Rethinking Wearable Health Sensing: Towards a Modular, Repairable and Sustainable Design Paradigm

Glenn J. Fernandes
Northwestern University
Chicago, Illinois, USA

Farzad Shahabi
Northwestern University
Chicago, Illinois, USA

Yuxin Du
Northwestern University
Chicago, Illinois, USA

Mahdi Pedram
University of North Texas
Denton, Texas, USA

Nabil Alshurafa
Northwestern University
Chicago, Illinois, USA

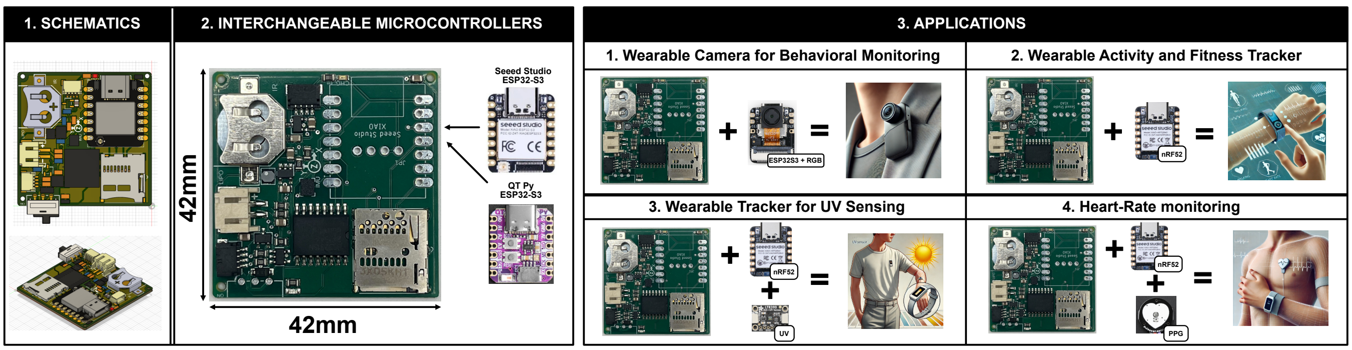

Figure 1: Section 1 displays the schematic and 3D render of the PRISM PCB. Section 2 illustrates the platform's compatibility with both Seeed Studio XIAO microcontrollers (MCUs) and Adafruit's QT Py series. Section 3 demonstrates various applications of the PRISM board: Part 1 shows its integration with an ESP32S3 board equipped with a camera for behavior monitoring (example: Fernandes et al. in HabitSense [1]); Part 2 highlights its use as a fitness tracker via an nRF52 MCU, leveraging PRISM's onboard IMU; Part 3 presents a UV sensing application following the approach of Lin et al. [2]; and Part 4 illustrates a heart rate monitoring application using an nRF MCU paired with a PPG sensor.

Abstract

Wearable health sensing technologies are increasingly essential for both clinical and consumer applications. However, many existing platforms are either custom-built with rigid designs or rely on fixed-function breakout boards, limiting their adaptability, repairability, and sustainability. In this paper, we introduce PRISM (Participant Recording and Integrated Sensing Module), a modular and customizable platform for wearable health sensing that supports rapid prototyping while promoting long-term viability through repairability and sustainable practices. PRISM incorporates core components required for health sensing research—such as a Real-Time Clock (RTC), Inertial Measurement Unit (IMU), robust power management, and modular I2C connectivity—and extends its functionality with energy-harvesting features, including solar panels. Furthermore, its compatibility with a variety of microcontrollers (e.g., XIAO Seeed Series and QT Py boards) enables researchers to tailor the platform to their specific needs, thereby reducing electronic waste and advancing environmental responsibility. By streamlining the integration of common sensing components, PRISM allows researchers to devote more time to research-intensive objectives rather than reinventing hardware solutions for each project.

CCS Concepts

• **Hardware → PCB design and layout**; **Sensor devices and platforms**; **Sensor applications and deployments**.

Keywords

wearables, sensing, on-device learning, PCB-design

ACM Reference Format:
Glenn J. Fernandes, Farzad Shahabi, Yuxin Du, Mahdi Pedram, and Nabil Alshurafa. 2025. Rethinking Wearable Health Sensing: Towards a Modular, Repairable and Sustainable Design Paradigm. In *Proceedings of (CHI '25 Workshop on Envisioning the Future of Interactive Health).* ACM, New York, NY, USA, 3 pages.

