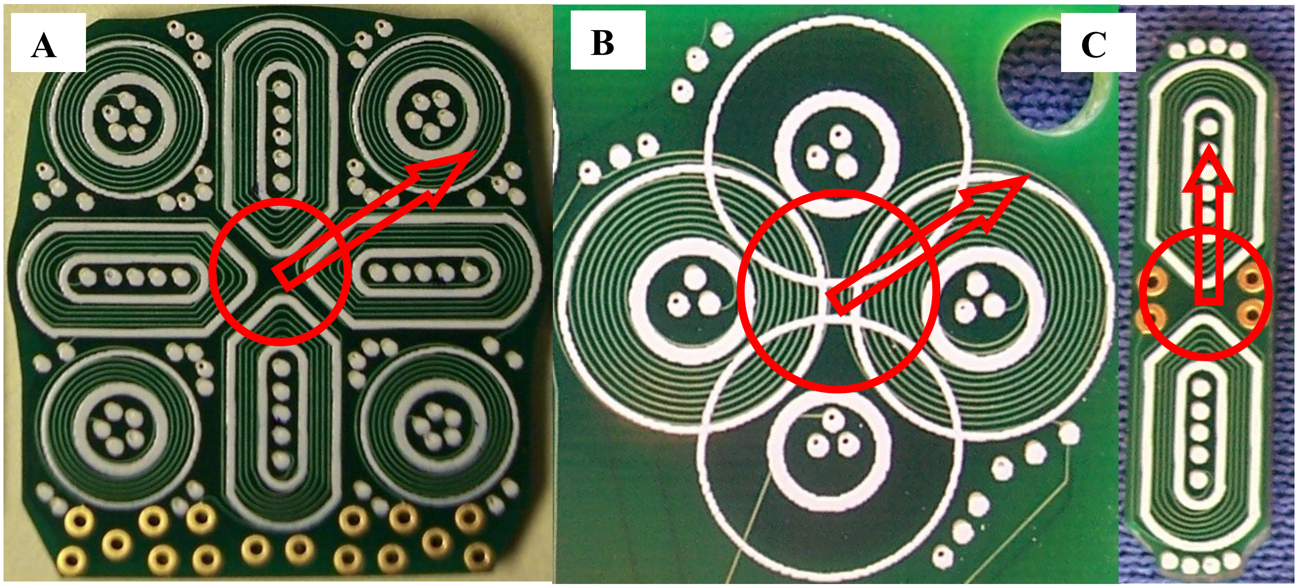

Figure 4. **A** Mouse pad implemented in the oral interface. **B** Proposed design with 4 interlaced sensors. **C** Proposed design with two sensors using linear translation. Activation unit of 4 mm diameter relative to each layout illustrated by the round circle in the middle of the pad.

A couple of years ago, a 10 layers PCB design with width of 100 μm of the copper wire and pad thickness of 1.2 mm was at the limit between standard and small series (i.e. research projects) PCB manufacturing. Two years ago a 10 layer and 75 μm copper wire design with pad thickness of 0.8 mm was manufactured, not without technical difficulties though. A high manufacturing tolerance for the width of the line and space produced boards with a relative high variability of impedance of sensors that required selection to avoid additional calibration measures. Lines and spaces of 50 μm can nowadays be obtained, however this limit cannot be further much lowered due to the increase in the sensor's impedance resulting in a reduced efficiency of activation. Furthermore, the number of layers manufactured has increased from 10 up to 20, in certain circumstances, having a reduced thickness of the core layers by almost 60%. Consequently a longer path of the current and building of 'more power' of the sensor along the height of the PCB sandwich structure may be obtained with the benefit of reducing the size of the planar loops. However a limit exists as well. The planes away from the surface of activation (i.e. the contact surface between the sensor and the activation unit) have a lower efficiency of activation as the distance to the activation surface increases [6].

