31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Inductive Pointing Device for Tongue Control System for Computers and Assistive Devices

Eugen R. Lontis, Hector A. Caltenco *Student Member, IEEE*, Bo Bentsen, Henrik V. Christensen, Morten E. Lund *Student Member, IEEE* and Lotte N. S. Andreasen Struijk

***Abstract*—Experimental results for pointing tasks using a tongue control system are reported in this paper. Ten untrained subjects participated in the experiment. Both typing and pointing tasks were performed, in three short-term training sessions, in consecutive days, by each subject. The system provided a key pad (14 sensors) and a mouse pad (10 sensors with joystick functionality) whose placements were interchanged (front, back) in half of the subjects. The pointing tasks consisted of selecting and tracking a target circle (of 50, 75 and 100 pixels diameter) that occurred randomly in each of the 16 positions uniformly distributed along the perimeter of a layout circle of 250 pixels diameter. The throughput was of 0.808 bits per second and the time on target was of 0.164 of the total tracking time. The pads layout, the subjects, the sessions, the target diameters, and the angle of the tracking direction had a statistically significant effect on the two performance measures. Long term training is required to assess the improvement of the user capability.**

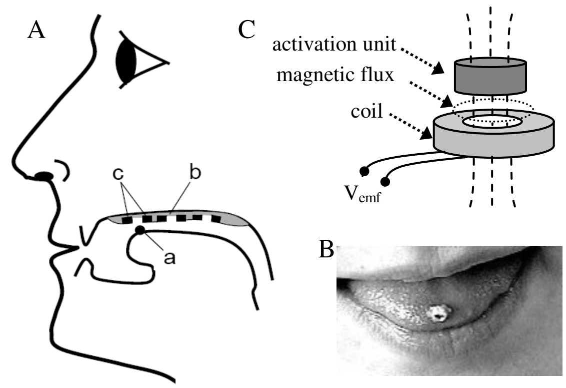

Fig. 1. Inductive tongue control system A. Placement of sensors and activation unit B. Activation unit C. Principle of activation. Modified from [2] with permission, © 2006 IEEE.

I. Introduction

Injuries of the sensory-motor system in humans induce a high degree of movement disability. Lost motor functions can often be compensated up to a degree by the personal aids such as wheelchairs, automatic doors, or kitchen hardware. Control can be obtained using the brain, eyes, head, voice and tongue, whose functionality is still intact after the injury [6], [7], [12]. The complexity and effectivity of the task performed and the limitations of the transducer (sensor) outline the technical difference between these systems. Furthermore, the user's preferences, such as esthetics and a reduced induced fatigue, are often decisive in appreciation of the system's quality. Interfacing systems have been continuously developed for a better performance with regards of both technical and commercial (user's) criteria [12]. Sensors play an important role in interfacing an assistive device with the user. Sensor design must consider the functionality, the ability to provide detectable signals at low power supply, and the complexity and cost of the manufacturing process.

Recently, a new system for tongue control interface has been developed, based on inductive sensors [2], [9]. The sensor consists of an air-cored coil and an activation unit (Fig. 1). This unit is a soft ferromagnetic material that, if placed in or at the core of the coil, changes the inductance 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 ratio of the magnetic flux to the current defines the inductance L (1). The induced voltage U_{emf} in the coil changes with inductance according to Faraday's law (2).

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

Mainly, this sensor functions as a switch, similar to a key from a keyboard [2]. To increase functionality, a network of sensors has been designed to provide as well a two-dimensional movement detection required by a pointing device possibly with different degrees of activation [9]. Furthermore, the geometry of the coil must be reduced such that a larger number of keys and a larger area of the movement detection can be accommodated in the palatal arch of the oral cavity.

The paper presents the experimental results obtained with the first prototype implemented for human use with sensors manufactured in printed circuit board technology [9]. The experiment has been performed during three consecutive

Manuscript received June, the 20th 2009. This work was supported in part by the Danish National Research Council and by TKS A/S.

E. R. Lontis is with Center for Sensory Motor Interaction (SMI), Dept. of Health Science and Technology, Aalborg University, Fredrik Bajers Vej 7, D3, 9220 Aalborg, Denmark (phone: +45 99409842; fax: +45 98154008; e-mail: lontis@hst.aau.dk).

