Noninvasive Module for Biomonitoring Live (NIMBL)

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1. PROJECT NARRATIVE

1.1 Background and Motivation

There are many situations in which simple biomonitoring can save a life. Whether providing important insights in an emergency situation or measuring the vitals of a sleeping baby, blood oxygen levels and heart rate are indicators of potentially serious threats. Our motivation with this project is to build a prototype that has the capability to be scaled down in future iterations to provide an inexpensive vitals monitoring system that could be dynamically included in many different use cases.

1.2 Goals and Objectives

The overarching goal of our project is to provide an inexpensive and low-profile device that can provide people with the ability to easily monitor two vital biometrics: their blood oxygen levels and heartbeat. Ultimately, our **goals** are as follows:

Basic

- Offer a <u>safe</u> and <u>accurate</u> noninvasive biomonitoring experience by featuring power element isolation between the electrical systems and the user. We will also radiate within the appropriate bandwidths and at the appropriate power levels for RF communications.

Advanced

- Make the device <u>versatile</u>. By versatile, we mean that the design should be modular in such a way that it could fit onto various mounts and inside of various casings.
- High power efficiency would also contribute to realizing a versatile biomonitor; the longer that the device can operate on a single charge, the better.

Stretch

- <u>Maximize long-term utility and data storage</u> by effectively communicating data to an external base station via RF communications.

From these goals, we can derive the following **objectives**.

Basic

- Isolate power storage and circuit elements from the user
- Accurately measure pulse rate and blood oxygen levels using noninvasive sensing
- Utilizing an on-board processor, leverage software to transform sense data into visualizations: a percentage (for blood oxygen monitoring) and a pulse rate measurement

Advanced

- Total prototype weight under 3kg
- Ensure that the prototype can operate for at least three continuous hours of screen-on time
- Communicate data via RF to a base station for storage

Stretch

- Establish software for processing stored biometric data to generate long-term analyses

2. FEATURES, REQUIREMENTS AND STANDARDS

2.1 Related Products and Reviews

2.1.1 - Owlet Dream Sock®

The Owlet Dream Sock® is designed for newborns and infants. It is a low-profile module that includes a sensor, flexible PCB, and onboard power storage [1]. It measures various biometrics, including heart rate and blood oxygen levels, before broadcasting these results to an external base station using RF. The data is finally processed from the base station to present parents with data regarding the health of their baby (pulse rate, blood oxygen, sleep cycle, etc).

The Dream Sock® is similar to NIMBL in that it measures heart activity and blood oxygen levels and has a strong emphasis on maintaining safety for its users (The Dream Sock® being an FDA-cleared product). One key difference is that the Dream Sock® aims to prioritize an incredibly low weight (<0.15kg) and a flexible profile (139.7mm x 82.6mm x 190.5mm) to optimize specifically for the comfort of babies. While it is still important for our prototype to be light, we aim to keep our prototype systems large for ease of troubleshooting, with an eye towards preserving the possibility of downscaling in future iterations. It is also worth noting that the bulk of the Dream Sock's® processing occurs after its data is transmitted to the base station; there is no display mechanism on the same frame as the sensor module. This is another difference from NIMBL, where we would want an on-board processor to perform the data processing and on-board displays to display the results. This addresses a popular complaint that customers have made regarding the Dream Sock®: that is, they say that the RF communication to its base station is unreliable at times, making it impossible to actually access the data being collected [2].

2.1.2 - Fingertip Oximeter: Nonin Onyx® Vantage 9590

Pulse Oximeters are devices dedicated to reading or monitoring pulse rate and blood oxygen saturation level (SpO2). They typically come in three form factors: fingertip, handheld, and wearable, each with different benefits and drawbacks. Fingertip Oximeters clip to the end of the finger and utilize spectrophotometry to identify the concentration of oxygenated and deoxygenated hemoglobin based on the absorption of different wavelengths of EM radiation, as well as the pulses of absorption rates (changes in arterial flow) to characterize heart rate. Fingertip Oximeters are typically more affordable than the other options; they are highly portable due to their small size, simple to use, provide fast readings, and are suitable for quick checks. However, they are not for constant monitoring; often do not include features such as data logging, smartphone apps, and alarms; and they can be susceptible to inaccuracies from movement or even skin tone [3].

The Nonin Onyx® Vantage 9590 Fingertip Oximeter is regarded as the "Gold Standard" for this form factor [3]. A study published in *eBiomedicine* concluded that this device was one of the two best performing devices for error related to skin pigmentation [4]. The Vantage 9590 utilizes a transmissive configuration where LEDs shine 660 nm wavelength red light and 910 nm infrared light [5] through the finger to a photodetector. This configuration makes measurements less sensitive to placement as well as more stable and repeatable [6]. The photodetector captures the waveform produced by the changes in light due to the pulse of the wearer, and passes it off to a digital signal processor (DSP) to filter the signal. Then the DSP uses an algorithm to detect pulse signals [3]. It is implied that there is an algorithm to calculate the SpO2 as well. The device also leverages another algorithm that allows for a variable averaging time so that the device can still provide a fast 3-second reading (or faster), or extend the reading if the signal is inconsistent or weak, maintaining device accuracy [7]. The numerical pulse and SpO2 measurements are displayed using 7 segment LEDs and a tricolor LED indicates pulse quality [8]. The device is powered by two AA batteries [5].

