MouthIO: Customizable Oral User Interfaces with Integrated Sensing and Actuation

Yijing Jiang
Computer Science Department
Aarhus University
Aarhus, Denmark
y.jiang@cs.au.dk

***Abstract*—MouthIO is a customizable intraoral user interface that can be equipped with various sensors and output components. It consists of an SLA-printed brace that houses a flexible PCB within a bite-proof enclosure positioned between the molar teeth and inner cheeks. All parts in contact with the oral cavity are made of bio-compatible materials to ensure safety, while the design takes into account both comfort and portability.**

I. Introduction

Wearable electronics are widely used for health monitoring and to sense user interaction as they are readily available to capture input and often have continuous access to the user's bio-signals, such as the user's heart rate. However, most wearable devices are worn on the skin or integrated into textiles, while intraoral wearable technology that is worn inside the mouth is still rare, providing potential room for innovation.

In this paper, we present MouthIO, a fully self-contained wearable device that integrates microcontrollers and batteries as the base components, and can house a multitude of sensors and output components, including temperature sensors, capacitive touchpads, accelerometers and vibration motors. Prototyping oral interfaces with MouthIO enables dental technicians, researchers, and experienced makers to embed interactivity in a near-invisible area of the body while being suitable for long-term usage and not hindering the user in daily activities.

II. Related work

Rapid advances in materials, electronics, and computing technologies have made DIY wearable electronics a research trend. Several studies have explored conductive materials like gold leaf [12], woven textiles [13], and conductive gels [14], as well as fabrication techniques with commodity machines like inkjet printer [15], 3D printer [16] and weaving machine [17], [18] to achieve rapid do-it-yourself on-body prototyping of interactive wearables and devices.

However, most wearable devices are on the skin, while intraoral wearable technology is rare and underdeveloped. Recent research has demonstrated that oral interfaces can provide a variety of discreet hands-free and eyes-free interactions and help improve the efficiency of multitasking [4], [7]. In addition, they can serve as assistive technologies to help people with physical disabilities regain basic interaction capabilities via tongue-controlled wheelchairs and computers [5], [9]. Oral interfaces also provide significant advantages in bio-monitoring. For example, saliva can be tested through biochemical ligatures on braces to detect metabolism changes [10]. Specific diseases such as diabetes [1], xerostomia [8] and bruxism [3], [6] can be reliably detected by sensors located in the user's mouth. However, these devices require complex electronic manufacturing processes or advanced dental equipment that are often unavailable outside of specialized labs. So far, there has been no research about DIY manufacturing technology for in-mouth interactive interfaces.

III. Working Principle

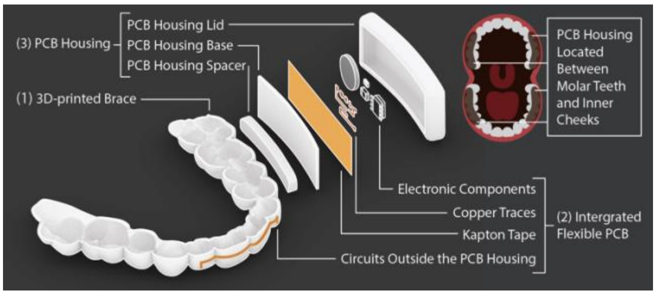

Figure 1: MouthIO schematic.

MouthIO consists of three components: (1) the 3D-printed brace that gets attached to the teeth, (2) the flexible PCB with circuits, batteries, microcontroller, and sensors, and (3) the PCB housing to water-proof encapsulate the electronics and make it bite-save (Figure 1).

The brace and the PCB housing are SLA-printed with bio-compatible dental resin. The brace gets attached to the teeth and the PCB housing encapsulates the flexible PCB with all electronics including a microcontroller, batteries and custom sensors. Some applications might require placing sensors or actuators outside of the PCB Housing. To enable such user interfaces, the maker can extend the PCB outside of the PCB housing and place small components on the brace.

IV. Applications Examples

A. *Monitoring of Food Consumption*

Consumption of very hot drinks and foods significantly increases the risk of esophageal cancer [2]. We implemented an ATTiny85, two coin batteries, a temperature sensor (MCP9700), and a vibration motor to help users be aware of high-temperature beverages. Since The International Agency for Research on Cancer (IARC) assesses "very hot" (>65°C) beverages as "possibly carcinogenic", the vibration motor is activated when the temperature sensor detects temperature over 65°C (Figure 2).