H. V. Christensen is with CISS, Dept. of Electronic Systems, Aalborg University, Fredrik Bajers Vej 7, C1, 9220 Aalborg, Denmark (e-mail: vie@es.aau.dk).

L. N. S. Andreasen Struijk (email: naja@hst.aau.dk), B. Bentsen (brasse@hst.aau.dk), M. E. Lund (mel@hst.aau.dk) and H. A. Caltenco (hca@hst.aau.dk) are with Center for Sensory Motor Interaction (SMI), Dept. of Health Science and Technology, Aalborg University, Fredrik Bajers Vej 7, D3, 9220 Aalborg, Denmark.

978-1-4244-3296-7/09/$25.00 ©2009 IEEE

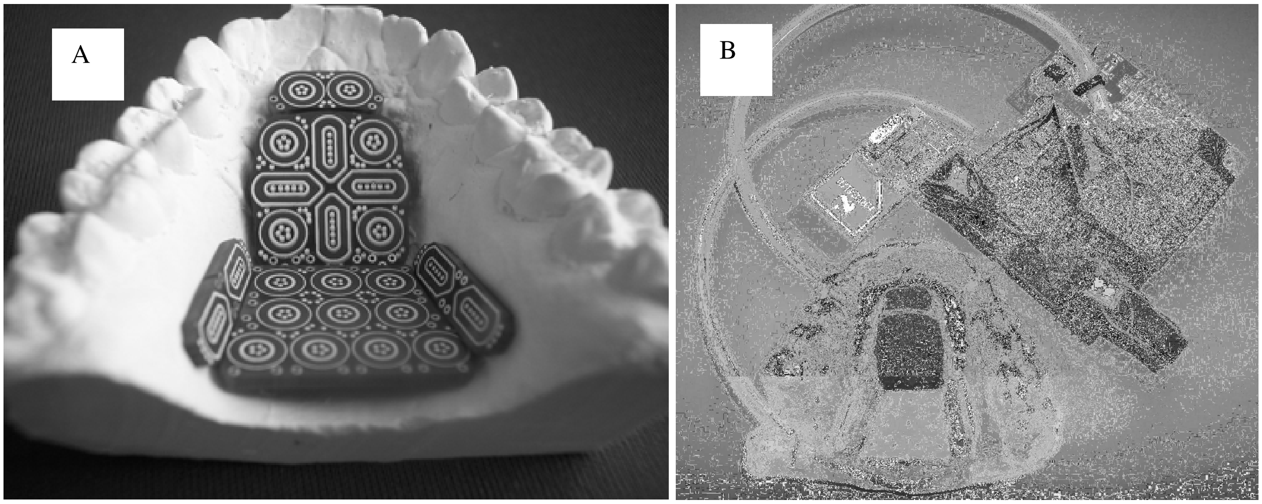

Fig 2. A. Sensors placement on the palate (illustrated on a mold of subject's oral cavity, not encapsulated panels). Two front panels used as mouse pad and the three back panels used as key pad. Two layouts are defined by the mouse pad position relative to the key pad position (front - back). Layout mouse pad front, key pad back is illustrated. B. The encapsulated mouthpiece connected by a cable to the electronics.

days. Each day, a training session of typing and pointing tasks has been performed. Results of the typing tasks have been reported in [5]. Further development of the tongue control system prototype used in this experiment has been described in [4], [10].

II. Methods

A. *Tongue Control System: Pointing Device*

Eight sensors build on the same panel (Fig. 2A) ensured a joystick type of functionality for the pointing device. The two frontmost sensors were used additionally as right and left click mouse functions. The lower panel with 10 sensors and the two lateral panels with two sensors each ensured a keyboard type of functionality, similar to a mobile phone keypad. The eight sensors panel of the mouse pad and the ten sensors panel of the key pad were interchanged in the two pad layouts used in two groups of subjects. The activation unit (AU) was glued at approximately 1 cm back of the tip of the tongue with tissue glue (Fig. 1B). AU was of cylindrical form of 4.5 mm diameter and 2 mm height, made of soft ferromagnetic material. AU positioning in the middle of the mouse pad (zero point) yielded no movement of the mouse pointer on the screen, whereas AU radial displacement yielded mouse pointer movement along approximately the same radial direction, with a speed proportional with the distance between the AU position and the zero point. All sensors panels were encapsulated in two DURAN thermoplastic sheets casted under vacuum on the mould of the subject's palate of the oral cavity (Fig. 2B), and sealed with dental acrylic. The sensors were connected through a cable to an external electronic device that provided a radio link with an USB based radio connected to a computer. Data was processed in Matlab by a fuzzy inference engine.

