TONGUE MOUSE - COMPARISON OF EXISTING APPROACHES

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Abstract: Elderly people often have difficulties using tools in their household with their own hands. While problems that occur due to presbyopia can be corrected with visual aids, there is no satisfactory universal solution for helping people with hand-related sensor or motor deficiencies. For that reason, we currently explore possibilities tongue-controlled Human Interface Device for use with personal computers: a „tongue mouse". An analysis of existing approaches showed there is currently no satisfactory, user-friendly concept. This paper provides an overview of the current state of the art and compares the existing approaches. First, requirements for a tongue mouse are set and then weighted by pair-wise comparison. For the already existing approaches, it is examined to what extent they meet the requirements. We find that optopalatography, piezoelectric sensors and resistopalatography are promising methods for the creation of a tongue mouse.

1 Introduction

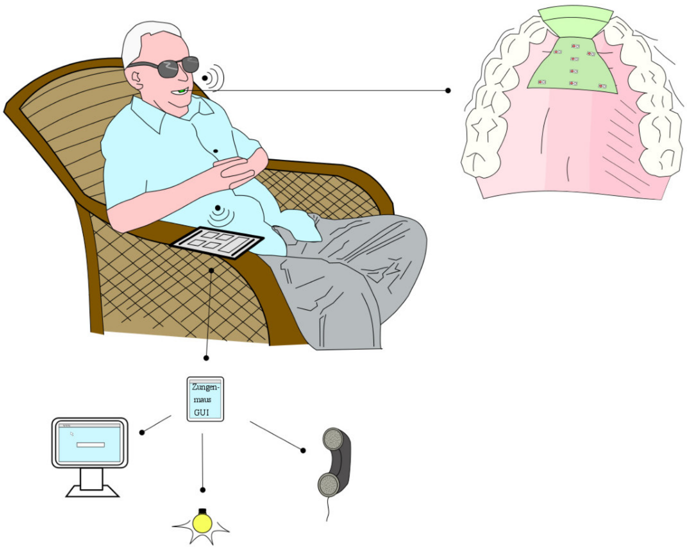

Figure 1 – Concept for a tongue mouse. The user can control devices with their tongue instead of using fingers.

Elderly people often have difficulties using tools in their household with their own hands. In Germany alone, half a million people suffer from rheumatism [1], the loss of function of one or more limbs (175.000 at the age of 55 years or older [2]), or Parkinson's disease with 220.000 affected patients [3]. Currently, there is no satisfactory universal solution to help people with hand-related sensor or motor deficiencies. For that reason, we currently explore possibilities tongue-controlled Human Interface Device for use with personal computers: a „tongue mouse“. The general idea of the tongue mouse is illustrated in Figure 1. An analysis of existing approaches showed that there is currently no satisfactory user-friendly concept. This paper gives an overview of the current state of the art. Figure 2 shows a taxonomic tree of the different methods , which have been used in tongue-based control units in the literature. Examples of these technologies are provided in Figure 3. According to our research, no commercially available system has yet been introduced to the general public.