Figure 2: (a) The MouthIO interface with temperature sensor and vibration motor for monitoring beverage temperature, (b) with the lid on. (c) Wearing the MouthIO interface on the upper teeth.

B. *Health Monitoring*

Bruxism is a widely occurring condition in which humans grind on their teeth in their sleep or even during awake times. To support the diagnosis of bruxism, we demonstrate a low-cost MouthIO solution that people can locally fabricate for monitoring teeth grinding during sleep. We developed a MouthIO brace to be positioned on the lower jaw, as it is the primary moving component during grinding. During the prototyping phase, we integrated a coin battery, and an accelerometer (ADXL345) into the PCB housing (Figure 3).

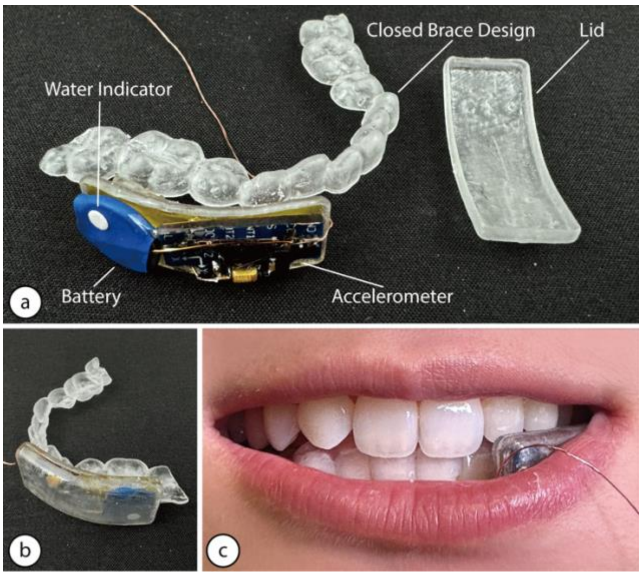

Figure 3: (a) The MouthIO interface with accelerometer monitoring grinding and biting, (b) with the lid on. (c) Wearing the MouthIO interface on the lower teeth.

C. *Assistive Technology for Users with Motor Impairments*

Nearly 2 million people are living with limb loss in the United States [11]. To support users with motor impairments in interacting with tongue-based user interfaces, we fabricated two capacitive touch pads located behind the upper teeth that can detect tapping with the user's tongue. We embedded an ATTiny85, a battery, and two resistors (1MΩ, for capacitive touch sensing) into the PCB housing. We extended two copper traces on Kapton tape out of the PCB housing along the front teeth. Each of these traces connects to a 5mmx4mm pad which we located behind the front teeth (Figure 4). We applied three coats of dental resin to the external circuits and cured it with UV light to ensure proper insulation.

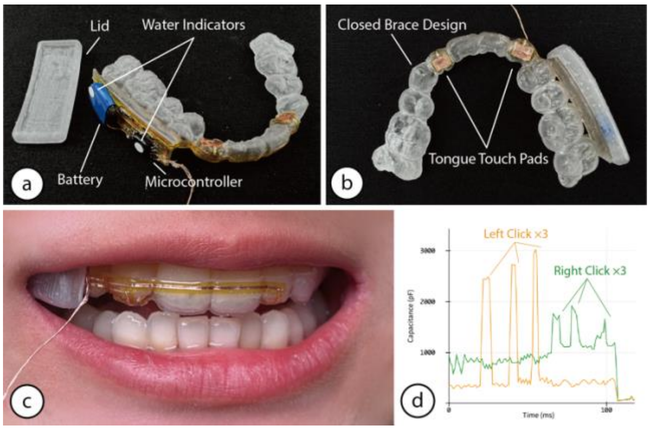

Figure 4: (a) The MouthIO interface with two capacitive touch pads for detecting tongue tapping, (b) with the lid on. (c) Wearing the MouthIO interface on the upper teeth. (d) Data showing the capacitive value pattern during tongue tapping on the touch pads.

V. Envisaged next prototype iteration

There are three main ideas for the next iteration of the MouthIO prototype. Firstly, enhancing MouthIO by incorporating features such as Bluetooth communication and wireless charging, which will be beneficial for long-term monitoring. Secondly, fabricating biosensors for use in intraoral interfaces. This poses a challenge since most biosensors need to come into contact with saliva, such as those measuring glucose levels [1] and pH values [10]. Thirdly, exploring the integration of miniature microphones and speakers into intraoral user interfaces, which can be utilized for voiceless communication.