CHI '25 Workshop on Envisioning the Future of Interactive Health, Yokohama, Japan

1 Introduction

Over the years, wearable health sensing systems have fundamentally transformed how we monitor and interact with personal health data by providing real-time insights critical for both preventive and diagnostic applications [3, 4]. Recent literature documents significant advancements in sensor technology, data processing algorithms, and wireless communication protocols, all of which have enhanced the accuracy and timeliness of these systems [5]. However, many existing designs tend to emphasize immediate functionality at the expense of long-term adaptability and sustainability. Frequently, devices are either custom-built with rigid architectures or rely on fixed-function breakout boards, which limit repairability and customization [6]. This lack of flexibility not only impedes ongoing improvements and innovation but also exacerbates the issue of electronic waste, as evidenced by multiple environmental impact assessments [7].

In response to these challenges, we present PRISM – a unified platform that integrates modularity with sustainability. By allowing individual sensing components to be easily replaced or upgraded, PRISM is engineered to evolve alongside emerging research requirements and technological advances while retaining a robust core of essential health sensing features. Although prior research has highlighted the benefits of modularity for enhancing interdisciplinary collaboration and expediting prototyping processes[8], few systems successfully combine these advantages with long-term viability. This comprehensive approach not only aligns with the evolving priorities within the HCI and Health communities but also establishes a foundation for more sustainable research practices by reducing electronic waste and extending the lifespan of devices.

In this paper, we present the initial prototype of PRISM, developed from our extensive experience at HABits Lab [9] in designing and deploying wearable systems across various user studies over the years. Our recent projects—such as HabitSense [1], HealthSense [10], UV Sensing [2], Smokemon [11], and AcitiSight [12]—have significantly informed the development of this platform. Based on our extensive experience, we identified six essential components that are consistently required for wearable health sensing projects: a clock for accurate timekeeping, secure on-device data storage, efficient communication between sensing modalities, the flexibility to interchange microcontrollers according to project requirements, an IMU for motion detection, and robust power management. We designed PRISM and integrated all components onto a single printed circuit board (PCB) at a cost of less than $30, with the goal of enabling scalable, low-cost deployment in health-sensing studies. By prioritizing accessibility, modularity, and ease of integration, PRISM is intended for use by researchers in health and HCI conducting field deployments, enabling custom sensing solutions.

We plan to provide a live demonstration of PRISM in conjunction with a poster presentation.

2 System Design and Implementation

2.1 The Six Essential Components for a Wearable Health Sensing PCB

The PRISM platform is implemented on a compact 42 mm × 42 mm printed circuit board (PCB) that consolidates all essential hardware components (Fig 1). The PCB integrates a Real-Time Clock (RTC) module to provide precise timekeeping, ensuring synchronized sensor outputs. An Inertial Measurement Unit (IMU), such as the LSM6DS3 [13], captures detailed motion data necessary for continuous monitoring and to know if the sensor is being worn or not. To accommodate various research needs, the platform supports multiple microcontroller footprints, including the XIAO Seeed Series [14] and Adafruit QT Py boards[15], offering flexibility in computational power and compatibility. A low-power microSD module is incorporated to enable real-time data logging, supporting continuous data collection for longitudinal studies. Additionally, a modular I2C connectivity system enabled through an integrated Qwiic connector allows seamless expansion by incorporating various sensors and peripherals, making the platform highly adaptable to evolving research requirements. Finally, a robust power management circuit is implemented to power the PCB and its connected peripherals.

2.2 Power Management and Energy-Harvesting Integration

We implemented a robust charging circuit that supports 3.7–4.2V LiPo batteries with a charging current of up to 500 mA, ensuring stable and efficient power management. This integration allows for extended operation periods while minimizing maintenance efforts associated with battery replacement or external charging, making the platform more sustainable and self-sufficient in long-term deployments. For example, when integrated with a thermal sensing system and powered by a 2000 mAh battery, the platform is expected to operate continuously for approximately 31.5 hours. PRISM is also designed to incorporate energy-harvesting capabilities if needed, thereby enhancing energy autonomy and reducing reliance on conventional power sources. For instance, integrated solar panels, in conjunction with PRISM's power management module, facilitate continuous recharging under ambient light conditions.

2.3 Repairability and Sustainability

Designed with long-term usability and environmental responsibility in mind, PRISM prioritizes repairability and sustainability. The modular construction enables individual components to be replaced or upgraded without discarding the entire system, significantly extending the device's operational lifespan while reducing electronic waste. Additionally, we aim to provide open-access design documentation to encourage community-driven maintenance and continuous improvement.

3 Preliminary Sytem Evalaution

The PRISM platform demonstrates significant advantages over traditional wearable health sensing systems. The modular design enables rapid prototyping and allows researchers to easily adapt the device to a wide range of health sensing applications. By permitting the replacement or upgrade of individual modules, PRISM significantly enhances repairability, thereby reducing both overall costs and electronic waste. Preliminary testing of the integrated solar energy-harvesting system indicates that the device can sustain operation across various lighting conditions. For instance, three hours of exposure to sunlight can provide up to 11 hours of operation, as demonstrated by Lin et al. [2]. These initial results are promising, and the next steps will involve further iterative testing through multiple design and evaluation phases to validate the system's modularity, repairability, and energy efficiency.