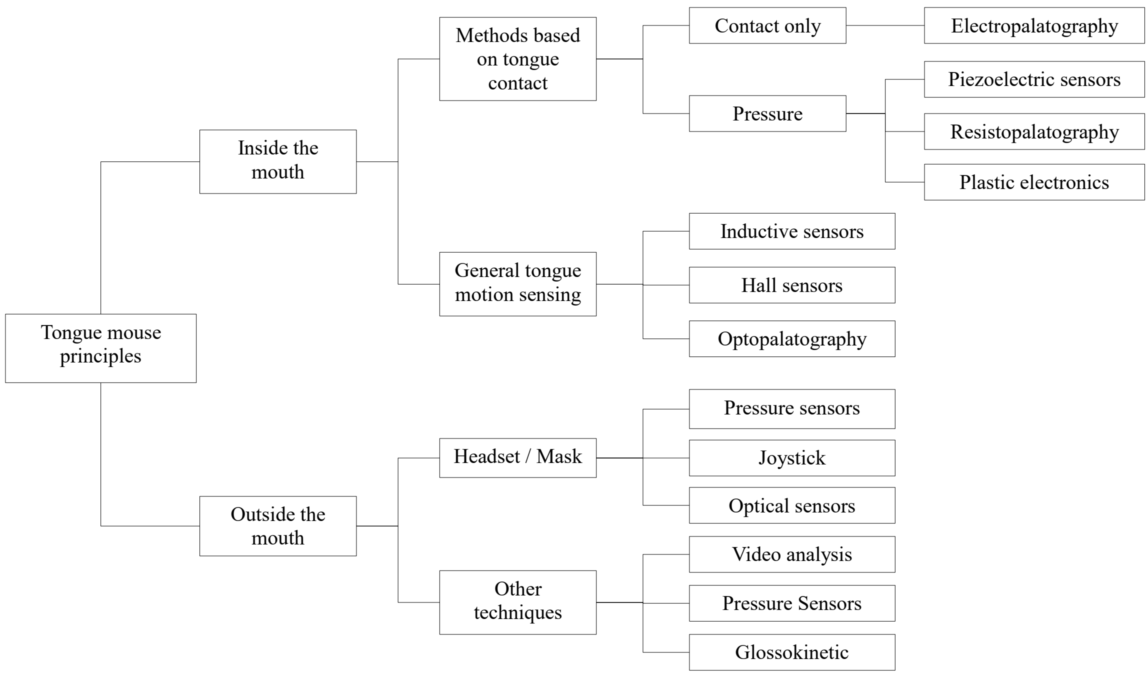

Figure 2 – Overview of existing approaches for a tongue mouse

2 Presentation of the technologies

Electropalatography is a method for the continuous measurement of tongue-palate contacts. The tongue contact is detected by means of a grid of electrodes (over 60 have been used in previous devices) placed on the surface of a thin artificial palate (a pseudopalate). An electrode attached to the user provides an alternating current signal. When the tongue touches one of the electrodes on the palate, the circuit is closed and the tongue-electrode contact is sent as a signal to the higher-level control system for further evaluation [4, 5, 6, 7, 8].

Piezoelectric sensors generate small charges when they are pressed. Nutt et al. [9] presented the first tongue mouse build on this concept in 1998. It consists of 16 x 16 piezoelectric ceramic strips. These strips are arranged in x- and y-direction. Thus, the strength and position of the tongue movement can be measured. By moving the tongue on this sensor field a mouse pointer can be controlled on a computer [9].

Resistopalatography systems consist of an intraoral device with force-sensitive resistance sensors. The sensors measure the pressure of the tongue against the hard palate. Horne et al. [10] developed a tongue mouse with 4 sensors to detect the direction, and a central one to implement the mouse click. Two years later, Horne et al. [11] improved their design with 8 sensors for the directions and one for the click event. This device consists of copper traces, which are covered with a polymer film layer. The resistance of the film decreases under pressure. This reduction in electrical resistance is measured and related to the corresponding force [10, 11].

Plastic electronics An ultra-thin array with resistive tactile sensors, which can also be used in aqueous environments, were developed by Kaltenbrunner et al. [12]. A one mm thick (PEN) film was used as substrate. The circuits were fabricated with a hybrid anodic alumina and a phosphonic acid self-assembly monolayer (SAM)-gate dielectric, an air-stable organic semiconductor and a parylene interlayer, separating the active matrix backplane from the sensor layer. A use as a sensor in the mouth is presented in [12].

Inductive sensors The changes of a magnetic field caused by a moving magnet attached to or implanted into the tongue is measured. The tongue control system is based on an intraoral device with sensors that track the movement of a ferromagnetic tongue piercing. Struijk [13] demonstrated the first system, in which inductors were placed on a pseudopalate. In 2009 Struijk et al. [14], Lund et al. [15] presented a further development of their system with 18 coils. Of those 18, 10 sensors to control the keyboard were placed in the anterior palate area and 8 sensors to control the mouth were placed in the posterior area. A clinical evaluation of a wireless version of their system was presented by Lontis et al. [16].

Hall sensors The movement of the tongue is detected by a series of Hall sensors. They measure the magnetic field generated by a small permanent magnet located on the tongue (pierced or glued). The movement of the magnet on the tongue changes the magnetic field. This change is recorded and converted into a mouse movement. Krishnamurthy and Ghovanloo [17] demonstrated a system, where the magnetic sensors were mounted on a dental brace and attached to the outside of the teeth. This made it possible to measure the magnetic field from different angles. Huo et al. [18], Huo and Ghovanloo [19, 20] presented a headset which carried the sensors. The same technique was used by Ramudu and Krishna [21] to design a control system for wheelchairs.