Limits of the PCB technology may be compensated through layout design such the proposed examples in this paper. Further detailed analysis of optimization of alternative layout design has to be performed. Association with ambiguous keyboard layouts may be beneficial in reducing the size of the oral interface.

References

[1] A. Craig, Y. Tran, P. McIsaac, and P. Boord, "The efficacy and benefits of environmental control systems for the severely disabled," Med. Sci.Monit., 11(1), 2004.

[2] D. Ding, R. A. Cooper, B.A. Kaminski, J. R. Kanaly, A. Allegretti, E. Chaves, and S. Hubbard, "Integrated control and related technology of assistive devices," Asst. Technol. 15, 2003.

[3] X. Huo and M. Ghovanloo. "Evaluation of a wireless wearable tongue-computer interface by individuals with high-level spinal cord injuries," J. of Neural Eng., 7(2), 2010.

[4] R. Raya, J. Roa, E. Rocon, R. Ceres, J.L. Pons. "Wearable inertial mouse for children with physical and cognitive impairments," Sensors and Actuators A: Physical 162(2), 2010.

[5] L. N. S. Andreasen Struijk, "An Inductive Tongue Computer Interface for Control of Computers and Assistive Devices," IEEE Trans on BME, 53(12), 2006.

[6] R. Lontis and L. N. S. Andreasen Struijk, "Design of inductive sensors for tongue control system for computers and assistive devices," Disabil Rehabil Assist Technol. 5(4), 2010.

[7] L. N. S. Andreasen Struijk, E. R. Lontis, B. Bentsen, H. V. Christensen, H. A. Caltenco, M. E. Lund, "Fully Integrated Wireless Inductive Tongue Computer Interface for Disabled People," EMBC 2009, Minneapolis USA, 2009.

[8] R. Lontis, M.E. Lund, H.V. Christensen, B. Bentsen, Bo, M. Gaihede, H. Caltenco, L.N.S. Andreasen Struijk. "Clinical evaluation of wireless inductive tongue computer interface for control of computers and assistive devices," EMBC2010 Buenos Aires, Argentina, 2010.

[9] R. Lontis, H. A. Caltenco , B. Bentsen, H. V. Christensen, M. E. Lund and Lotte N. S. Andreasen Struijk , "Inductive Pointing Device for Tongue Control System for Computers and Assistive Devices," EMBC 2009, Minneapolis USA, 2009.

[10] H. Caltenco, R. Lontis, and L.N.S. Andreasen Struijk. "Fuzzy inference system for analog joystick emulation with an inductive tongue-computer interface**,"** Int. Federation for Med. & Biol. Eng. Proc., 34, 2011.

[11] M. E. Lund, H. A. Caltenco, E. R. Lontis, H. V. Christensen, B. Bentsen and L. N. S. Andreasen Struijk, "A Framework for Mouse and Keyboard Emulation in a Tongue Control System," EMBC 2009, Minneapolis USA, 2009.

[12] M. E. Lund, H. V. Christiensen, H. A. Caltenco, E. R. Lontis, B. Bentsen, L. N. S. Andreasen Struijk, "Inductive Tongue Control of Powered Wheelchairs," EMBC 2010, Buenos Aires, Argentina, 2010.

[13] H. A. Caltenco, L. N. S. Andreasen Struijk and B. Breidegard, "TongueWise: Tongue-computer interface software for people with tetraplegia," EMBC 2010, Buenos Aires Argentina, 2010.

[14] H. Caltenco, R. Lontis, S. Boudreau, B. Bentsen, J. Struijk, L.N.S. Andreasen Struijk. "Tip of the tongue selectivity and motor learning in the palatal area," IEEE Trans. on BME., 59 (1), 2012.

[15] H. Caltenco, B. Breidegard, B. Jönsson, L.N.S. Andreasen Struijk. "Understanding computer users with tetraplegia : survey of assistive technology users," Int. J. of Human-Comp. Inter., 2012.