Fabrication and Development of an Optical Biomedical Sensor

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***Abstract*—Portable biomedical devices have proven useful during the COVID-19 pandemic, as devices like optical pulse oximeters and rapid detection tests have been readily available to the public. This paper presents a prototype version of a non-invasive, portable, Mie scattering-based blood quality sensor, developed by the authors for their theses.**

***Index Terms*—biomedical sensors, Mie scattering, circuit board, machine learning, embedded systems, optics, data analysis**

I. Introduction

THIS paper represents the combined efforts of the four authors throughout multiple years. After a proof of concept was submitted by Karakostas et al[2], a prototype of the apparatus was developed by two of the authors. A second, improved version is currently in development, aiming to upgrade the sensor's hardware and optics, implement new features, and improve the data analysis using more advanced algorithms, as well as machine learning.

The apparatus uses a light source and a detector for the detection of Mie scattering in blood cells. Mie scattering describes the behaviour of electromagnetic waves when encountering particles larger or equal to $\frac{1}{10}$ of the wavelength, but is most useful for particles with a diameter comparable to the wavelength. Depending on the wavelength of light and the particle's size and optical properties, a distinct intensity pattern will be identified at different angles of the detector.[1]

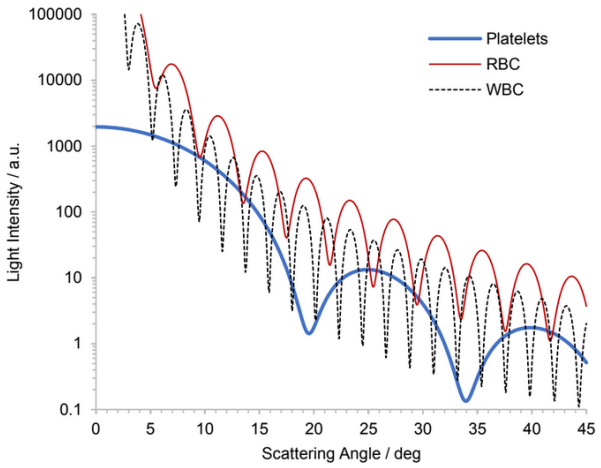

Figure 1: Mie scattering simulation for different types of blood cells, in Mieplot[2][3]

II. Hardware

The prototype was composed of a Beaglebone Black Rev. C microcomputer, a circuit board, a 655nm laser diode, a photodiode array, an RGB LED, a button, and the 3D-printed case. Modifications to the 3D-printed case of the project are crucial to ensure our ability to examine auricular cartilage tissue, as the current housing was designed for in-vitro blood samples in cuvettes and in-vivo finger samples.[1][4]

Moreover, the proper cooling of the Beaglebone Black rev. C,

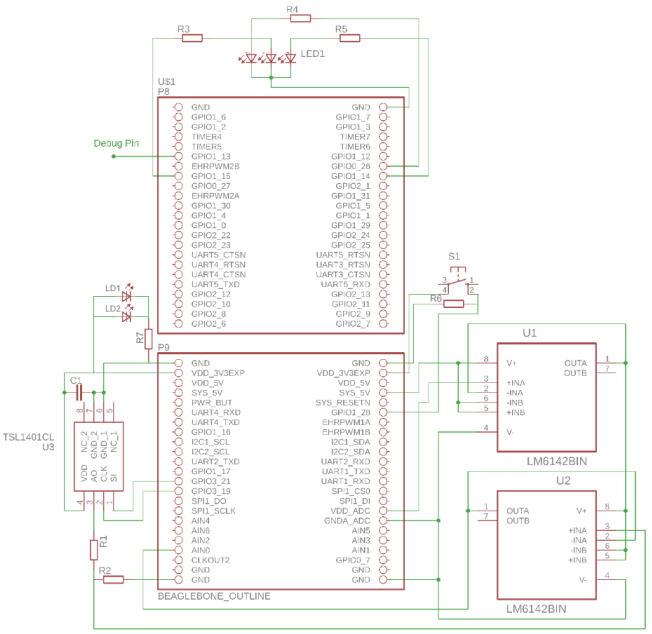

Figure 2: The circuit diagram of the device[4]

which can reach up to 54.6^{o}C, should be taken into account for the longevity of the device. For this purpose, heat sinks and air vents will be added inside the case. Furthermore, the addition of two optical polarizing filters - one in front of the laser beam and one in front of the PDA - were added to the apparatus for noise reduction and polarizing angle experimentation.