Optopalatography A number of optical distance sensors are mounted on a pseudopalate and measure the distance between the palate and the tongue. Infrared light is emitted from the sensors, which is then diffusely reflected by the surface of the tongue. The sensors measure the intensity of the reflected light, which is related to the distance between the reflecting surface and the receiver [22]. This allows the position of the tongue to be determined and its direction of movement to be deduced or even the reconstruction of the entire tongue contour [23]. An OPG-controlled serious game to support mouth motor exercises was developed by Preuß et al. [24]. Saponas et al. [25] presented in 2009 his first tongue mouse that utilized this measurement principle. A system where the optical sensors are placed behind the teeth was demonstrated by Hashimoto et al. [26].

Headset / Mask Technologies in which sensors are used outside the mouth in the form of a headset or a mask. It is controlled via the tongue, which does not come into direct contact with the sensors. Dang et al. [27] presented two systems with pressure sensors for mouse control with the tongue. The first device was a face mask consisting of four force sensors on the right cheek, two force sensors on the left cheek and one force sensor below the chin. The four force sensors on the left cheek are used to control the mouse, the 5th sensor under the chin is used to implement the mouse click or to select a function. With the two right sensors the scrolling of the mouse can be implemented. The force sensors measure the movement of the tongue within the mouth. The second device presented by Dang et al. [27] is an analog joystick, as it is used in video game controllers, mounted on a headset. On the right side is the joystick to control the mouse, on the left side a single pressure sensor for clicking and selecting. In 2013, Menon et al. [28] presented a technique, where optical sensors are placed on a headset.

Video analysis A video camera mounted outside the mouth films the movements of the tongue, which needs to protrude from the mouth. Using machine vision techniques, these images are converted into mouse movements. Liu et al. [29] and Miyauchi et al. [30] each presented a system of this type.

Pressure sensors By means of pressure sensors, outside the moth a system for recording tongue movements is possible. Chou et al. [31] developed a system, where extra-oral pressure sensors are placed near the mylohyoid muscle. The mylohyoid muscle stretches or shrinks when the user moves the tongue. When the tongue is moved to the left, the left mylohyoid muscle will stretch and the right mylohyoid muscle will shrink. The pressure sensors detect this change.

Glossokinetic The movements of the tongue cause artefacts that are visible in electroencephalography (EEG). These can be measured at various points in the head area. According to Nam et al. [32] the cause is considered to be the glossokinetic potential. They took advantage of this and developed a technique that records the tongue movement by means of electrodes on the head [33, 34, 35]. Nguyen et al. [36] additionally measure the muscle movements with sensors behind the ear by means of electromyography (EMG) and skin surface deformation (SKD).

3 Evaluation

From the the presented measurement technologies, we want to identify the most promising candidate for a tongue mouse.. In order to achieve this, requirements were formulated for the tongue mouse, and evaluated with respect to their relative importance.

No implant The user should not have to tolerate a permanent intervention on the body, such as piercing the tongue.

No contact with electricity The tongue should not come into direct contact with any electric current.

Low tongue effort The tongues' range of motion should be kept relatively low to reduce physical effort. A fatigue-free use of the tongue mouse should be guaranteed.

Low sensor size Due to the limited space within or around the oral cavity, attention should be paid to small sensors. The sensor size should be small enough to build small devices.

Mouse cursor control It should be possible for the user to move the mouse directly in any direction, as opposed to having a limited, discrete set of movement directions (e.g. up, down, left, right).

High sensitivity Although the tongue can be moved almost effortlessly, it can only apply limited pressure without early fatigue. According to [37], $F_{max} = 8.03\,\mathrm{N}$ is the maximum force of the tongue. In their experiments, it has been shown that this force can only be applied by a few test persons. They recommend $F_{actual} < 0.78\,\mathrm{N}$ as the maximum required tongue force.

