PathTracker: A Smartphone Clip-on Instrument for HIV detection

ECE 445 Project Proposal — Fall 2019

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1. Introduction

1.1 Objective

HIV remains one of the most serious global health threats of our time. Statistically, 1.8 million people were infected with HIV and 940,000 died of AIDS-related causes in 2017.On the other hand, 54 percent of the people living with HIV are not receiving the treatment that they need [1]. In their daily lives, HIV patients undergoing antiretroviral therapy need to perform frequent blood tests to monitor their virus levels and the effectiveness of the treatment. In this context, a point-of-care, high-sensitivity device requiring no laboratory expertise will be very helpful.

Therefore, we will be collaborating with Prof. Cunningham and a group of bioengineering students for an innovative solution: a smartphone clip-on device that enables efficient HIV sensing at the point of care. In our plan, the device is mainly composed of a macro lens, a ring-shape LED illuminator, a heater and a cradle to hold patients' blood sample. This device will provide the required conditions for HIV examination. Specifically, under proper illumination and temperature, a fluorescent reaction will happen in the specially designed assay containing patient's blood sample, creating visible green dots in the cartridge. Finally, video will be captured through the rear-facing camera of the smartphone and analyzed later as test data.

1.2 Background

Previously, Prof. Cunningham and his graduate students solved a similar pathogen sensing problem which used a similar smartphone-based portable detector for the diagnosis of equine respiratory disease [2]. However, that sensing device is specific to repository diseases in horses and can't be used for HIV virus. In addition, that device is too big to clip on the smartphone which could be less convenient for patients.

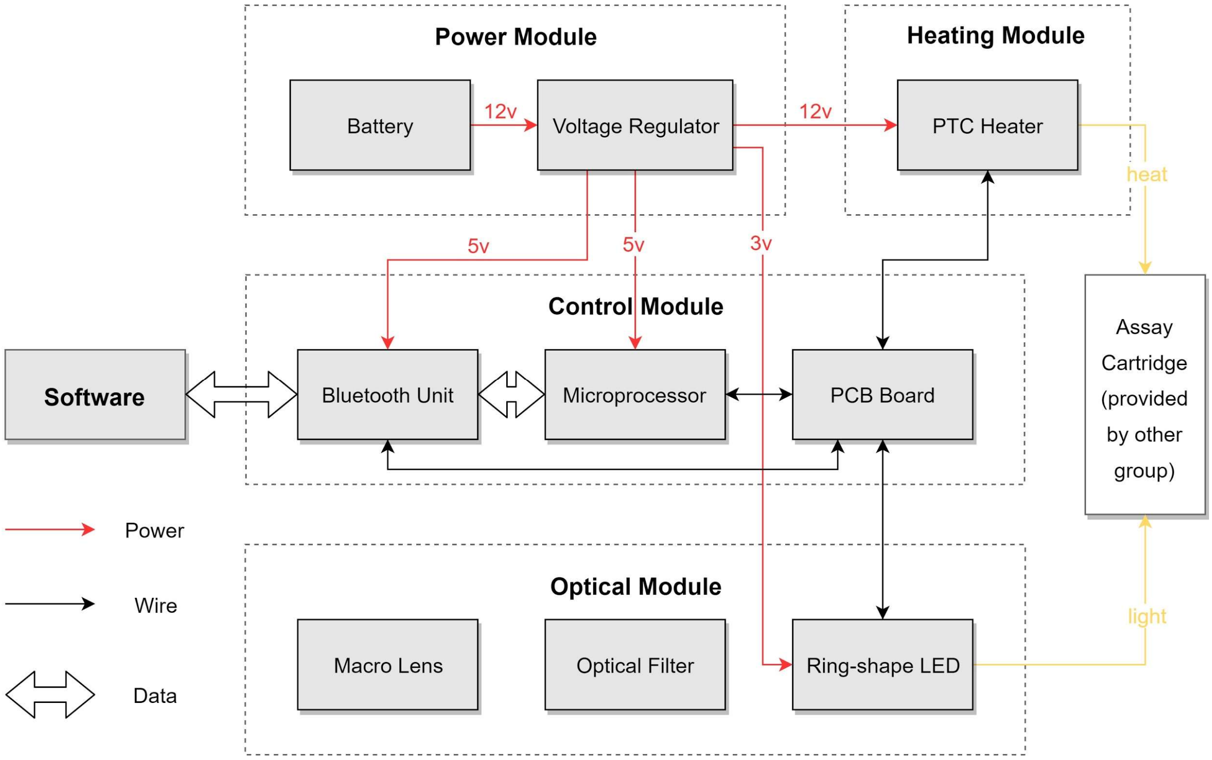
Our approach will yield a small home monitoring tool so that those patients could clip it on the smartphone to help facilitate the prevention of HIV progression. We will design an inexpensive (< $10) clip-on instrument that enables the rear-facing camera of any modern smartphone to function as a fluorescence microscope that illuminates and isothermally (70 C) heats a silicon-based test cartridge that is pre-loaded with primers for Loop-Mediated Isothermal Amplification (LAMP) of HIV-specific nucleic acid sequences. This process creates green, fluorescent foci in the test sample. Then, the presence of the HIV virus can be clearly shown in the phone's footage and sent to the doctor for analysis conveniently.