4 Conclusion and Future Work

PRISM represents a foundational step toward the development of wearable health sensing systems that are both flexible and sustainable. By integrating essential components into a modular architecture, the platform facilitates rapid prototyping and continuous innovation while also reducing the environmental impact associated with electronic waste. The repairable design of PRISM ensures that individual components can be upgraded or replaced as needed, significantly extending the lifecycle of the device. Future work will focus on expanding the compatibility of the platform with additional sensors and microcontrollers, enhancing the efficiency of the solar energy-harvesting system, and conducting long-term field studies to further evaluate its repairability and sustainability benefits. The development of PRISM is intended to inspire the HCI and Health communities to embrace research that is not only technologically advanced but also environmentally responsible.

References

[1] Glenn J Fernandes, Jiayi Zheng, Mahdi Pedram, Christopher Romano, Farzad Shahabi, Blaine Rothrock, Thomas Cohen, Helen Zhu, Tanmeet S Butani, Josiah Hester, et al. Habitsense: A privacy-aware, ai-enhanced multimodal wearable platform for mhealth applications. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, 8(3):1–48, 2024.

[2] Chenghong Lin, Yuxin Du, Neel Pendse, Glenn Fernandes, Nabil Alshurafa, and Mahdi Pedram. Self-sustaining wearable uv sensor for passive and continuous sun protection. In *2024 IEEE 20th International Conference on Body Sensor Networks (BSN)*, pages 1–4. IEEE, 2024.

[3] Minjeong Ha, Seongdong Lim, and Hyunhyub Ko. Wearable and flexible sensors for user-interactive health-monitoring devices. *Journal of Materials Chemistry B*, 6(24):4043–4064, 2018.

[4] Xuewen Wang, Zheng Liu, and Ting Zhang. Flexible sensing electronics for wearable/attachable health monitoring. *Small*, 13(25):1602790, 2017.

[5] Babajide A Salau, Atul Rawal, and Danda B Rawat. Recent advances in artificial intelligence for wireless internet of things and cyber–physical systems: A comprehensive survey. *IEEE Internet of Things Journal*, 9(15):12916–12930, 2022.

[6] Ji-Young Oh, Chi-Sun Hwang, Yong Suk Yang, Myoung Song, Junmo Kim, Taek-Soo Kim, Sujung Kim, Himchan Oh, Seung Youl Kang, Jae-Eun Pi, et al. Dual-functional self-attachable and stretchable interface for universal three-dimensional modular electronics. *ACS Applied Materials & Interfaces*, 14(43):49303–49312, 2022.

[7] Abhishek Kumar Awasthi, Xianlai Zeng, and Jinhui Li. Environmental pollution of electronic waste recycling in india: A critical review. *Environmental pollution*, 211:259–270, 2016.

[8] Richard Tee, Andrew Davies, and Jennifer Whyte. Modular designs and integrating practices: Managing collaboration through coordination and cooperation. *Research policy*, 48(1):51–61, 2019.

[9] The Habits Lab. The Habits Lab Website, 2025. Accessed: February 20, 2025.

[10] Glenn Fernandes, Boyang Wei, Christopher Romano, Deniz Ulusel, Henry K Dambanemuya, Yang Gao, Roozbeh Ghaffari, John Rogers, and Nabil Alshurafa. Healthsense: Unobtrusive continuous stress monitoring using a novel dual ecg-ppg patch. In *2024 IEEE 20th International Conference on Body Sensor Networks (BSN)*, pages 1–4. IEEE, 2024.

[11] Rawan Alharbi, Soroush Shahi, Stefany Cruz, Lingfeng Li, Sougata Sen, Mahdi Pedram, Christopher Romano, Josiah Hester, Aggelos K Katsaggelos, and Nabil Alshurafa. Smokemon: unobtrusive extraction of smoking topography using wearable energy-efficient thermal. *Proceedings of the ACM on interactive, mobile, wearable and ubiquitous technologies*, 6(4):1–25, 2023.

[12] Rawan Alharbi, Sougata Sen, Ada Ng, Nabil Alshurafa, and Josiah Hester. Actisight: wearer foreground extraction using a practical rgb-thermal wearable. In *2022 IEEE International Conference on Pervasive Computing and Communications (PerCom)*, pages 237–246. IEEE, 2022.

[13] STMicroelectronics. Lsm6ds3: inemo inertial module: always-on 3d accelerometer and 3d gyroscope, 2015. Accessed: 2025-02-20.

[14] Seeed Studio. Seeed studio xiao series, 2025. Accessed: 2025-02-20.

[15] Adafruit Industries. Adafruit Wearable Electronics Category, 2025. Accessed: February 20, 2025.