1-1-2023

# Improving Optical Heart Rate Sensitivity in the Obese and Dark Skin Tones Using Time-Resolved Monte Carlo (TRMC)

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# RCEU 2023 Project Proposal

## Project Title

Improving Optical Heart Rate Sensitivity in the Obese and Dark Skin Tones Using Time-Resolved Monte Carlo (TRMC)

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## Proposal ID RCEU23-LE-PH-01

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## I. Project Description

Alabama's rate of adult obesity is 39.9% (41.1% for West Central counties), which places the Alabama in the third highest position in the nation. Obesity can cause hypertension (elevated blood pressure - BP) and is often linked to cardiovascular diseases (CVD) because hypertension is a major risk for CVD. Research into cuff-less and continuous BP devices based on optical photoplethysmography (PPG) is rapidly expanding in the U.S. market with the U.S. Food and Drug Administration (FDA) approval of commercial wearable devices for BP monitoring. Currently, majority of optical PPG sensors rely on the measurement of steady state diffuse reflection signal from skin. However, such technique produces poor sensitivity when considering photon from deep dermis where capillary vessels are found, and when considering individuals with darker skin tones (poor depth sensitivity for thick patients and low detection efficiency for dark skin tone patients). This research project intends to explore the potential of time-of-flight spectroscopy techniques to improve PPG sensitivity in obese individuals and those with darker skin tones. This is preliminarily accomplished by using time-resolved (time-domain) Monte Carlo simulations of photon transport in skin to study optical PPG.

## II. Student Duties, Contributions, and Outcomes

*a. Specific Student Duties*

Overall, the student will (1) learn skin anatomy and its dynamic changes with obese progression from the provided papers, (2) perform computational modeling of PPG wave in individuals with different skin tones and various obese using both skin anatomy, skin optical parameters, and common wearable device design, (3) analyze the results and compare between time-resolved PPG and continuous wave PPG. Table 1 summarizes student's workload in 10 weeks.

**Table 1. Summary of Student Duties**

| **Timeline 10 weeks** | **Week** | | | | |
|---|---|---|---|---|---|
| | 2 | 4 | 6 | 8 | 10 |
| Review skin anatomy, skin optics and obese | | | | | |
| Simulate full-wave PPG using steady-state Monte Carlo | | | | | |
| Simulate full-wave PPG using time-resolved Monte Carlo | | | | | |
| Compare and contrast two approaches | | | | | |
| Make preliminary conclusion | | | | | |

*b. Tangible Contributions by the Student to the Project (10% of Review)*

The student will start with reviewing key concepts of tissue optics and how skin optical properties change as obese progresses and demonstrating the ability to generate similar results to investigator's previous publications using a generic Monte Carlo program to simulate of Apple watch design. The student then will use a more novel time-domain Monte Carlo method (commercially available) to generate PPG signal across different skin tones and in the obese. The

student will compare the Apple Watch errors in heart rate monitoring between light and darker skin tone, normal and obese individuals, between the time-domain Monte Carlo and generic Monte Carlo simulation.

*c. Specific Outcomes Provided by the Project to the Student* *(30% of Review)*

The key message is to inspire the student to design bio-optical engineering products more effectively by considering end-user diversity, in this case, skin tones, obese status and more advance technology. This project will provide student with valuable information regarding the obese disparity in underserved populations who have limited access to health care and heavily rely on wearable technologies. As such, the project will also inspire the student to change the paradigm for the health of underserved populations and areas by developing revolutionary and cost-effective technologies and systems at the point-of-care.

## III. Student Selection Criteria

This project looks for an undergraduate student with a major in engineering or science who has a basic knowledge of MATLAB programming and has some background in optics. Furthermore, students who are eager to apply engineering knowledge to improve human disease detection accuracy are strong candidates for this project.

## IV. Project Mentorship *(30% of Review)*

The mentorship will rely on three key components: planning, establishing expectation, daily communication, and respect.

At the beginning of the project, I will work with the student to set goals, deadlines, and expectations. I will take the time to teach the students to appreciate the research process including literature review, generating effective graphs and figures, and data storage. I will encourage the student to disseminate his work in the same way that a graduate student would and inform the student that undergraduate research publication opportunities do exist in my laboratory. Since the student is new to research, I will budget time for the student to acquire necessary background in tissue optics. Additionally, because the student previously expressed interest in computational modeling, we will utilize simulation in different computational languages (C++, CUDA, MATLAB) that will allow the student to have intellectual ownership.

I will communicate daily and clearly with student, following up with him shortly after giving new direction so he can ask any questions that came about during the initial processing of the information. In addition, I will provide positive, constructive feedback and encouragement through our interaction.

The student will be treated as professionals and be given the same respect and opportunities for development as other students in my lab. After the research project is complete, I will provide continued mentorship if needed and offer career guidance.