2.1.3 - Handheld Oximeter: Masimo Rad-G®

Handheld Oximeters can offer more accuracy over Fingertip Oximeters, as well as greater versatility if they utilize probes that can attach to other areas of the body than the finger. They can often include additional features due to their larger form factor, and are typically more robust. The Masimo Rad-G® is a handheld pulse oximeter that was designed to be durable enough to survive 6 ft drops onto hard surfaces. It is able to interface with various sensor probes so it can be used in various situations. The Rad-G® measures SpO2 and pulse rate just like the Vantage 9590. The handheld is also engineered with additional features; it displays the Plethysmorograph (the PG in PPG) waveform on its screen as well as the Perfusion Index (PI), the Respiration Rate, and the Plethysmograph Variability Index (PVI) [9]. PI is a parameter that represents the strength of the pulses of blood flow at the sensor. This PI value is useful for determining shock or other circulatory issues in a patient. The PVI is an indicator of a patient's fluid responsiveness to determine if additional fluids will benefit a patient's circulation. The PVI can be obtained noninvasively. Finally, the Respiration Rate measurement allows users to monitor a patient's breathing through fluctuations in the Plethysmorograph. This reduces the amount of equipment the user would otherwise need [3]. It has a 2.8" (diagonal) color LCD display and is powered by a rechargeable Lithium ion battery. It is capable of storing data measurements for 96 hours [9].

2.1.4 - Wearable Oximeter: Withings ScanWatch 2

Wearable Oximeters benefit over the other form factors because they are more suited for continuous monitoring and data logging. However, they can be less accurate due to motion and varying contact conditions. ScanWatch2 is an example of a Wearable Oximeter. It is designed to look and function like a watch. It uses a Multi-wavelength PPG with 16 channels to improve monitoring accuracy of SpO2 and pulse rate. It supports many additional features: temperature tracking, AFib detection, sleep quality measurements, breathing quality measurements, accelerometer, altimeter, smart watch features, the ability to connect to other biomonitoring devices, and more [10]. Unlike the Fingertip Oximeter and Handheld Oximeter examples, the ScanWatch 2 uses a reflective configuration for the PPG sensor, meaning the photodetector is on the same plane as the LEDs and measures the amount of light reflected. This configuration allows the sensor to be used on other parts of the body where a transmissive PPG could not be [6]. The watch also has an OLED screen to display information and is charged using a docking station. It is capable of storing health data for 7 days locally, or unlimited storage in the cloud [10].

2.1.5 - Related Products' Features Applied to NIMBL's Features

From our research on other products, there are a few features that have been applied to our project. The robustness and rechargeable battery from the Masimo Rad-G® were clear additions to bring. We took inspiration from the simplicity of the Nonin Onyx® Vantage 9590's display and chose to use a simplistic LCD screen for the same type of display. Having an LCD display enables the flexibility of displaying text in a budget-friendly manner. From the DreamSock®, we would like to preserve the transmission of data via RF to a base station for storage and potentially further processing. We will likely utilize a PPG sensor to obtain vitals information since they work well for a cursory measurement and present lower risk than electrodes. Our choice in the PPG sensor is inspired by the ScanWatch 2 so our device can be used in various different applications.

2.2 Features and Functionality

We have highlighted key features in pursuit of reading two vital biometrics. The project's main feature is the biometric sensor module (likely PPG). This will be placed in an easy-to-access location where a user can hold their finger up to the scanner. As we read a user's biometric data, the MCU will run an algorithm that filters the noise to ensure an accurate reading is displayed. A custom 3D-printed enclosure will house the electronics, providing an aesthetic shell as well as protecting the parts from environmental factors and physical damage. Additionally, a micro-USB port is placed on the back for easy charging. Users do not have to worry about overcharging or shorting the battery, as protection circuits will be designed. On top of the enclosure will be two LCD screens that show the readings of heart rate and blood oxygen levels. The displayed values will be continuously updated as the user keeps their finger on the sensor. Near the sensor module, we will also include an on-off switch so the user can save battery life when the product is not in use. The MCU will also put the device into a sleep mode if no finger is detected on the sensors after 10 seconds.

3. KEY ENGINEERING SPECIFICATIONS

3.1 Overall System Specifications

Marketing Requirements	Engineering Requirements	Justification
2,3	*Pulse rate* should be obtained *within 10 seconds* of contact.	There could be noise as we read data, so this time frame should give us an accurate measurement with fast responses.
4	*Screen-on time* should be ≥ *3*	Users should be able to read vital

	hours.	information for a long time without frequent charges.
1	We must *transmit* a *maximum of 36dBm EIRP.*	Compliance with FCC regulations (Part 15.247) on RF communications.
1	We must *transmit between 902-928MHz*.	Compliance with FCC regulations (Part 15.247) on RF communications.
5	*Wireless transmission* should be successfully received from *at least 10 meters away*.	Being able to save data via wireless communication allows for further analysis of health patterns.