VI. Responsible innovation

MouthIO enables dental technicians, researchers, and experienced makers to fabricate intraoral user interfaces equipped with various sensors and actuators. This research will impact the HCI field by introducing novel fabrication techniques that support customization at a low cost. Furthermore, this project will benefit the healthcare industry by advancing better e-health solutions.

To address potential environmental costs, the next steps involve transitioning from disposable coin cell batteries to rechargeable batteries and incorporating wireless charging. Additionally, the use of the TENG principle will be explored to generate energy from oral activity, creating self-powered sensors. There is also a potential to use recyclable and biodegradable materials for the main structure of the brace.

VII. Author Bio

I am currently a first-year PhD student working in the field of human-computer interaction. The goal of my PhD is to design and develop flexible and wearable (bio-)sensors with user interfaces to enable continuous, seamless, and portable monitoring. My expertise includes Personal Fabrication, Assistive Technology and User-Centered Design. I have built tools and experiences that span domains such as healthcare, gamification, assistive technologies and Internet of Things. My previous works can be found on my website: https://yijingjiang.webflow.io/.

I'm good at 3D modeling, 2D design, and various fabrication techniques, including FDM & SLA 3D printing, laser cutting, vinyl cutting flexible circuits, and conductive inkjet printing. Additionally, I'm capable of Arduino and Processing.

VIII. Acknowledgements

This research was supported by the Novo Nordisk Start Package Grant. The project was a collaboration between my colleagues Julia Kleinau, Till Max Eckroth, Eve Hoggan, and Michael Wessely from Aarhus Univerisity, and Stefanie Mueller from MIT CSAIL.

IX. References

[1] Takahiro Arakawa, Keisuke Tomoto, Hiroki Nitta, Koji Toma, Shuhei Takeuchi, Toshiaki Sekita, Shunsuke Minakuchi, and Kohji Mitsubayashi. 2020. A wear-able cellulose acetate-coated mouthguard biosensor for in vivo salivary glucose measurement. Analytical Chemistry 92, 18 (2020), 12201–12207.

[2] Yawen Chen, Yeqing Tong, Chen Yang, Yong Gan, Huilian Sun, Huashan Bi, Shiyi Cao, Xiaoxv Yin, and Zuxun Lu. 2015. Consumption of hot beverages and foods and the risk of esophageal cancer: a meta-analysis of observational studies. BMC cancer 15 (2015), 1–13.

[3] Arthur Claude, Olivier Robin, Claudine Gehin, and Bertrand Massot. 2019. Design and evaluation of a novel technology for ambulatory monitoring of bruxism events. Sensors and Actuators A: Physical 295 (2019), 532–540.

[4] Pablo Gallego Cascón, Denys J.C. Matthies, Sachith Muthukumarana, and Suranga Nanayakkara. 2019. ChewIt. An Intraoral Interface for Discreet Interactions. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (Glasgow, Scotland Uk) (CHI '19). Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3290605.3300556

[5] Xueliang Huo, Jia Wang, and Maysam Ghovanloo. 2008. A Magneto-Inductive Sensor Based Wireless Tongue-Computer Interface. IEEE Transactions on Neural Systems and Rehabilitation Engineering 16, 5 (2008), 497–504. https://doi.org/10.1109/TNSRE.2008.2003375

[6] Jung Ho Kim, Padraig McAuliffe, Brian O'Connell, Dermot Diamond, and King-Tong Lau. 2010. Development of a wireless autonomous bruxism monitoring device. BIOSIGNAL 2010 - 20th Biennial International EURASIP conference, 27-29 June, 2010, Brno, Czech Republic. (2010).

[7] Richard Li, Jason Wu, and Thad Starner. 2019. TongueBoard: An Oral Interface for Subtle Input. In Proceedings of the 10th Augmented Human International Conference 2019 (Reims, France) (AH2019). Association for Computing Machinery, New York, NY, USA, Article 1, 9 pages. https://doi.org/10.1145/3311823.3311831

[8] Frank P Strietzel, Gloria I Lafaurie, Gloria R Bautista Mendoza, Ivan Alajbeg, Slavica Pejda, Lea Vuletić, Rubén Mantilla, Denise P Falcão, Soraya C Leal, Ana C Barreto Bezerra, et al . 2011. Efficacy and safety of an intraoral electrostimulation device for xerostomia relief: a multicenter, randomized trial. Arthritis & Rheumatism 63, 1 (2011), 180–190.

