On the Tip of my Tongue – A Non-Invasive Pressure-Based Tongue Interface

Jingyuan Cheng, Ayano Okoso*, Kai Kunze*, Niels Henze, Albrecht Schmidt**, Paul Lukowicz, Koichi Kise***
DFKI Kaiserslautern, Germany
*Osaka Prefecture University, Japan
**Stuttgart University, Germany
jingyuan.cheng@dfki.de, {okoso,kunze}@m.cs.osakafu-u.ac.jp

ABSTRACT
Mobile and wearable devices became pervasive in daily life. The dominant input techniques for mobile and wearable technology are touch and speech. Both approaches are not appropriate in all settings. Therefore, we propose a novel interface that is controlled through the tongue. It is based on an array of textile pressure sensors attached to the user's cheek. It can be easily integrated into helmets or face masks in a non-invasive way. In an initial study, we investigate gestures for tongue-based interface. Six participants repeatedly performed five simple tongue gestures. We show that gestures can be recognized with 98% accuracy. Based on feedback from participants, we discuss potential use cases and provide an outlook on further improvement of the system.

Author Keywords
Tongue interface; pressure sensor; user interface; hands-free gestures; mobile HCI; wearable computing

ACM Classification Keywords
I.5.4 Pattern Recognition Applications: Signal processing; H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
With wearable and mobile devices on the rise, computing gets more and more integrated into daily lives. A body of work investigated output techniques for mobile applications. Input techniques to control such devices, however, still remain a major challenge. Traditional devices such as keyboard and mouse are of limited use for mobile users. With the ongoing success of smartphones, touch screens are the dominant input technique for mobile interaction. As touch interfaces are typically operated with the hand they do not allow hands-free interaction. Therefore, hands-free input modalities, most prominently voice has gained momentum [15]. However, Shneiderman argues that speech used as an input technique might have inherent limitations [9] and similarly Starner argues that "speech interfaces are not the holy grail for wearables" [10]. The recognition rate of current system is still restrained in noisy settings and social acceptability of using speech-based interfaces in public seems limited.

AH '14, March 07 - 09 2014, Kobe, Japan.

http://dx.doi.org/10.1145/2582051.2582063

Figure 1. Two ways to attach the tongue interface to the cheek. On the left tape is used and on the right a flexible fabric that is also used in the conducted study.

Previous work on assistive devices showed that tongue-based interfaces are a interesting opportunity for human-computer interaction [11]. The amount of sensory receptor on the tongue's surface is comparable to the number of sensory receptor on the hands' surface. Similarly, the number of brain cells that is dedicated to control tongue and mouth movement are approximately the same as the number of cells for controlling our hands [2]. As the tongue is a very flexible muscle, humans are able to perform highly delicate movements. We therefore suspect that users are able perform minute, specialized gestures with their tongue, making the tongue a promising alternative for computer interfaces.

Previous work on tongue-based interfaces focused on assistive systems for users with special needs [**?**]. As these users often rely on assistive technologies they are more willing to use invasive interfaces that, for example, require attaching sensors to the tongue. As tongue-based interaction enables hands-free use we believe that it also offers potential for other user groups. In particular, for situations where users cannot use their hands while interacting with the computer, be it while doing maintenance at machines [3], but also while being in a very crowed metro, riding a motorbike or during surgical operations. Tongue-based interaction requires, however, an interface that is non-invasive and easy to use.

In this paper we present a novel interface that is controlled through the tongue (see Figure 1). An array of resistive textile sensors that can easily be integrated into helmets or face masks is attached to the user's cheek. In the following we first provide an overview about related work. This is followed by a description the interface we developed to enable non-invasive tongue-based interaction. Further, we describe the results of a study that we conducted to explore the use of tongue gestures for human-computer interaction. We close the paper with our conclusions and an outlook to future work.

RELATED WORK

A body of work investigated approaches to provide information via the tongue using tactile feedback. Tang and Beebe, for example, developed an electrotactile display for the roof of the mouth [12]. Similarly, Vuillerme et al. used a tongue placed tactile output device generating electrotactile stimulation of the tongue to provide biofeedback [13].

Previous work that explored how to use the tongue for input, focused on interfaces designed for people with special needs. In particular, inductive or magnetoresistive sensing is used to determine the pose of the tongue inside the user's mouth [5, 7]. These invasive sensing technologies require to place sensors on the user's tongue or to place sensors inside the mouth. Similarly, researchers used optical tracking or piezoelectric film sensors inside the mouth to facilitate tongue-based input [8, 6]. Researchers even investigated the optimal placement of sensor on the tongue to increase tracking accuracy [14]. Such invasive interfaces can have an enormous potential for users that cannot use common input devices due to motor impairments or other special needs. While these systems are, thus, well suited for special target groups in specific situations, we assume that the sensing approaches are to invasive to be used by other user groups.