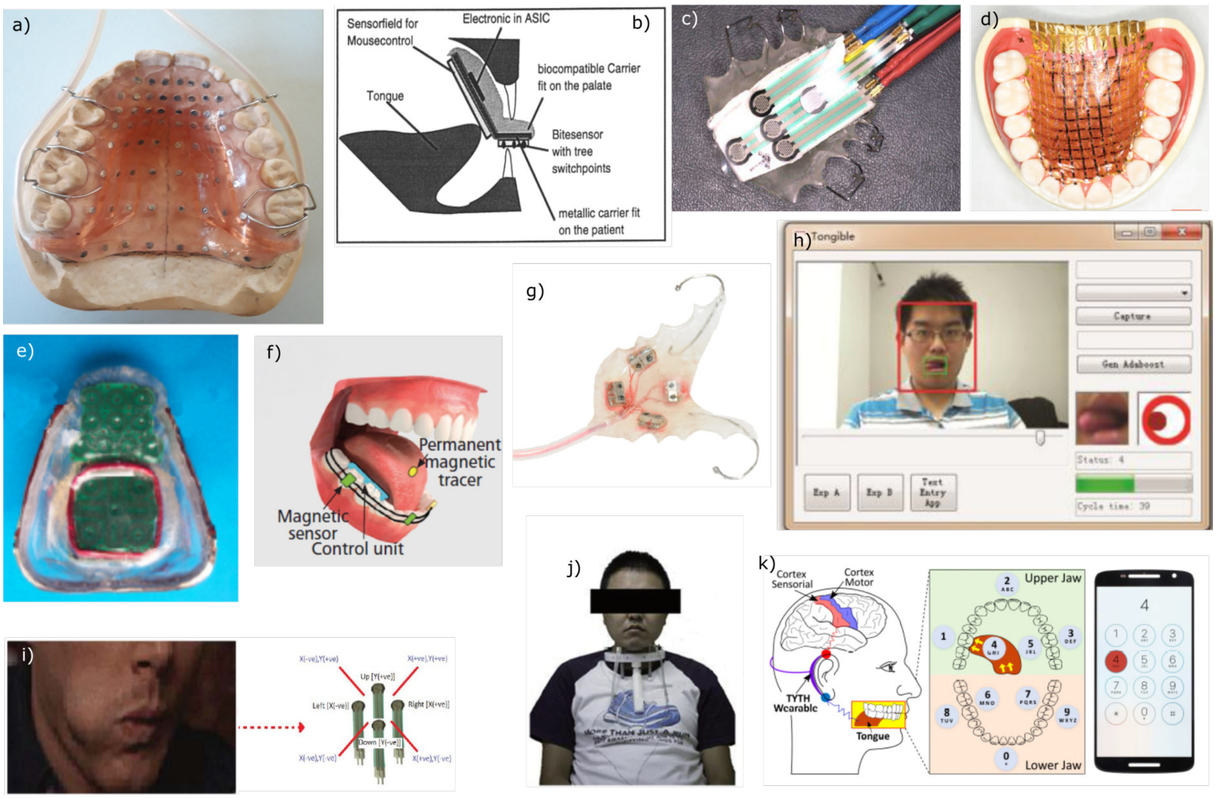

Figure 3 – a) Electropalatography, b) Piezoelectric sensor [9], c) Resistopalatography [10], d) Plastic Electronics [12], e) Inductive sensors [14], f) Hall sensor [17], g) Optopalatography [25], h) Video analysis [29], i) Pressure sensors in a mask [27], j) Pressure sensors on mylohyoid muscle [31], k) Glossokinetic [36]

For oral usage The technology of choice must be applicable for intraoral operation. This means that it must be suitable for operation in a humid, dark environment.

Low power Low energy consumption is desirable because a tongue mouse would most likely be battery-powered and frequent change or recharging of the battery is not user-friendly.

Wireless data transfer The tongue mouse should not have any bothersome cables exiting the user's mouth.

Good reproducibility A high and robust reproducibility of the measurement results ensures trouble-free working with the tongue mouse.

No response to speech If possible, the device should not respond to speech movement. Ideally, the user should be able to speak while wearing the tongue mouse. A movement of the cursor should not be caused by speaking.

No visibility The technology should not be visible from the outside.