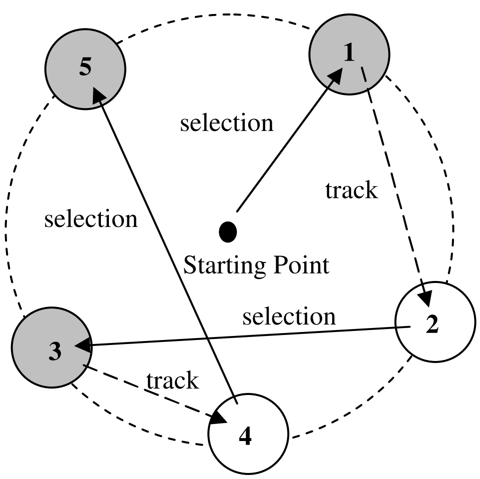

Fig. 3 Example of 5 consecutive positions of the target circle at random along the layout circle during tracking and selection tasks.

B. *Experimental Protocol*

Ten subjects participated in the experiment and signed a consent form. However, one subject did not complete the pointing task, and the data was discarded. Five personalized mouthpieces for each of the two layouts (mouse pad in front, key pad in the back, illustrated in Fig. 2A, and mouse pad in the back, key pad in front) were manufactured, respectively. Typing and pointing tasked that last approximately two hours were performed by all subjects, in a random order during the experiment, in three sessions in three consecutive days.

The pointing task required target selection and target tracking. Circles of 50, 75 and 100 pixels in diameter occurred randomly in each of the 16 positions uniformly distributed along a layout circle of 250 pixels radius. The center of the layout circle was the starting point for the pointing task, respectively for the selection task. As long as the target circle was selected, it moved along a straight line towards a new position on the layout circle. Reaching the new position determined a jump of the circle and the start of a new selection procedure (Fig. 3). The circle stopped if the mouse pointer was positioned outside the circle. Tracking continued after the mouse cursor was positioned again inside of the target.

C. Data Analysis

Target selection task was evaluated by *throughput* (*THP*), expressed in bits per seconds (bps) defined according to the ISO 9241-9 standard for evaluating pointing devices [1], [8], [11]:

$$Throughput = \frac{ID}{MT} \quad (3) \quad ID = \log_2\left(\frac{A}{W_e}+1\right) \quad (4),$$

where MT is the movement time, expressed in seconds, used as measure for the speed of selection. ID is the index of difficulty expressed in bits; A is the distance to the target and W_e is the diameter of target circles.

Tracking task was evaluated by *time on target* (*TOT*). *TOT* was the ratio between the time when the pointer was inside the target and the total time required by the target to move between two consecutive positions on the layout circle, during the tracking task [8].

Analysis of variance for repeated measures was performed to evaluate the effects of the following factors: subjects of 9 levels, session of 3 levels, diameter of the target circle of 3 levels, and the angle of the tracking line of 16 levels, with 2 repetitions. The effect of the layout was evaluated with treatment comparison.

TABLE I
ANOVA TABLE FOR THE MAIN FACTORS

	DF	SSq	MSq	F
Throughput (*THP*): factorial design				
subject	8	107.6	13.45	151.9
session	2	30.28	15.14	170.9
target	2	6.05	3.02	34.16
angle	15	9.41	0.62	7.08
Residual	1296	114.8	0.088	
Total	2591	399.9		
Time On Target (*TOT*): factorial design				
subject	8	4.35	0.5440	26.86
session	2	1.79	0.8964	44.27
target	2	8.77	4.3893	216.79
angle	15	4.85	0.3235	15.98
Residual	1296	26.23	0.0202	
Total	2591	51.75		
Throughput (*THP*): treatment comparison				
layout	1	1.84	1.84	11.99
Residual	2590	398.06	0.15	
Total	2591	399.9		
Time On Target (*TOT*): treatment comparison				
layout	1	1.13	1.13	57.92
Residual	2590	50.62	0.019	
Total	2591	51.75		

DF: degrees of freedom SSq: sum of squares
MSq: mean sum of squares F: MSq_factor/MSq_residual

III. RESULTS

Throughput and *time on target* are illustrated in Fig. 3 for a target circle of 100 pixels diameter, for both layouts of the mouse-key pads and for all levels of the factors subject, session and angle of the tracking direction. Analysis of variance is illustrated in Table 1 for factorial design and for treatment comparison.