Invasive tongue interfaces require wearing sensors inside the mouth. They therefore make it difficult to speak, chew or make other use of mouth and tongue. Yousefi et al. investigated less-invasive tongue-based interaction using an externally tracked magnetic tongue stud [16]. Through a trial over five sessions they found that all performance measures improved over time. Liu et al. presented another step towards non-invasive tongue-based interaction [4]. They use an optical system to track tongue gestures while the tongue is outside the user's mouth. Although this is no longer invasive, social acceptability might still be limited.

In summary, previous work showed the potential of tongue-based interfaces. Still, truly a non-invasive input technique is needed to provide a socially acceptable interaction technique. In the following we describe, to the best of our knowledge, the first tongue interface that does neither require augmenting the tongue nor the mouth with an artificial object. We present a pressure-based tongue interface that can easily be attached to the cheeks using a helmet or a mask. The design of the interface is similar to the textile pressure matrix sensor proposed by Zhou et.al. for smart clothing and smart table cloth [17] and is also related to the general trend towards mainstream smart textile [1]. We, however, developed a textile pressure matrix with a much a higher resolution to enable a novel application of smart textiles. In addition, we present an initial study that investigates tongue gestures using a non-invasive tongue interface.

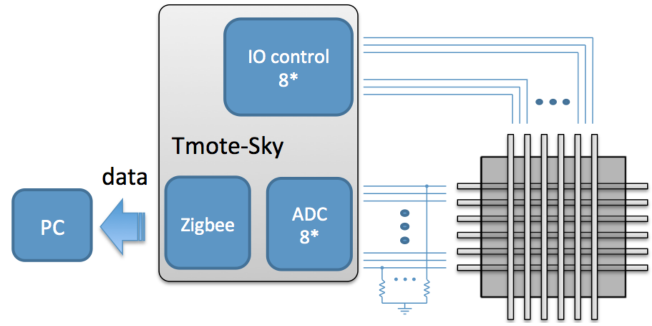

Figure 2. Architecture of the hardware. On the right is the 8 x 8 pressure matrix connected to a Tmote-Sky. While we currently transmit the data over USB, the board has also wireless communication capabilities.

PRESSURE-BASED TONGUE INTERFACE

In contrast to previous work, we decided to detect pressure applied with the tongue on the inside of the cheek using a sensor array attached to the outside of the cheek. This has the advantage of being non-invasive and gives us the possibility to integrate the interface easily in helmets and face masks. In the following, we discuss the hardware design and how we currently attach the prototype to the cheeks.

Hardware Design

To determine the pressure generated by the tongue onto the cheek, we designed a small pressure sensing matrix. The basis for this matrix is a fabric material that has high resistivity in general, yet reduces its resistivity if vertical pressure is applied. When applying two groups of parallel conductive stripes onto the top and bottom side of the pressure-resistive material, each crossing point becomes a pressure sensor. By applying high voltage (setting IO to output '1') on one column and low voltage (setting IO to output '0') on the rest,

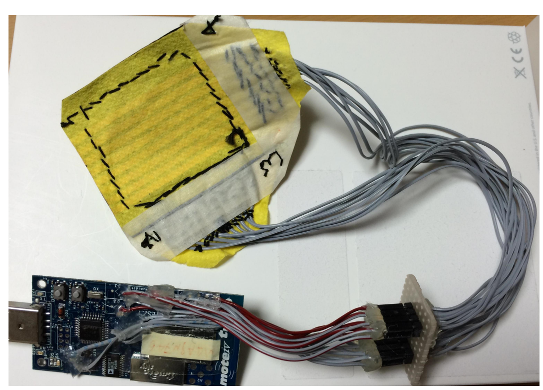

Figure 3. The hardware prototype used for the experiments. The pressure matrix in yellow, connected to the T-Mote Skye in the foreground.

a column of sensors is selected. The voltage is divided by an external resister and reflects the change of the material's local resistance and thus the pressure. After digitalizing this column with a group of ADCs, this column is set to '0' and the next column to '1'.

We cut normal ESD bags for the pressure-resistive material, where the density of mix-in carbon powder grows with pressure and the resistivity drops. We use the Tmote-Sky measuring platform, which provides 8 IO pins, 8 embedded 12-bits ADCs and a USB-Serial interface for data communication, forming a 8×8 pressure matrix with a sampling rate of 13Hz. The system discretizes the 8×8 pressure values from the matrix between 0, for low to no pressure, to 255 for high pressure. The overall architecture is shown in Figure 2.

