Sweatcessory: a Wearable Necklace for Sensing Biological Data in Sweat

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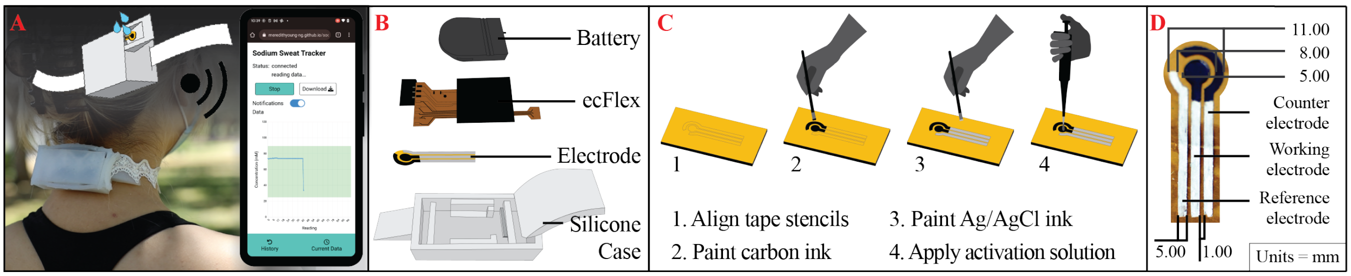

Figure 1: A. Sweatcessory prototype. B. Biosensor components. C. Electrode fabrication process. D. Example of painted electrode.

ABSTRACT

Sweat contains various analytes (biochemical data) that can be used to monitor health. Electrochemical sweat biosensors non-invasively monitor analytes via an electrode in contact with the skin. We introduce Sweatcessory, a novel form factor (a wearable necklace) with a sodium-detecting sweat biosensor whose data can be viewed in a Bluetooth web app. We present a design rationale for sweat biosensor form factors, our implementation process for Sweatcessory, an app for visualization, and an electrode functional evaluation.

CCS CONCEPTS

• **Human-centered computing** → **Interaction devices**; **Ubiquitous and mobile devices**.

KEYWORDS

sweat sensors; wearables; electrochemical biosensors

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1 INTRODUCTION

In contrast to most wearable devices that sense physical data, this project senses biochemical data from body fluids. Existing biosensors invasively puncture the skin with needles to sample blood [11], microneedles to sample interstitial fluid [5], or permanent tattoos to interface with interstitial fluid [17]. Alternatively, sweat can be sampled directly from the top of the skin, and contains analytes such as glucose, lactate, and metal ions that can help diagnose various health conditions such as diabetes, cystic fibrosis, skin diseases, and toxic metal exposure [6, 7, 10, 16]. Sweat electrochemical biosensors can convert biochemical changes to electrical signals via electrodes through potentiometry or amperometry.

We present Sweatcessory, a wearable choker with a sodium-detecting electrochemical sweat biosensor, compatible with a web app for data visualization (Fig. 1A). A choker is a tight necklace that can aesthetically secure an electrode to the skin. Existing form factors mount biosensors on accessories such as smartwatches [3] and rings [8], on clothing [14], or on temporary tattoos [4, 10], but different body regions produce different amounts of sweat [2]. Sweatcessory's choker non-invasively attaches electrodes to the back of the neck, leveraging the rear neck's higher sweat density [2] and avoiding adhesives in contrast to tattoo electrodes [4]. Each electrode can only sense one analyte, so Sweatcessory supports electrode interchangeability via an easy-access case. Its current electrode detects sodium, an analyte whose high concentration in sweat may indicate health issues such as cystic fibrosis, dehydration, and hyponatremia [7, 13].

2 IMPLEMENTATION

2.1 Form Factor

The wearable biosensor's main components are a potentiometric ecFlex, CR2032 3V battery with case, and sodium detection electrode (Fig. 1B). The ecFlex (Zimmer and Peacock) is connected to the electrode and sends the data to our web app via Bluetooth. To embed the biosensor in the choker, we designed a silicone case which flexes to keep the case's triangular electrode-holding extension in contact with the skin. We fabricated the case by 3D printing a two-part inverse mold, pouring Dragon Skin FX-Pro silicone (Smooth-On) into the mold's cavity, and curing the silicone.