III. Optics

A few modifications have been suggested that would make a significant difference to the existing device. The use of two 43mm polarizing lenses is beneficial for the reduction of noise because polarization has been proven advantageous in such configurations, by preventing multiple scattering events from interfering with the resulting data. Another proposed change is the usage of two identical lasers on a beam-merging,

polarizing configuration in order to increase the signal-to-noise ratio of the data. The final proposed change is a three-laser configuration so a dichroic filter could be added to the previously mentioned design along with a waveplate and a laser on a different frequency, allowing the gathering of more information compared to previous designs.[2][3]

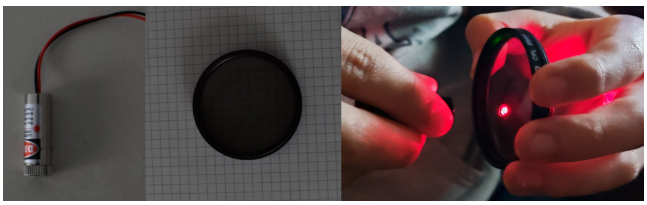

Figure 3: One of the laser diodes (a), a polarizing lens blocking unpolarized light (b), the lens allowing most of the laser diode's light through (c)

IV. Software

The Beaglebone's SoC contains an ARM CPU and two programmable real-time units (PRUs). The ARM processor is responsible for handling the system services of Debian GNU/Linux, such as the handling of sample files, the execution of the main program, the initialisation of the PRUs, and memory management. The PRUs are responsible for driving the photodiode array (PDA) and creating interrupts (PRU0), or for handling the Analog-to-Digital Converter and storing the sensor's data (PRU1). Frame-capturing cycles are divided into three parts, the first of which is integration. During the integration time, the PDA is operated normally but any samples are ignored. Secondly, during the sampling period, the PDA is operated normally and its samples are collected. Lastly, a delaying phase is executed, during which the PRUs do not execute operations, to keep the number of sampling cycles per second equal to the number requested by the user. This process is repeated until the end of the measurement, when the number of recorded frames matches the number requested by the user.[4]

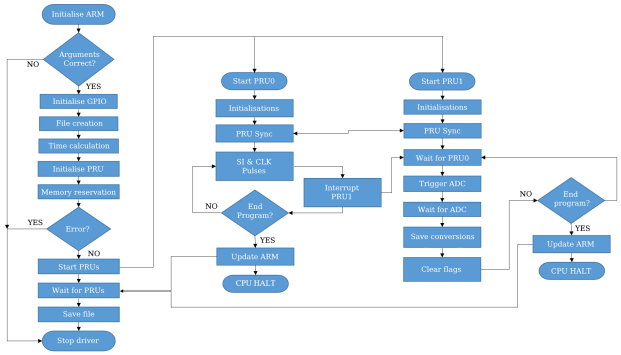

Figure 4: A flow diagram of the software driver[4]

V. Data Analysis & Machine Learning

Since the apparatus currently only records and stores raw data, an external device is required for data analysis. Any personal computer capable of executing C++, Python, and Matlab programs can be used for this purpose. The first programs, developed in Matlab, would execute simple algorithms to determine the accuracy and repeatability of the sensor and would analyse the sample to ascertain the concentration of the particles, the size of the particles, and (for in-vivo samples) the heart rate of the subject. One such program would also draw the Mie plot of the average sample with its expected plot. New programs are currently in development in C++ and Python, implementing more complex algorithms in order to improve the quality of the results and the time efficiency of the process. One such example is programming a good approximation of the model in order to acquire more information about the size, number, and type of particles in the liquid sample.

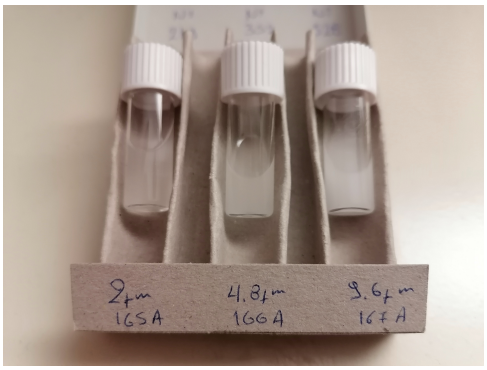

Figure 5: Cuvettes with latex spheres, used for the calibration of the sensor

Assuming a scanning frequency of 50 frames per second and a duration of 5 seconds, the 128-pixel sensor will return a sample of 32000 12-bit unsigned integers every time the code is executed. It is unlikely that a human could adequately recognise patterns between several samples of this size and type. Therefore, machine learning is also being considered as a means to analyse the sensor's data. The training dataset will be *voluntarily* provided by individuals at a microbiological laboratory, where their anonymous samples will be paired with the results of their blood test. A first draft of the multilayer neural network is currently under development in Python. The authors are also looking into unsupervised machine learning algorithms, such as the K-means algorithm, in order to discover any unknown underlying patterns.[5]

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