Table 1 shows the pairwise comparison of the above mentioned requirements for the tongue mouse. It shows that the requirements „For oral usage“ and „No implant“ receive the highest weighting.

With these requirements, a utility analysis was carried out for the technologies mentioned. For all the technologies considered, the established requirements were examined with regard to their degree of fulfilment and weighted by the factor from the pairwise comparison. Factor "10" means that the criterion is fully met. A lower factor indicates that the corresponding requirement is met less well or not at all. Full score was given when the corresponding requirement does

Table 1 – Pairwise comparison - each criterion is compared with each other. Each column and each row states the respective requirements. At the crossing point of each row and column, the two requirements are compared. If the requirements in the row is more important than the one in the column, the cell is filled with a „1“, otherwise with a „0“. At the end of each row the corresponding total and a percentage factor for weighting are calculated.

	a)	b)	c)	d)	e)	f)	g)	h)	i)	j)	k)	l)	Sum	**Percentage**
a) No implant		1	1	1	1	1	0	1	1	1	1	1	10	**15 %**
b) No contact with electricity	0		1	1	1	1	0	1	1	1	1	1	9	**14 %**
c) Low tongue effort	0	0		0	1	1	0	1	0	0	1	1	5	**8 %**
d) Low sensor size	0	0	1		1	1	0	1	0	0	0	1	5	**8 %**
e) Mouse cursor control	0	0	0	0		0	0	0	0	0	1	1	2	**3 %**
f) High sensitivity	0	0	0	0	1		0	0	1	0	0	0	2	**3 %**
g) For oral usage	1	1	1	1	1	1		1	1	1	1	1	11	**17 %**
h) Low power	0	0	0	0	1	1	0		1	0	0	0	3	**5 %**
i) Wireless transfer	0	0	1	1	1	0	0	0		0	0	0	3	**5 %**
j) Good reproducibility	0	0	1	1	1	1	0	1	1		1	1	7	**11 %**
k) No response to speech	0	0	0	1	0	1	0	1	1	0		0	4	**6 %**
l) No visibility	0	0	0	0	0	1	0	1	1	0	1		4	**6 %**
Sum													**65**	**100 %**

not apply to for the technology under consideration. These entries are marked with *. All weighted factors are summed up per technology. The sum thus obtained gives an impression of which technologies are suitable for a tongue mouse. The analysis is presented in Table 2. Optopalatography reaches the highest value with 8.54 points, followed by piezoelectric sensors and Resistopalatography with 7.94 points each and video analysis with 7.86 points. These four techniques are therefore most suitable to be used in a tongue mouse.

4 Summary

Scientists have been dealing with the topic of controlling a computer or other devices with the tongue for some time. Over the course of the last decades, several prototypes have been developed using numerous measurement technologies to capture tongue movement. To the best of our knowledge, none of them have been implemented in a commercially available device. After requirements for a tongue mouse were established, they were weighted by pairwise comparison. For the already existing approaches, it was examined to what extent they meet the requirements. Based on this analysis, promising methods for the creation of a tongue mouse could be identified: optopalatography, piezoelectric sensor and resistopalatography.

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References

[1] D. G. F. Rheumatologie: *www.drgh.de*. 2019. URL `https://dgrh.de/Start/DGRh/Presse/Daten-und-Fakten/Rheuma-in-Zahlen.html`. [Accessed on: 2019-15-12].

[2] Statistisches Bundesamt: *Statistik der schwerbehinderten Menschen*. 2017. URL `http://www.gbe-bund.de/oowa921-install/servlet/oowa/aw92/`

Table 2 – Utility analysis. For all technologies considered, the criteria established are examined with regard to their degree of fulfilment and weighted by the factor from the pairwise comparison. The resulting sum for each technology gives an impression of which technologies are suitable for a tongue mouse.(* Full score was given here because the corresponding requirement does not apply for the technology under consideration.)