The total mean for *THP* was of 0.808 bps and for *TOT* was of 0.164. The change in the layouts of the mouse-key pads produced a statistically significant difference in the system

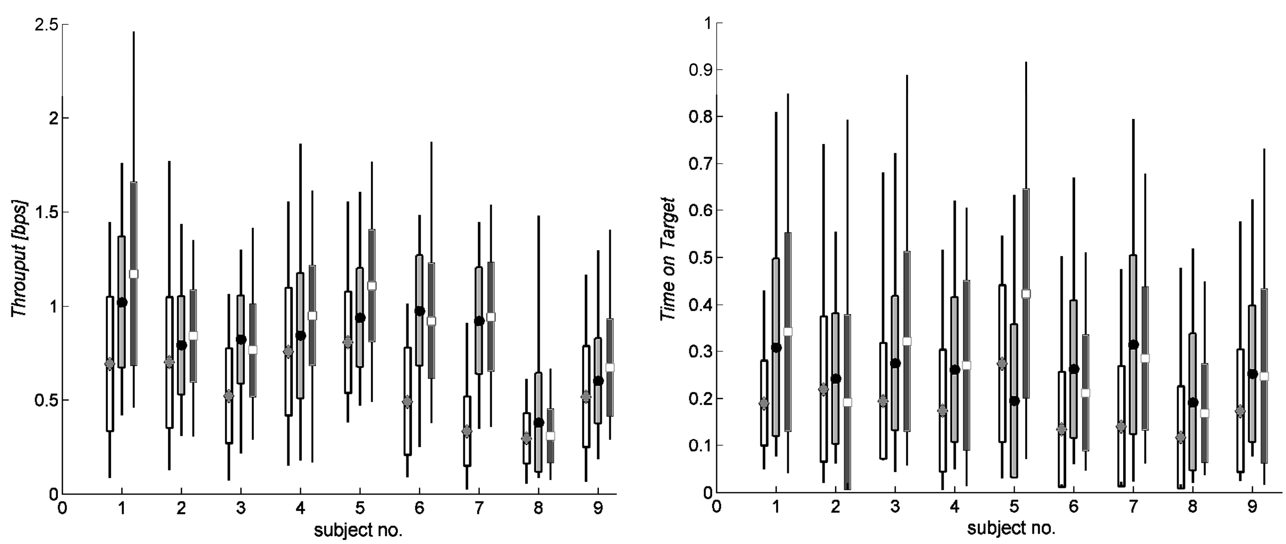

Fig. 3. *Throughput* and *time on target* for targets of 100 pixels diameter. The mean value (diamond, star and square), the standard deviation (empty, gray and black rectangles), and the maximum and minimum values (line ends) are shown for each of the three session, for each subject. Subjects 1, 2, 6 and 8 used the mouse pad in the front, key pad in the back layout, and subjects 3, 4, 5, 7, 9 used the key pad in the front, mouse pad in the back layout.

performance ($p<0.01$) with the marginal mean of 0.14 and 0.183 for *TOT* and of 0.778 and 0.832 bps for *THP*. All factors in the factorial design produced a statistically significant difference in *THP* and *TOT* ($p<0.01$). Minimum and maximum marginal mean for the subject factor were of 0.372 and 1.089 bps for *THP* and of 0.101 and 0.185 for *TOT*; for the session factor were of 0.657 and 0.863 bps for *THP* and of 0.127 and 0.186 for *TOT*; for the diameter of the target factor were of 0.744 and 0.818 bps for *THP* and of 0.101 and 0.185 for *TOT*, and for the angle of the tracking direction factor were of 0.633 and 0.836 bps for *THP* and of 0.194 and 0.225 for *TOT*.

IV. Discussions

Comparative to results reported in the literature [1], the pointing device presented in this paper has a lower performance (*THP* of 0.8 bps and *TOT* of 0.16) than the joystick (*THP* of 1.09 bps and *TOT* of approx 0.82). The performance is even lower as compared with the standard mouse and touch screen (approx. *THP* of 2.2 bps and *TOT* of 0.95), and with the eye tracking system (approx. *THP* of 2 bps and *TOT* of 0.7).