2.2 Electrode Fabrication

Carbon and Ag/AgCl (60/40) inks (Zimmer and Peacock) were manually painted in a disk shape [1] onto a polyimide (Kapton) film substrate, using aligned stencils cut from packing tape, to create the reference, counter, and working electrode (Fig. 1C and D). The carbon ink on the non-reference electrodes was cured at 60°C for 5 minutes before removing the top stencil, painting the rest of the electrodes with Ag/AgCl ink, and curing again for 5 minutes at 60°C. Then, 10 μL of sodium activation solution (Zimmer and Peacock) was applied to the working electrode, which was cured at 4-7°C for 24 hours. Finally, the bottom stencil was removed. The bottom end of the electrode connectors was folded back and secured with double-sided tape so that the electrodes fit into the ecFlex connector.

2.3 App Visualization

Both current and historical biosensor data can be visualized in our Bluetooth web application (Android/Mac/Windows), through line graphs of time vs. sodium concentration. The healthy range of sodium in adult human sweat (25.0-89.3 mM) [12] is shaded in green; a mobile notification is sent when sodium levels fall outside this range.

3 FUNCTIONAL EVALUATION

To determine whether our biosensor properly detects changes in sodium concentration, we tested electrodes with 0 to 63.67 mM sodium acetate solutions, titrated from 1 M (Fig. 2). A calibration curve was obtained to extract the sodium concentration of a solution based on the voltage. We verified the concentration curve by testing again with sodium acetate calibration solutions, obtaining the expected values. In addition, we tested our electrodes with 0-350 mM sodium citrate and 0-20 mM glucose solutions to verify that our electrodes are selective for sensing sodium ions.

4 DISCUSSION AND FUTURE WORK

Sweatcessory present a novel form factor for sensing biochemical data from sweat. It can be adapted to monitor additional analytes due to its electrode interchangability, diagnosing other medical conditions ranging from diabetes [9] to skin diseases [16]. Future work includes further functional evaluation (using serial dilution), as

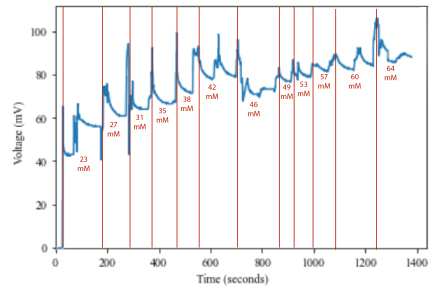

Figure 2: Voltage vs. time biosensor measurements, using 0 to 63.67 mM solutions from a 1 M sodium acetate titration.

well as adding microfluidics to redirect sweat, a multiple-electrode platform to monitor multiple analytes to detect illnesses such as hypertension and cardiovascular disease (using sodium-potassium ratios [15]), and other physical data sensors such as humidity, activity recognition. Wearability can be improved by reducing device size with customized PCBs and screen-printed electrodes, made via inkjet printing to decrease the variance caused by our current manual painting method. Furthermore, we plan to conduct user studies with fashion designers to investigate design considerations such as ergonomics, aesthetics, and materials for wearable electrochemical biosensors. Future user studies will also explore electrode durability, wearability, and functionality on different areas of the body, as well as methods for inducing sweat.

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REFERENCES

[1] Fabiana Arduini, Fabio Di Nardo, Aziz Amine, Laura Micheli, Giuseppe Palleschi, and Danila Moscone. 2012. Carbon black-modified screen-printed electrodes as electroanalytical tools. *Electroanalysis* 24, 4 (2012), 743–751.

[2] Lindsay B Baker, Corey T Ungaro, Bridget C Sopeña, Ryan P Nuccio, Adam J Reimel, James M Carter, John R Stofan, and Kelly A Barnes. 2018. Body map of regional vs. whole body sweating rate and sweat electrolyte concentrations in men and women during moderate exercise-heat stress. *Journal of Applied Physiology* 124, 5 (2018), 1304–1318.

[3] Ananta Narayanan Balaji, Chen Yuan, Bo Wang, Li-Shiuan Peh, and Huilin Shao. 2019. pH Watch-Leveraging pulse oximeters in existing wearables for reusable, real-time monitoring of pH in sweat. In *Proceedings of the 17th Annual International Conference on Mobile Systems, Applications, and Services.* 262–274.