		Electropalatography		Piezoelectric sensors		Resistopalatography		Plastic electronics		Inductive sensors		Hall sensors	
	Weighting	Evaluation	Value	Evaluation	Value	Evaluation	Value	Evaluation	Value	Evaluation	Value	Evaluation	Value
No implant	15%	10	1.54	10	1.54	10	1.54	10	1.54	-	-	-	-
No contact with electricity	14%	-	-	10	1.38	10	1.38	10	1.38	10	1.38	10	1.38
Low tongue effort	8%	10	0.77	5	0.38	5	0.38	5	0.38	10	0.77	10	0.77
Low sensor size	8%	10	0.77	8	0.62	8	0.62	10	0.77	10	0.77	10	0.77
Mouse cursor control	3%	10	0.31	5	0.15	5	0.15	7	0.22	7	0.22	7	0.22
High sensitivity	3%	5	0.15	5	0.15	5	0.15	5	0.15	5	0.15	5	0.15
For oral usage	17%	10	1.69	10	1.69	10	1.69	10	1.69	10	1.69	10	1.69
Low power	5%	5	0.23	5	0.23	5	0.23	5	0.23	5	0.23	5	0.23
Wireless transfer	5%	-	-	-	-	-	-	-	-	10	0.46	-	-
Good reproducibility	11%	8	0.86	8	0.86	8	0.86	5	0.54	8	0.86	8	0.86
No response to speech	6%	5	0.31	5	0.31	5	0.31	5	0.31	5	0.31	5	0.31
No visibility	6%	10	0.62	10	0.62	10	0.62	10	0.62	10	0.62	10	0.62
Sum			7.25		7.94		7.94		7.83		7.46		7.00

		Optopalatography		Headset / Mask		Video analysis		Pressure sensors		Glossokinetik	
	Weighting	Evaluation	Value	Evaluation	Value	Evaluation	Value	Evaluation	Value	Evaluation	Value
No implant	15%	10	1.54	10	1.54	10	1.54	10	1.54	10	1.54
No contact with electricity	14%	10	1.38	10	1.38	10	1.38	10	1.38	10	1.38
Low tongue effort	8%	10	0.77	3	0.23	10	0.77	5	0.38	5	0.38
Low sensor size	8%	10	0.77	8	0.62	4	0.31	5	0.38	5	0.38
Mouse cursor control	3%	7	0.22	3	0.09	10	0.31	10	0.31	10	0.31
High sensitivity	3%	5	0.15	5	0.15	5	0.15	5	0.15	5	0.15
For oral usage	17%	10	1.69	10*	1.69	10	1.69	10*	1.69	10*	1.69
Low power	5%	5	0.23	5	0.23	5	0.23	5	0.23	2	0.09
Wireless transfer	5%	-	-	-	-	-	-	-	-	-	-
Good reproducibility	11%	8	0.86	8	0.86	8	0.86	5	0.54	5	0.54
No response to speech	6%	5	0.31	5	0.31	5	0.31	5	0.31	5	0.31
No visibility	6%	10	0.62	8	0.49	5	0.31	-	-	-	-
Sum			**8.54**		7.60		7.86		6.92		6.78

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[3] *Parkinson aktuell*. 2019. URL https://www.parkinson-aktuell.de/was-ist-parkinson/haeufigkeit-und-formen-von-parkinson. [Accessed on: 2019-15-12].

[4] BIRKHOLZ, P. and C. NEUSCHAEFER-RUBE: *Combined optical distance sensing and electropalatography to measure articulation*. In *Proc. of the Twelfth Annual Conference of the International Speech Communication Association*, pp. 258–288. Florence, Italy, 2011.

[5] VERHOEVEN, J., N. MILLER, L. DAEMS, and C. REYES-ALDASORO: *Visualisation and analysis of speech production with electropalatography*. *Journal of Imaging*, 5(3), p. 40, 2019.

[6] CLAYTON, C. J.: *An intra-oral access device*. *Journal of Medical Engineering & Technology*, 16(5), pp. 204–209, 1992.

[7] TANG, H. and D. BEEBE: *An oral tactile interface for two-way communication*. In *Proc. of the 1st Annual International IEEE-EMBS Special Topic Conference on Microtechnologies in Medicine and Biology*, pp. 639–643. Lyon, France, 2000.

[8] DRAGHICI, O., I. BATKIN, M. BOLIC, and I. CHAPMAN: *The mouthpad: A tongue-computer interface*. In *Proc. of the IEEE International Symposium on Medical Measurements and Applications (MeMeA)*, pp. 315–319. Gatineau, QC, Canada, 2013.