Attachment to the Face

We tested different ways to attach the tongue interface to the cheek. The easiest is to integrate it in a helmet, as the helmet is steady and provides a hard surface to press against. We did some test runs with a helmet and the signal is excellent, better than the data recorded during the experiments. However, we also envision integrating the tongue interface in masks and softer fabric. The best results we got so far is using the soft and elastic fabric shown in Figure 1 that we used in the study described in the following.

EXPERIMENT

To determine if the system is able to recognize tongue gestures, we conducted a controlled lab study. 6 participants (2 female, 4 male, age 20-35) took part in the study. Each participant wore the hardware prototype on the right cheek, we ask the participants to press the tongue in the middle of the cheek, and fixate the tongue interface on top of the pressed position with a flexible fabric (as seen in Figure 1). After attaching the interface we performed an initial calibration. We ensured that interface provides a low-noise signal and the pressure matrix can be easily pressed by the tongue through the cheek.

After applying the interface, participants performed 5 gestures with their tongue: swipe up, swipe down, swipe left, swipe right and "click" (just pressing the tongue against the middle of the interface). The directions are performed from the view point of the user. We initially planned to include a "draw a circle" gesture, yet as 4 of the 6 participants were not able to perform this gesture with their tongue, we exclude the gesture from the analysis. Each participant performs each of the 5 gesture 10 times, resulting in 300 gestures. In addition to testing the device, we conducted semi-structured interview with the participants to discuss the usefulness of the interface and explore potential application scenarios.

Exemplary "pressure maps" for the five gestures are shown in Figure 4. The x and y axis are the respective channels, the diagram is laid out the way a participant would wear the device. This means the top of the diagram is towards "the up direction" for the user. The 8×8 pressure values are displayed using a heat map. Blue is shown no pressure and red the maximum pressure. For each of the 8 x 8 pressure values we calculate the mean and the variance over a 15 samples long sliding window with and overlap of 10 samples. This roughly corresponds to a 0.75 second sliding window with 0.5 seconds overlap. We used k-nearest neighbors algorithm to recognize if the participant interacts with the device and to recognize the gestures.

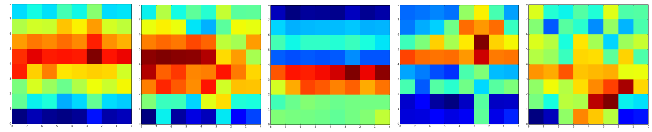

Figure 4. Exemplary pressure maps for the five gestures. From left to right: First is the "click" gesture, then "swipe left", "swipe right", "swipe up", "swipe down". Red signifies a high pressure value, blue a lower pressure value, the scale is discretized between 0 (displayed as dark blue) and 255 (displayed as dark red).

RESULTS

In the following we first analyze the performance of the gesture recognition and provide an overview about participants' feedback gathered through post interviews.

Gesture Recognition

We first determined if the system is able recognize if the participants is interacting with the device by applying pressure to the cheek or not. Using a k-nearest neighbors algorithm (k = 3), we can correctly distinguish between usage and non-usage with 99% accuracy.

Afterwards we again used a k-nearest neighbors algorithm (k = 5) to determine the actual gesture with an 80% frame by frame classification. Applying a majority decision on top of each interaction interval detected, we can correctly classify 98% of the 300 gestures. Only 6 gestures were not correctly classified. For 2 participants, the click gesture was not correctly classified. In addition, the "right swipe" gesture was misclassified as "click" 4 times. This is also understandable, as "left swipe" was difficult to perform easily, as some participants told us.

Interviews

Regarding the interview, all 6 participants considered this type of interface as useful, especially if one needs to operate a computer hands-free when wearing gloves, having wet hands or being in a subway with too little space. Participants main concern was the bulkiness of the current hardware prototype. They stated that they would not want to wear it in public. If the size and shape is reduced to a face mask (usually worn in Japan to avoid infections), they could imagine wearing it.

Asked about potential application areas, most participants stated that the interface might be good for operating navigation systems or music/video applications, while riding a motorbike or bicycle. One participant found it interesting to combine a head-mounted display (HMD) with the interface and would like to accept or make video calls hands-free using the tongue interface.

The most difficult gestures for the participants to perform are "circle" and "left to right", which could already be seen from the experimental data. 4 of the 6 participants were not even able to perform the "circle" motion correctly and stated that it's too difficult for them. For one participant "up" was the most difficult. Asked for other potential tongue gestures, 3 participants wanted to use both cheeks as interaction interface. They thought it would be useful, especially if already wearing a helmet or a mask. Potential gestures proposed by participants include alternating presses on the two cheeks. One participant mentioned that the front of the mouth (under and above the lips) might be preferable for gestures, as it's easier reachable and more complex gestures like "circle" might be possible. Two participants raised concerns that wearing it on just one cheek and interacting with it more often might make them "tongue tired". So far, we have not experienced any problems, as the force needed is very low.

