Evapinator: A low-cost point-of-care blowdown evaporator for biofluid diagnostics

Charles Anderson*
Electrical Engineering
Georgia Institute of Technlogy
Atlanta, USA
charlesanderson12321@gatech.edu

Rajas Poorna*
Bioengineering
Georgia Institute of Technlogy
Atlanta, USA
rajasp@gatech.edu

Saad Bhamla
Chemical and Biomolecular Engineering
Georgia Institute of Technology
Atlanta, USA
saadb@gatech.edu

*equal contribution

Abstract*— Billions of people around the planet live in areas without infrastructure for effective medical diagnostics. This leads to ineffective treatments and hundreds of thousands of avoidable deaths every year. Evapinator aims to address this need by making a wide variety of biofluid-based diagnostics accessible even at a remote point-of-care (POC). To do this, it adopts a two-pronged approach: A) improving the accuracy of existing POC tests by concentrating biofluid samples such as blood serum and urine, and, B) faithfully preserving patient samples, enabling transportation without a cold chain for analysis at better-equipped facilities. This paper discusses our preliminary prototype, its mechanism, and its future trajectory.

I. Introduction

Early disease diagnosis is instrumental for prevention and optimal treatment of life-threatening conditions. Measuring relevant biomarkers requires sensitive testing equipment for accurate diagnosis. Laboratory techniques such as PCR and ELISA serve as the gold standard for this measurement but often require complex equipment, long testing periods, and trained personnel [1].

Point-of-care (POC) testing allows for rapid and inexpensive diagnosis directly at the site of patient care. These tests enable timely medical care in remote and resource-limited settings but can suffer from limited sensitivity, especially when compared to lab-based testing [2]. For tuberculosis alone, the development of a fast, accurate POC test can save hundreds of thousands of lives every year [3].

Further, many tests do not have POC analogs [4]. In this case, patient samples can be sampled at the POC and transported with refrigeration to a better-equipped facility for analysis. However, remote POCs usually lack this cold chain, forcing patients to travel long distances for diagnostics. This can result in patients simply being given empirical or incorrect treatment, leading to negative patient-care outcomes.

In this paper, we present Evapinator, which aims to address both these requirements at the POC. The device dries samples in a controlled environment while maintaining sample stability. Partial drying increases the concentration of the analyte, which can improve the sensitivity of POC tests, potentially making them comparable to lab tests. When this approach is insufficient, the sample can be completely dried, preserving the sample even at room temperature. This enables sample transport without a cold chain, enabling even remote POCs to offer a substantial variety of diagnostic tests.

II. Related Work

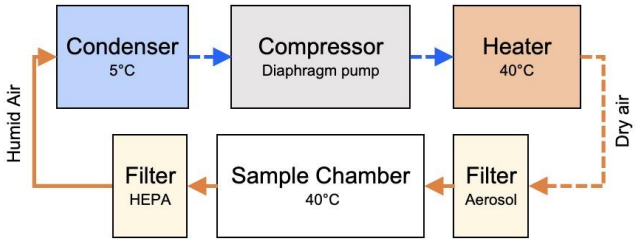
To improve the accuracy of POC tests, it is important to improve their limit-of-detection (LOD). The LOD is the lowest concentration of analyte that can be confidently identified by a test [5]. Several methods have been proposed to improve the sensitivity of these tests, ranging from physical [6], chemical [7], to electrochemical [8] modifications with varying degrees of success. However, these proposed techniques require significant alteration of each POC test, making these methods unrealistic for immediate application.

By contrast, Evapinator can improve the LOD of an unmodified POC test by simply increasing analyte concentration. Little research has been published exploring this method for increasing the sensitivity of POC tests.

For preserving biofluid samples, several methods exist, such as lyophilization, centrifugal vacuum evaporation, and nitrogen blowdown evaporation. However, these require expensive (>$20,000) and bulky equipment, making them inaccessible to those who need it most. Evapinator aims to be an affordable (<$100) alternative that can be deployed in the field for patient use in resource-limited settings.

III. A First Prototype

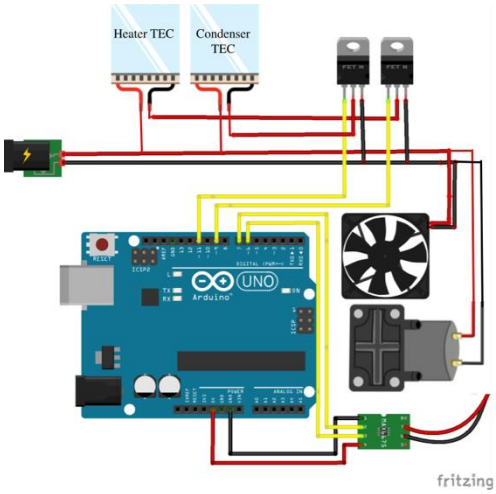
The goal of Evapinator was to create a closed system that would keep samples at an elevated temperature (usually 40°C) while removing water from the system to concentrate or preserve the biofluid. The system operates by forcing dry air over biofluids held in centrifuge tubes, which are heated via contact with an aluminum holder at the set temperature. This air is passed through the condenser unit, where it is cooled (to ~5°C) to remove the water vapor collected from the sample, drying it for the next cycle. The air is filtered using HEPA and aerosol filters to prevent atmospheric contamination, while air channels for different samples are isolated to prevent sample cross-contamination.