[9] NUTT, W., C. ARLANCH, S. NIGG, and G. STAUFERT: *Tongue-mouse for quadriplegics*. *Journal of Micromechanics and Microengineering*, 8(2), pp. 155–157, 1998.

[10] HORNE, R., S. W. KELLY, and P. LEE: *A framework for mouse emulation that uses a minimally invasive tongue palate control device utilizing resistopalatography*. In *Proc. of the HUMASCEND*. Manchester, UK, 2013.

[11] HORNE, R., S. KELLY, and P. SHARP: *Resistopalatography as an assistive technology for users with spinal cord injuries*. In *Proc. of the 2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, pp. 4367–4370. Milan, Italy, 2015.

[12] KALTENBRUNNER, M., T. SEKITANI, J. REEDER, T. YOKOTA, K. KURIBARA, T. TOKUHARA, M. DRACK, R. SCHWÖDIAUER, I. GRAZ, S. BAUER-GOGONEA, S. BAUER, and T. SOMEYA: *An ultra-lightweight design for imperceptible plastic electronics*. *Nature*, 499(7459), pp. 458–463, 2013.

[13] STRUIJK, L.: *An inductive tongue computer interface for control of computers and assistive devices*. *IEEE Transactions on Biomedical Engineering*, 53(12), pp. 2594–2597, 2006.

[14] STRUIJK, L. A., E. LONTIS, B. BENTSEN, H. CHRISTENSEN, H. CALTENCO, and M. LUND: *Fully integrated wireless inductive tongue computer interface for disabled people*. In *Proc. of the 2009 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, pp. 547–550. Minneapolis, MN, USA, 2009.

[15] LUND, M., H. CALTENCO, E. LONTIS, H. CHRISTIENSEN, B. BENTSEN, and L. STRUIJK: *A framework for mouse and keyboard emulation in a tongue control system.* In *Proc. of the 2009 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, pp. 815–818. Minneapolis, MN, USA, 2009.

[16] LONTIS, E. R., M. E. LUND, H. V. CHRISTENSEN, B. BENTSEN, M. GAIHEDE, H. A. CALTENCO, and L. N. S. A. STRUIJK: *Clinical evaluation of wireless inductive tongue computer interface for control of computers and assistive devices.* In *Proc. of the 2010 Annual International Conference of the IEEE Engineering in Medicine and Biology*, pp. 3365–3368. Buenos Aires, Argentina, 2010.

[17] KRISHNAMURTHY, G. and M. GHOVANLOO: *Tongue drive: a tongue operated magnetic sensor based wireless assistive technology for people with severe disabilities.* In *Proc. of the 2006 IEEE International Symposium on Circuits and Systems*, p. 4 pp. Island of Kos, Greece, 2006.

[18] HUO, X., J. WANG, and M. GHOVANLOO: *A magneto-inductive sensor based wireless tongue-computer interface. IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 16(5), pp. 497–504, 2008.

[19] HUO, X. and M. GHOVANLOO: *Using unconstrained tongue motion as an alternative control mechanism for wheeled mobility. IEEE Transactions on Biomedical Engineering*, 56(6), pp. 1719–1726, 2009.

[20] HUO, X. and M. GHOVANLOO: *Tongue drive: a wireless tongue- operated means for people with severe disabilities to communicate their intentions. IEEE Communications Magazine*, 50(10), pp. 128–135, 2012.

[21] RAMUDU, P. and P. M. KRISHNA: *Tongue operated robotic wheel chair using tongue drive assistive technology. International Journal of Engineering Research & Technology (IJERT)*, 2(9), pp. 1209–1212, 2013.

[22] PREUSS, S. and P. BIRKHOLZ: *Optical sensor calibration for electro-optical stomatography.* In *Proc. of the Interspeech*, pp. 618–622. Dresden, Germany, 2015.

[23] PREUSS, S., C. NEUSCHAEFER-RUBE, and P. BIRKHOLZ: *Real-time control of a 2d animation model of the vocal tract using optopalatography.* In *Proc. of the Interspeech*, pp. 997–1001. Lyon, France, 2013.