1.3 High-level Requirement List

- The device must enable the LAMP chemical reaction to happen in the assay containing HIV sample, which requires the heater to be set on 70 degree Celsius with tolerance of 2 degree Celsius, stably through 30 minutes.
- A clear footage needs to be captured through smartphone and it should clearly show the fluorescent foci of the HIV viruses, which requires the cartridge to be illuminated evenly and all the optical components, including the illuminator, filter and microscope, to be properly aligned.
- All components must be organized in a clip-on container of suitable size such that the heater can work safely without damaging other electronic parts or the phone.

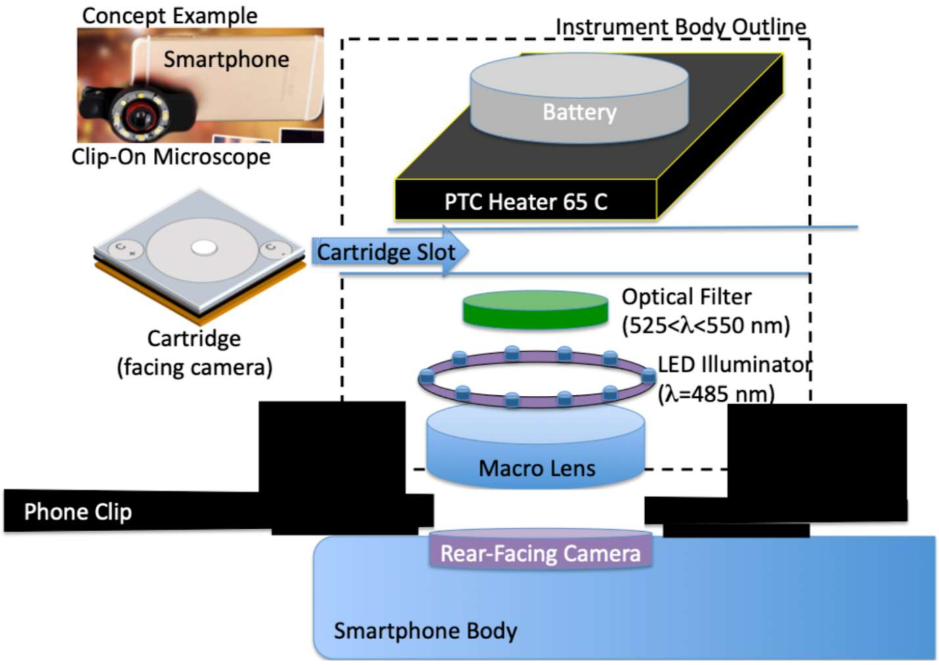
2. Design

2.1 Block Diagram



The design is divided into 6 main modules: the power module, the heating module, the optical module, the control module, the clip-on container and the phone software. The power module will provide power for electrical components in the other modules. The heating module and the optical module will heat the assay cartridge under certain temperature and light it with certain wavelength light so that the reaction will be triggered and the camera is able to capture the result. The control module will control the switch of the whole circuit and interact with the software via Bluetooth. The software will interact with the control module via Bluetooth to control the switch of the circuit and will also use the phone's rear-facing camera for video taking. Finally, every hardware modules will be organized in a 3d-printed, clip-on container.

2.2 Physical Design



The instrument is comprised of a macro lens, a ring-shape LED illuminator, an emission filter, a PTC (positive temperature coefficient) heater, a rechargeable battery, and a clip-on container. The system fits over the rear-facing camera of a smartphone and has a slot to accept the test cartridge after reagents are added. Physical design picture credits to the PFI Proposal provided by Prof. Cunningham.

2.3 Modular Description

2.3.1 Power Module

The power module is comprised of a rechargeable battery and a voltage regulator. The battery will provide power for all electrical components and the voltage regulator should provide different voltages to different components according to their working voltages. It provides power to heating module, control module, and optical module.

Requirement 1: The battery should able to provide power for at least 1 assay, which lasts about 30 minutes.

Requirement 2: The voltage regulator should able to provide different voltages to different components according to their working voltages.

2.3.2 Heating Module

The heating module will only contain a PTC heater. The PTC heater should heat to a certain temperature under power and able to keep the temperature so that the reaction in the assay cartridge is triggered. It receives power from the power module, is controlled by the control module.

Requirement 1: The PTC heater should able to heat to 70 degree Celsius and keep the temperature at 70 ± 2 degree Celsius when switched on.