CONCLUSION AND FUTURE WORK

In this paper, we presented our initial work towards implementing an affordable, resistive tongue interface for hands-free human computer interaction. We show a fully functional hardware prototype and evaluate its performance in a lab study. In addition, we gather impressions and potential improvements from the users for future tongue interface systems and application scenarios.

The high recognition rates are encouraging, yet in the controlled lab environment we still take control on how to attach the device. This is crucial to get a good recognition rate. Problems can also be seen in the pressure plots in Figure 4. We envision different approaches to ensure high recognition rates even outside the lab: Users could receive guidance from the system when putting on the interface, using a less flexible material could ensure that the interface can only mounted at the "right" cheek position, or an interface that spans a larger area could be calibrated after putting it on.

As a next step, we plan to evaluate the interface during everyday life. In particular, we are interested in how often the gesture recognition is triggered unintentionally if a user wears it during a day. Furthermore, we plan to improve the sampling rate and the precision by adopting the approach presented by Zhou et.al. [17]. Thereby we can also reduce the device's size and a make it less obtrusive. We believe that the interface is mainly interesting for users that already wear helmets or masks during work, e.g. surgeons, motorcyclists. Thus, we will focus on these scenarios for future hardware prototypes.

Acknowledgment

This work was partially supported by the collaborative project SimpleSkin under contract with the European Commission (#323849) in the FP7 FET Open framework. The support is gratefully acknowledged.

REFERENCES

1. Cheng, J., Lukowicz, P., Henze, N., Schmidt, A., Amft, O., Salvatore, G. A., and Troster, G. Smart textiles: From niche to mainstream. *Pervasive Computing* (2013).
2. Coren, S., Ward, L. M., and Enns, J. T. *Sensation and perception*. John Wiley & Sons, 2004.
3. Kunze, K., Wagner, F., Kartal, E., Kluge, E. M., and Lukowicz, P. Does context matter?-a quantitative evaluation in a real world maintenance scenario. In *Pervasive Computing*. 2009.
4. Liu, L., Niu, S., Ren, J., and Zhang, J. Tongible: a non-contact tongue-based interaction technique. In *Conference on Computers and accessibility* (2012).
5. Lund, M. E., Christiensen, H. V., Caltenco, H. A., Lontis, E. R., Bentsen, B., and Andreasen Struijk, L. Inductive tongue control of powered wheelchairs. In *Conference on Engineering in Medicine and Biology* (2010).
6. Monczak, L., Shapiro, D., Borisenko, A., Draghici, O., and Bolic, M. Characterization of piezoelectric film sensors for tongue-computer interface. In *Workshop on Medical Measurements and Applications* (2011).
7. Park, H., Gosselin, B., Kiani, M., Lee, H.-M., Kim, J., Huo, X., and Ghovanloo, M. A wireless magnetoresistive sensing system for an intra-oral tongue-computer interface. In *Conference on Solid-State Circuits* (2012).
8. Saponas, T. S., Kelly, D., Parviz, B. A., and Tan, D. S. Optically sensing tongue gestures for computer input. In *Symposium on User interface software and technology* (2009).
9. Shneiderman, B. The limits of speech recognition. *Communications ACM* (2000).
10. Starner, T. E. The role of speech input in wearable computing. *Pervasive Computing* (2002).
11. Struijk, L. N. A. An inductive tongue computer interface for control of computers and assistive devices. *Transactions on Biomedical Engineering* (2006).
12. Tang, H., and Beebe, D. J. An ultra-flexible electrotactile display for the roof mouth. In *Conference on Engineering in Medicine and Biology and Meeting Biomedical Engineering Soc.* (1999).
13. Vuillerme, N., Pinsault, N., Chenu, O., Fleury, A., Payan, Y., and Demongeot, J. A wireless embedded tongue tactile biofeedback system for balance control. *Pervasive and Mobile Computing* (2009).
14. Wang, Y. K., Nash, M. P., Pullan, A. J., Kieser, J. A., and Röhrle, O. Model-based identification of motion sensor placement for tracking retraction and elongation tongue. *Biomechanics and modeling in mechanobiology* (2013).
15. Witt, H., Nicolai, T., and Kenn, H. Designing a wearable user interface for hands-free interaction in maintenance applications. In *Conference on Pervasive Computing and Communications* (2006).
16. Yousefi, B., Huo, X., Veledar, E., and Ghovanloo, M. Quantitative and comparative assessment of learning in a tongue-operated computer input device. *Transactions on Information Technology in Biomedicine* (2011).
17. Zhou, B., Cheng, J., Sundholm, M., and Lukowicz, P. From smart clothing to smart table cloth: Design and implementation of a large scale, textile pressure matrix sensor. In *Conference on Architecture of Computing Systems* (2014).