[24] PREUSS, S., C. ECKERS, P. BIRKHOLZ, and C. NEUSCHAEFER-RUBE: *Ein opg-gesteuertes serious game zur unterstützung mundmotorischer übungen. Studientexte zur Sprachkommunikation: Elektronische Sprachsignalverarbeitung 2014*, pp. 134–141, 2014.

[25] SAPONAS, T. S., D. KELLY, B. A. PARVIZ, and D. S. TAN: *Optically sensing tongue gestures for computer input.* In *Proc. of the 22nd annual ACM symposium on User interface software and technology - UIST*, pp. 177–180. Victoria, British Columbia, Canada, 2009.

[26] HASHIMOTO, T., S. LOW, K. FUJITA, R. USUMI, H. YANAGIHARA, C. TAKAHASHI, M. SUGIMOTO, and Y. SUGIURA: *TongueInput: Input method by tongue gestures using optical sensors embedded in mouthpiece.* In *Proc. of the 2018 57th Annual Conference of the Society of Instrument and Control Engineers of Japan (SICE)*, pp. 1219–1224. Nara, Japan, 2018.

[27] DANG, B., B. PUROHIT, D. SARANG, and K. GEORGE: *Tongue driven wireless electronic communication device*. In *Proc. of the 2017 IEEE Sensors Applications Symposium (SAS)*, pp. 1–5. Glassboro, NJ, USA, 2017.

[28] MENON, K. A. U., R. JAYARAM, and P. DIVYA: *Wearable wireless tongue controlled assistive device using optical sensors*. In *Proc. of the 2013 Tenth International Conference on Wireless and Optical Communications Networks (WOCN)*, pp. 1–5. Bhopal, India, 2013.

[29] LIU, L., S. NIU, J. REN, and J. ZHANG: *Tongible*. In *Proc. of the 14th international ACM SIGACCESS conference on Computers and accessibility - ASSETS*, pp. 233–234. Boulder, Colorado, USA, 2012.

[30] MIYAUCHI, M., T. KIMURA, and T. NOJIMA: *Development of a non-contact tongue-motion acquisition system*. In *Adjunct Proc. of the 25th annual ACM symposium on User interface software and technology - UIST Adjunct Proceedings*, pp. 75–76. Cambridge, Massachusetts, USA, 2012.

[31] CHOU, C.-H., Y.-S. HWANG, C.-C. CHEN, S.-C. CHEN, S.-W. CHOU, and Y.-L. CHEN: *Noninvasive tongue-motion controlled computer mouse for the disabled*. *Technology and Health Care*, 24(3), pp. 401–408, 2016.

[32] NAM, Y., Q. ZHAO, A. CICHOCKI, and S. CHOI: *A tongue-machine interface: Detection of tongue positions by glossokinetic potentials*. In *Proc. of the Neural Information Processing. Models and Applications*, pp. 34–41. Berlin, Heidelberg, 2010.

[33] NAM, Y., Q. ZHAO, A. CICHOCKI, and S. CHOI: *Tongue-rudder: A glossokinetic-potential-based tongue–machine interface*. *IEEE Transactions on Biomedical Engineering*, 59(1), pp. 290–299, 2012.

[34] NAM, Y., B. KOO, A. CICHOCKI, and S. CHOI: *Glossokinetic potentials for a tongue-machine interface: How can we trace tongue movements with electrodes?* *IEEE Systems, Man, and Cybernetics Magazine*, 2(1), pp. 6–13, 2016.

[35] NAM, Y., B. KOO, A. CICHOCKI, and S. CHOI: *GOM-face: GKP, EOG, and EMG-based multimodal interface with application to humanoid robot control*. *IEEE Transactions on Biomedical Engineering*, 61(2), pp. 453–462, 2014.

[36] NGUYEN, P., N. BUI, A. NGUYEN, H. TRUONG, A. SURESH, M. WHITLOCK, D. PHAM, T. DINH, and T. VU: *TYTH-typing on your teeth*. In *Proc. of the 16th Annual International Conference on Mobile Systems, Applications, and Services - MobiSys*, pp. 269–282. Munich, Germany, 2018.

[37] KIM, D., M. E. TYLER, and D. J. BEEBE: *Development of a tongue-operated switch array as an alternative input device*. *International Journal of Human-Computer Interaction*, 18(1), pp. 19–38, 2005.