Evapinator consists primarily of an Arduino Uno, aluminum heating and condensing blocks, thermoelectric coolers (TECs), air filters, and a 3D-printed PLA sample chamber. All components were available for purchase either on Amazon.com or Digikey.com. The sample chamber was printed on the Bambu X1 printer using commonly available PLA filament. The aluminum heat block was milled from stock. The remaining mounting was performed with laser-cut acrylic.

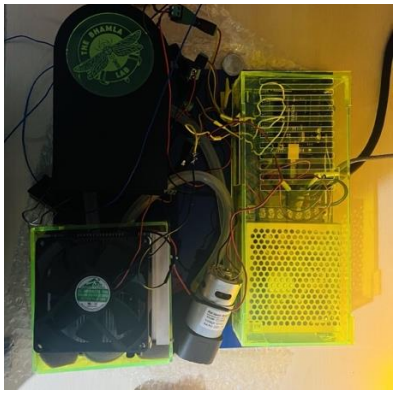
A. Wiring Diagram

The figure below shows the electrical wiring to an Arduino to control temperature and cycle air through an Evapinator.



B. Photo of prototype

The initial prototype, shown below, had a bill-of-materials cost of only $59.29 in bulk (for 1000 pieces). It can evaporate four (typical) 1 mL samples in 75 minutes, compared to 5 hours for a LabConco Centrivap centrifugal evaporator. With a maximum power draw of 40 W, it can operate for ~2 hours on a typical 20,000 mAh USB power bank; sufficient for 1 run.



IV. Envisaged Next Prototype Iteration

Future iterations of this system will focus on improving POC compatibility and manufacturing scalability. POC compatibility can be improved through circular placement of sample wells for even sample drying as well as an increase in the number of wells from 4 to 12 wells. We will also reduce the system's power consumption through improved thermal design. We envision that this pro^2 Summer School will help improve our isotyping and medium-scale manufacturing strategy.

V. Responsible Innovation

The Evapinator has the potential to make a wide range of diseases diagnosable at the POC by improving either the sensitivity of existing POC tests or patient access to well-equipped laboratories. This will enable early detection and treatment of various diseases, saving countless lives. As a result, the benefits of this device are far-reaching.

Nonetheless, given the stringent conditions that an Evapinator will be operating in (remote, low-resource POC), it is particularly important to consider its fault diagnosability and repairability. All components must be inexpensive, accessible, and easily replaceable. Repairability was already prioritized in the development of the initial prototype, with almost all parts easily sourced from common vendors. In future iterations, fault diagnosability must also be accounted for.

VI. Author Bio

Charles Anderson: I am an undergraduate student pursuing a degree in electrical engineering with a minor in Biomedical Engineering at the Georgia Institute of Technology. I am passionate about developing frugal medical devices for resource-limited regions and working towards building wearable health monitoring devices. I am skilled with 3D modeling software including Fusion360 and coding in Python and Mathematica.

I designed and built the Evapinator. I implemented the atmospheric drying mechanism and developed it into a field-friendly prototype, ensuring that it could dry multiple samples while preventing contamination and remaining cost-effective (under $100). This will facilitate field-testing of the device with collaborators in Thailand.

Rajas Poorna: I am a physicist-turned-bioengineer in the field of low-cost medical diagnostics. I believe that most medical diagnostic technologies today can be made affordable and accessible by creatively combining insights from fundamental physics with modern advances in low-cost electronics.

My technical expertise includes analytical and numerical modeling of physical systems, bio-inspired design, optics, microfluidics, medical diagnostic technologies, internet-of-things, embedded systems, wearable technologies, mechatronic design, rapid prototyping, and machine learning. I am good at designing electronics (digital/analog), PCB design and soldering, 3D mechanical design, and coding in Python and C++.

I served as the main mentor and provided guidance throughout this project. I envisioned the Evapinator's fundamental mechanism: atmospheric blowdown evaporation using a cold-trap for moisture, as opposed to the

vacuum system used in a traditional centrifugal evaporator. This approach allows us to attain fast drying using simple components, sidestepping the cost, bulk, and power consumption of a vacuum system.

Saad Bhamla: I am a biomechanist focused on the intersection of biology, physics, and engineering to create knowledge and tools that inspire curiosity and innovation. I believe that understanding biomechanics across species can lead to transformative inventions, especially in the realm of ultra-low-cost devices for global health.

As an inventor, I have developed several notable low-cost devices, including a paper centrifuge, a low-cost electroporator, and a low-cost hearing aid. My contributions have been recognized with numerous early career awards.

I served as the Principal Investigator on this project in our lab at Georgia Tech, contributing to need identifying, field testing, technical feedback, overall project management, team mentorship, and obtaining funding for this project.

VII. Acknowledgements

The Evapinator started as LyphoX, a low-cost lyophilizer led by Aditya Prabhakar as a high-school science project. He is now a neuroscience undergraduate student at Georgia Institute of Technology. We pivoted to this evaporation mechanism once we realized that we could get around the requirement for a bulky vacuum pump and chamber.

VIII. References

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