Secure Bio-Engineered Sensors for Healthcare and Environmental Monitoring

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Personnel:

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In the quest for effectively assessing and enhancing the performance of biosensors for real-world applications, conventional experimental methods can be challenging due to their labor-intensive nature. This challenge becomes particularly significant when attempting to evaluate extensive biosensor libraries, comprising millions of combinations, across various environmental and chemical variables. Our approach entails the co-design of a modular low-cost droplet microfluidic device seamlessly integrated with embedded custom CMOS sensors, such as luminescence sensing and impedance spectroscopy as demonstrated at the IEEE ISSCC SRP'23 with a live hardware demonstration [Best Poster Award)] and to be presented at the IEEE ISSCC'24. This state-of-the-art innovation transforms the testing process, facilitating swift screening of the biological design space in diverse environments. The outcome is an improved biosensor performance finely adjusted to specific application conditions, such as wastewater monitoring, ensuring optimal sensitivity, specificity, and durability.

In the initial phase of the Deployable Microfluidic Automation Machine (DepMAM) development, the primary focus was translating the proposal's context into a tangible design and prototype for real-time monitoring of pathogens and toxic chemicals in wastewater. This involved a design comparison with findings from an initial literature review. The project integrated scalable microfluidics, CMOS technology, and biosensors, aligning with the requirements of biology, mechanics, electronics, and software. The breakdown of the proposed design into construction and experimentation categories facilitated focused development in key areas, such as Flow Control, Automatic Stages, Sensing/Incubation, Storage/Waste, Energy Supply, and Control System. Following the design structure, the first execution phase was centered on flow control, implementing automatic syringe pumps, valves, and tubing regulating the flow of water, media, nutrient supplements, and waste disposal from the incubation chambers and other fluid dynamics of the system. The initial design and experimentation were for a 3D-printed prototype pump system, controlled by DC motors and Arduinos, achieving precision in syringe injection or refill. Furthermore, the development of an automation code with key parameters, including flow rate (dispensed in mL/h), total quantity (in mL), and mode (infusion or refill), progressed up to the point of subsystem integration.

Building on these achievements, a second version of the initial design was introduced after a second literature review, emphasizing miniaturization and simplification of microfluidics flow control. This version addressed engineering complexities associated with dispensing and sensing, resulting in reduced energy consumption, device miniaturization for portability, a plug-and-play design, and improved electronics integration for enhanced deployment, replacing the category "Automation stages" for "Automation". Experimentation involved various fabrication methods, including PDMS chips with 3D printed molds and milling in polycarbonate boards, with the aim of optimizing fluid dispensing into the incubation chambers. The milling method was selected for its advantages in fast prototyping, allowing for subsequent geometry variations experiments in channels, chambers, mixers, and filtering. The fluid control phase achieved a design where the fluid is dispensed equally in all chambers, with a minimal time difference in filling complete incubation chambers, and avoiding issues such as bubbles, leaking, turbulent flow, and cross-contamination.

In the next phase, we will focus on the experimentation of sensing and incubation. This involves the strategic use of fast fabrication electrodes with different geometries and materials to maintain precise temperature control within the device. The target is to achieve and sustain temperatures below 30°C with an accuracy of +/- 0.5°C across all chambers. Another aspect of the electrodes will contribute to maintaining optimal cultivation conditions while sensing the internal environment. Different geometries in electrodes and materials will be employed to ensure efficient energy consumption, temperature conductance in the device, and sensitivity to diverse characteristics for the stability of the internal environment.

New Publications and Presentations:

2024

Qijun Liu, Diana Arguijo, Alperen Yasar, Dilara Caygara, Aya Kassem, **Douglas Densmore**, **Rabia Tugce Yazicigil**, “Droplet microfluidics co-designed with real-time CMOS luminescence sensing and impedance spectroscopy of 4 nL droplets at a 67 mm/s velocity”, with a live **hardware demonstration**, 2024 IEEE International Solid-State Circuits Conference (ISSCC) (Accepted), February 2024. This work is supported by NSF SemiSynBio-II program and Catalyst Foundation.

2023

Juan Jose Robayo Yepes, **Rabia Yazicigil**, **Douglas Densmore**, “DepMAM: Deployable Microfluidic Automation Machine”, Poster presentation at the Boston University Biological Design Center (BDC) Symposium, October 2023.

Rabia Yazicigil, “Cyber-Secure Biological Systems”, Featured Talks at the Boston University Biological Design Center (BDC) Symposium, October 2023.

Rabia Yazicigil, “The Future is Now! ASICs for Biosensing and Wireless Communications”, Brown University, March 2023.

Rabia Yazicigil, “The Future is Now! ASICs for Biosensing and Wireless Communications”, Berkeley Wireless Research Center, UC Berkeley, February 2023.

Qijun Liu, Diana Arguijo, Alperen Yasar, David Mcintyre, Dilara Caygara, **Douglas Densmore**, **Rabia Tugce Yazicigil**, “Hybrid Bio-Electronic Microfluidic Memory Arrays”, 2023 International Solid-State Circuits Conference (ISSCC) Student Research Preview, February 2023. This work is supported by NSF SemiSynBio-II program and Catalyst Foundation.

Awards / Achievements:

2024

- Rabia Yazicigil, NSF Faculty Early Career Development (CAREER) Award

- Rabia Yazicigil and Douglas Densmore, Semiconductor Research Corporation (SRC) award for the extension of the work currently supported by the Catalyst Foundation

Achievements of Qijun Liu (Ph.D. Candidate from Yazicigil Lab at BU):

2024

- Selected to participate at the IEEE Solid-State Circuits Society Rising Stars Program
- 2023 IEEE International Solid-State Circuits Conference (ISSCC) Student Research Preview (SRP) Best Poster Award (Co-Recipients: Douglas Densmore and Rabia Yazicigil)

2023

- IEEE Solid-State Circuits Society Predoctoral Achievement Award