2.3.3 Optical Module

The optical module is comprised of several concentric ring-shape LED illuminators, an optical filter, and a macro lens. The light emitted from the LED will pass through the optical filter onto the assay cartridge so that the foci of fluorescence will absorb light and start to shine, emitting light through the macro lens into the rear-facing camera of a smartphone. It receives power from the power module, is controlled by the control module.

Requirement 1: LED are individually tuned to achieve best-possible light uniformity shining upon the cartridge and the darkest and brightest spots should differ no more than 100 lux.

Requirement 2: Fluorescent foci can be visually differentiated from the background, with contrast higher than 320 lux.

2.3.4 Control Module

The control module is comprised of a PCB board, a microprocessor, and a Bluetooth unit. Every electrical component, including microprocessor, Bluetooth unit, battery, PTC heater, and the ring-shape LED will be connected to the PCB. The Bluetooth unit will receive signal from the software and send the data to the microprocessor, and the microprocessor will switch on/off the PTC heater and the LED according to the operation on the software. It receives power from the power module, controls the heating module and the optical module by the switching on/off of the PTC heater and the LED, interacts with the software via Bluetooth.

Requirement 1: The control module should be able to interact with software via Bluetooth and switch on/off the PTC heater and LED accordingly.

Requirement 2: The control module should be able to cut off the power of the PTC heater if the temperature is too high to prevent possible safety issues.

2.3.5 Clip

The clip is 3D printed will provide space for holding all other modules. It will align the optical filter, the ring-shape LED and the macro lens, and clip on the back of a smartphone.

Requirement 1: The clip should be able to align the optical filter, the ring-shape LED and the macro lens, and able to hold clip on the back of a smartphone.

Requirement 2: The clip should not melt under heater's heat, and should protect the PCB board and the smartphone from overheated by the heater.

2.3.6 Software

A simple smartphone application will be designed on Android system. It will be used to control the instrument, as well as utilize smartphone camera to capture footage of the sample.

Requirement 1: The application incorporates the phone's camera to take clear images and video of the sample undergoing reaction.

Requirement 2: With input received from the user, the application should turn LED and heater on and off accordingly, through Bluetooth communication.

2.4 Risk Analysis

To achieve ideal outcome, the optical module needs the most attention to design and assemble.

First of all, since the LED will be aligned in a ring-shape, their individual brightness must be carefully determined and tuned to achieve best light uniformity. Specifically, all the fluorescent dots in the assay should both absorb and emit an even amount of light so that the footage can be more readily analyzed. This process requires a large number of trials and is highly dependent on the specific assay composition. We will run simulation upon the completion of the illumination component to decide the individual brightness and append different resistance to the circuit to meet this requirement. Then, more tests will be done given the assay provided by BioE team from Prof.Cunningham.

Secondly, the optical filter also needs to be carefully designed. The most important role it plays is to filter out the LED reflective light, which is only about 50 nm apart from the fluorescent light. Moreover, it's not supposed to alter the original brightness of the sample, which might potentially cause miscalculation when the footage is processed. A careful design choice needs to be made corresponding to the LED illuminator and the assay used.

3. Ethics and Safety

There are several potential safety issues that could happen if we do not take care of. During the design process, the PCB might have serious defects that could short circuit or even burn the other devices. Therefore, we need to make sure that the PCB itself is tested thoroughly before integrating other parts of hardware.

One of the most important concerns about the misuses is that the PTC heater may be overcharged or brought to extremely high temperature which could destroy the whole device and lead to potential explosion. Although the PTC heater is designed to be safer than other ceramic heaters, its working temperature cannot exceed 200 C. Otherwise, it may cause flames if it falls on a flammable surface. More importantly, the extremely high temperature could burn down the PCB and other hardware device including the smartphone. Thus, in order to prevent above hazards from happening, we will make sure the correct power is supplied (120-volt 60Hz AC) and the heater will never be left unattended for a long time. Furthermore, we will also use a thermometer to monitor the temperature of the heated assay so that we can turn off the heater immediately if the temperature exceeds the threshold.

Moreover, there are some IEEE and ACM ethics codes that are relevant to our project and thus we need to examine them carefully. The IEEE Codes of Ethics #2 states that “to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist” [3]. Since we work closely with the patients’ health information related to HIV, we need to disclose this information and make them only available to the patients and related doctors. We need to make sure that we will not send those data to other interested parties who may utilize this private information for their own purposes.

In addition, the IEEE Codes of Ethics #9 states that “to avoid injuring others, their property, reputation, or employment by false or malicious action” [3]. In our case, we need to make sure that our product will not do harm or injury to the user. For example, the user may heat the PTC heater to the wrong temperature so that the heater may possibly burn the users. In order to prevent this, we will add some protections that will cut off the power of the heater if it is overheating.

According to the ACM General Ethical Principle 1.3 “Be honest and trustworthy” [4], we should be honest about their qualifications, and about any limitations in our competence to complete a task. Specifically, we should honestly disclose the efficiency of our device. We should also provide the users with the limitations of our design like running environment and the running time.

Reference

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