Better performance has been obtained for the configuration key pad front, mouse pad back. This configuration is recommended as well for further implementations due to eating and drinking effects. These effects have been evaluated at the end of the third session and only the first two rows of sensors placed frontmost have been activated. Acknowledgment time technique for activation can be use to counter these effects. Furthermore, a piercing will replace the glued activation unit for long term use [4], [10].

The system developed represents the proof of concept of the mouse and key pad activated by tongue using inductive sensors. The performance of the system can be improved by a better system design (better signals and sensors arrangement), and a prolonged user training. Tongue fatigue has been rated as 2.25 in the mean on a scale from 0 (no effort) to 10 (very hard). However, the normal use of our mouse pad differs slightly from a standard joystick. As soon as the stick is released in a standard joystick no signals are provided and the stick returns to the zero point. A new activation can be predicted by the way the stick is manipulated. For our joystick, however, as soon as the activation unit is lifted from the sensor no visual feedback (i.e. lack of reference) is provided by the mouse cursor on the screen and a new landing of the activation unit on the mouse pad in an other position than the zero point may induce an undesired displacement of the mouse cursor on the screen. Furthermore, the lack of reference has been seen not only when lifting the AU, but when AU slides around the border of the eight sensors panel of the mouse pad as well. A high border around this panel can provide adequate tactile reference, so that the movement of the AU can be limited to the active surface of the panel. The lack of reference might be the main cause of the high variability of each factor in the analysis performed, however training and appropriate visual feedback (such as cursor size and shape on screen) may compensate for this loss.

The session factor has shown statistically significant difference induced in system performance. Based on the first prototype with only a key pad of hand made sensors [2], [9] relative simple typing tasks can be learned (i.e. close to the plateau area of the learning curve after three sessions). Due to the extra complexity of the typing tasks added during a session, we estimate that the subject has not reached the plateau of the learning curve, and extra practice is required. Performance analysis of the typing tasks has shown as well that the learning curve for typing has not been reached. We expect that long term training would improve the overall performance of the system.

References

[1] J. San Agustin, J. Schantz, and J. P. Hansen, “Eye Trackers: Are They Game?,” Proceedings of the 3rd Conference on Communication by Gaze Interaction, COGAIN 2007, Leicester, UK.

[2] L. N. S. Andreasen Struijk, “An Inductive Tongue Computer Interface for Control of Computers and Assistive Devices,” IEEE Trans on BME, vol 53, 12, pp 2594-2597, Dec 2006.

[3] L. N. S. Andreasen Struijk, “Tongue based control method and system for performing the method,”.International Patent application WO 2006/105797 A2, 2006.

[4] 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,” Submitted for publication in EMBC 2009, 31st Annual International Conference of the IEEE Engineering in Medicine and Biology Society. 2009.

[5] H. A. Caltenco, E. R. Lontis, J. J. Struijk, M. E. Lund and L. N. S. Andreasen Struijk, “Character Activation Time Prediction Model for Tongue-Typing: Adaption of Fitts’s Law,” Submitted for publication in EMBC 2009, 31st Annual International Conference of the IEEE Engineering in Medicine and Biology Society. 2009.

[6] 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.

[7] 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. vol 15 pp 89–97, 2003.

[8] C. Klochek and I. S. MacKenzie, “Performance measures of game controllers in a three-dimensional environment,” Proceedings of Graphics Interface 2006, pp. 73-79. Toronto: CIPS, 2006.

[9] R. Lontis and L. N. S. Andreasen Struijk, “Design of inductive sensors for tongue control system for computers and assistive devices,” International Convention on Rehabilitation Engineering & Assistive Technology, i-CREATe2008, 13-15 May 2008, Bangkok, Thailand. pp. 83-86, 2008.

[10] 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,” Submitted for publication in EMBC 2009, 31st Annual International Conference of the IEEE Engineering in Medicine and Biology Society. 2009.

[11] I. S. MacKenzie, T. Kauppinen, and M. Silfverberg, “Accuracy measures for evaluating computer pointing devices,” Proceedings of the ACM Conference on Human Factors in Computing Systems - CHI 2001, pp. 9-16. New York: ACM, 2001.

[12] R. Platts, and M. Fraser, “Assistive Technology in the Rehabilitation of Patients with High Spinal Cord Lesions,” Para-Plegia, vol. 313, pp 280–287, 1993.