[4] Amay J Bandodkar, Vinci WS Hung, Wenzhao Jia, Gabriela Valdés-Ramírez, Joshua R Windmiller, Alexandra G Martinez, Julian Ramírez, Garrett Chan, Kagan Kerman, and Joseph Wang. 2013. Tattoo-based potentiometric ion-selective sensors for epidermal pH monitoring. *Analyst* 138, 1 (2013), 123–128.

[5] Shubhmita Bhatnagar, Kaushalkumar Dave, and Venkata Vamsi Krishna Venuganti. 2017. Microneedles in the clinic. *Journal of controlled release* 260 (2017), 164–182.

[6] Stephen J Genuis, Detlef Birkholz, Ilia Rodushkin, and Sanjay Beesoon. 2011. Blood, urine, and sweat (BUS) study: monitoring and elimination of bioaccumulated toxic elements. *Archives of environmental contamination and toxicology* 61, 2 (2011), 344–357.

[7] Anne Green, Jean Kirk, and Guidelines Development Group. 2007. Guidelines for the performance of the sweat test for the diagnosis of cystic fibrosis. *Annals of clinical biochemistry* 44, 1 (2007), 25–34.

[8] Vassiliki Katseli, Anastasios Economou, and Christos Kokkinos. 2021. Smartphone-addressable 3D-printed electrochemical ring for nonenzymatic self-monitoring of glucose in human sweat. *Analytical Chemistry* 93, 7 (2021), 3331–3336.

[9] Jayoung Kim, Alan S Campbell, and Joseph Wang. 2018. Wearable non-invasive epidermal glucose sensors: A review. *Talanta* 177 (2018), 163–170.

[10] Jayoung Kim, William R de Araujo, Izabela A Samek, Amay J Bandodkar, Wenzhao Jia, Barbara Brunetti, Thiago RLC Paixao, and Joseph Wang. 2015. Wearable temporary tattoo sensor for real-time trace metal monitoring in human sweat. *Electrochemistry Communications* 51 (2015), 41–45.

[11] David C Klonoff. 2005. Continuous glucose monitoring: roadmap for 21st century diabetes therapy. *Diabetes care* 28, 5 (2005), 1231–1239.

[12] Avantika Mishra, Ronda Greaves, Katherine Smith, John B Carlin, Andrew Wootton, Rob Stirling, and John Massie. 2008. Diagnosis of cystic fibrosis by sweat testing: age-specific reference intervals. *The Journal of pediatrics* 153, 6 (2008), 758–763.

[13] AM Vinu Mohan, Vinoth Rajendran, Rupesh K Mishra, and Mathiyarasu Jayaraman. 2020. Recent advances and perspectives in sweat based wearable electrochemical sensors. *TrAC Trends in Analytical Chemistry* 131 (2020), 116024.

[14] Dr Susanne Oertel, Dr Michael Jank, Björn Schmitz, and Dr Nadine Lang. 2016. Monitoring of biomarkers in sweat with printed sensors combined with sport wearables. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct*. 893–898.

[15] Ross L Prentice, Ying Huang, Marian L Neuhouser, JoAnn E Manson, Yasmin Mossavar-Rahmani, Fridtjof Thomas, Lesley F Tinker, Matthew Allison, Karen C Johnson, Sylvia Wassertheil-Smoller, et al. 2017. Associations of biomarker-calibrated sodium and potassium intakes with cardiovascular disease risk among postmenopausal women. *American journal of epidemiology* 186, 9 (2017), 1035–1043.

[16] M-H Schmid-Wendtner and Hans Christian Korting. 2006. The pH of the skin surface and its impact on the barrier function. *Skin pharmacology and physiology* 19, 6 (2006), 296–302.

[17] Katia Vega, Nan Jiang, Xin Liu, Viirj Kan, Nick Barry, Pattie Maes, Ali Yetisen, and Joe Paradiso. 2017. The dermal abyss: Interfacing with the skin by tattooing biosensors. In *Proceedings of the 2017 ACM International Symposium on Wearable Computers*. 138–145.