[9] Lotte NS Andreasen Struijk. 2006. An inductive tongue computer interface for control of computers and assistive devices. IEEE Transactions on biomedical Engineering 53, 12 (2006), 2594–2597.

[10] Eldy S. Lazaro Vasquez, Ali K. Yetisen, and Katia Vega. 2020. BraceIO: Biosensing through Hydrogel Dental Ligatures. In Proceedings of the 2020 ACM International Symposium on Wearable Computers (Virtual Event, Mexico) (ISWC '20). Association for Computing Machinery, New York, NY, USA, 87–89. https://doi.org/10.1145/3410531.3414290

[11] Kathryn Ziegler-Graham, Ellen J MacKenzie, Patti L Ephraim, Thomas G Travison, and Ron Brookmeyer. 2008. Estimating the prevalence of limb loss in the United States: 2005 to 2050. Archives of physical medicine and rehabilitation 89, 3 (2008), 422–429. Received 20 February 2007; revised 12 March 2009 2024-05-20 13:18. Page 3 of 1–3.

[12] Hsin-Liu (Cindy) Kao, Christian Holz, Asta Roseway, Andres Calvo, and Chris Schmandt. 2016. DuoSkin: Rapidly Prototyping on-Skin User Interfaces Using Skin-Friendly Materials. In Proceedings of the 2016 ACM International Symposium on Wearable Computers (Heidelberg, Germany) (ISWC '16). Association for Computing Machinery, New York, NY, USA, 16–23.

[13] Jingwen Zhu, Nadine El Nesr, Christina Simon, Nola Rettenmaier, Kaitlyn Beiler, and Cindy Hsin-Liu Kao. 2023. BioWeave: Weaving Thread-Based Sweat-Sensing On-Skin Interfaces. In Proceedings of the 36th Annual ACM Symposium on User Interface Software and Technology (San Francisco, CA, USA) (UIST '23). Association for Computing Machinery, New York, NY, USA, Article 35, 11 pages.

[14] Hsin-Liu (Cindy) Kao, Miren Bamforth, David Kim, and Chris Schmandt. 2018. Skinmorph: Texture-Tunable on-Skin Interface through Thin, Programmable Gel. In Proceedings of the 2018 ACM International Symposium on Wearable Computers (Singapore, Singapore) (ISWC '18). Association for Computing Machinery, New York, NY, USA, 196–203.

[15] Aditya Shekhar Nittala, Arshad Khan, Klaus Kruttwig, Tobias Kraus, and Jürgen Steimle. 2020. PhysioSkin: Rapid Fabrication of Skin-Conformal Physiological Interfaces. In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (Honolulu, HI, USA) (CHI '20). Association for Computing Machinery, New York, NY, USA, 1–10.

[16] Aluna Everitt, Alexander Keith Eady, and Audrey Girouard. 2022. Enabling Multi-Material 3D Printing for Designing and Rapid Prototyping of Deformable and Interactive Wearables. In Proceedings of the 20th International Conference on Mobile and Ubiquitous Multimedia (Leuven, Belgium) (MUM '21). Association for Computing Machinery, New York, NY, USA, 1–11.

[17] Kunpeng Huang, Ruojia Sun, Ximeng Zhang, Md. Tahmidul Islam Molla, Margaret Dunne, Francois Guimbretiere, and Cindy Hsin-Liu Kao. 2021. WovenProbe: Probing Possibilities for Weaving Fully-Integrated On-Skin Systems Deployable in the Field. In Proceedings of the 2021 ACM Designing Interactive Systems Conference (Virtual Event, USA) (DIS '21). Association for Computing Machinery, New York, NY, USA, 1143–1158.

[18] Jingwen Zhu, Nadine El Nesr, Nola Rettenmaier, and Cindy Hsin-Liu Kao. 2023. SkinPaper: Exploring Opportunities for Woven Paper as a Wearable Material for On-Skin Interactions. In Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (Hamburg, Germany) (CHI '23). Association for Computing Machinery, New York, NY, USA, Article 479, 16 pages.