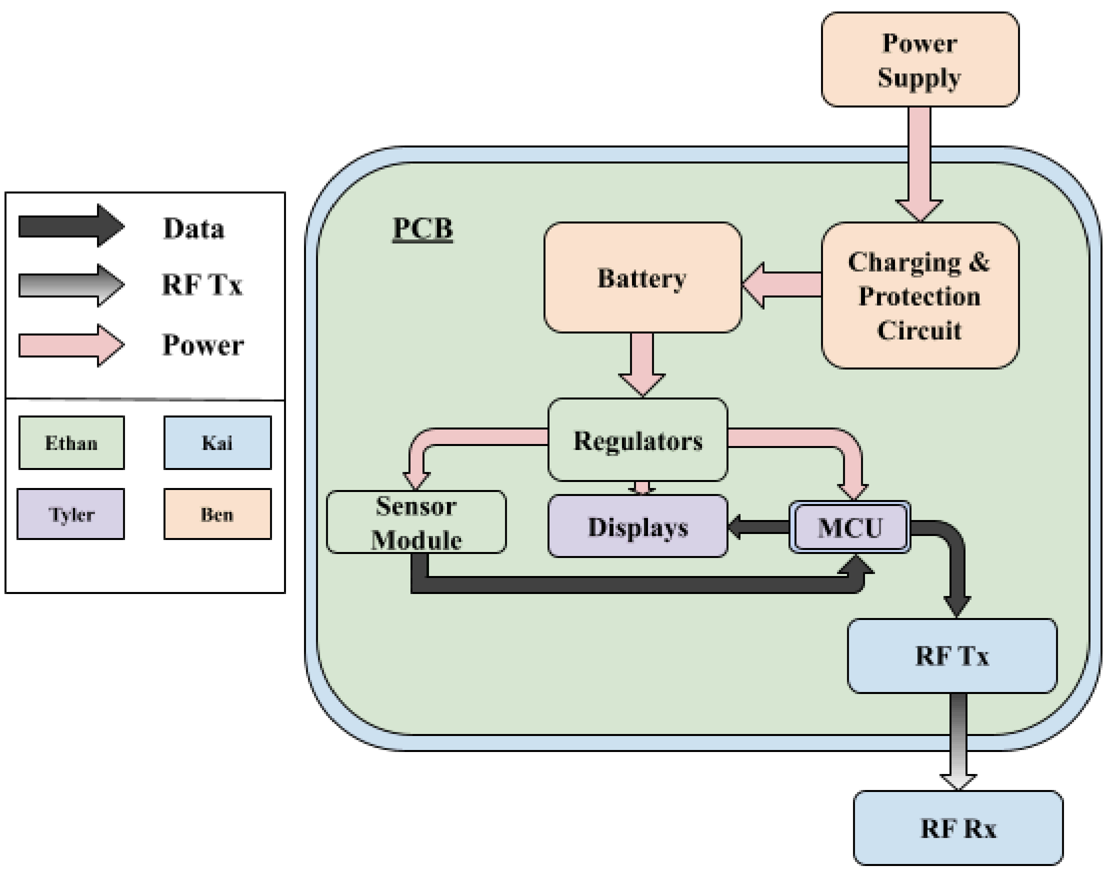
Marketing Requirements
1. The prototype must be safe and compliant.
2. The prototype should provide accurate measurements of blood oxygen and pulse rate.
3. The prototype should respond quickly.
4. The prototype should have good battery life.
5. The prototype should maximize long-term utility and data storage options if possible.

3.2 Subsystem Specifications

Subsystem	Parameter	Specification
Power	ACDC Conversion	DC Output
Power	DC Power	< 10W
Power	Battery Type	Lithium Ion
Power	Charge Port Interface	Micro-USB
Power	Nominal Battery Voltage	3.7V
Power	Maximum Battery Output Power	< 10W
Power	Regulator Voltages	3.3V & 5V
Power	Shut-Off Temperature	≤ 60°C
Sensor	Sensor Type	PPG

Sensor	Minimum Sensor Sampling Interval	≤ 1s
Sensor	Sensor Communication Protocol	SPI
Software/Hardware	MCU Clock Speed	16MHz
Software/Hardware	MCU Programming Language	C
Software/Hardware	Display Type	LCD
Software/Hardware	Initial Data Display Time	≤ 10s
RF	Transmission Distance	≥10m
RF	EIRP	≤36dBm
RF	Operating Frequency	902-928MHz
Sensor	Contact Time Before Thermal Injury	>8 hours

4. HARDWARE BLOCK DIAGRAM



5. SOFTWARE FLOWCHART

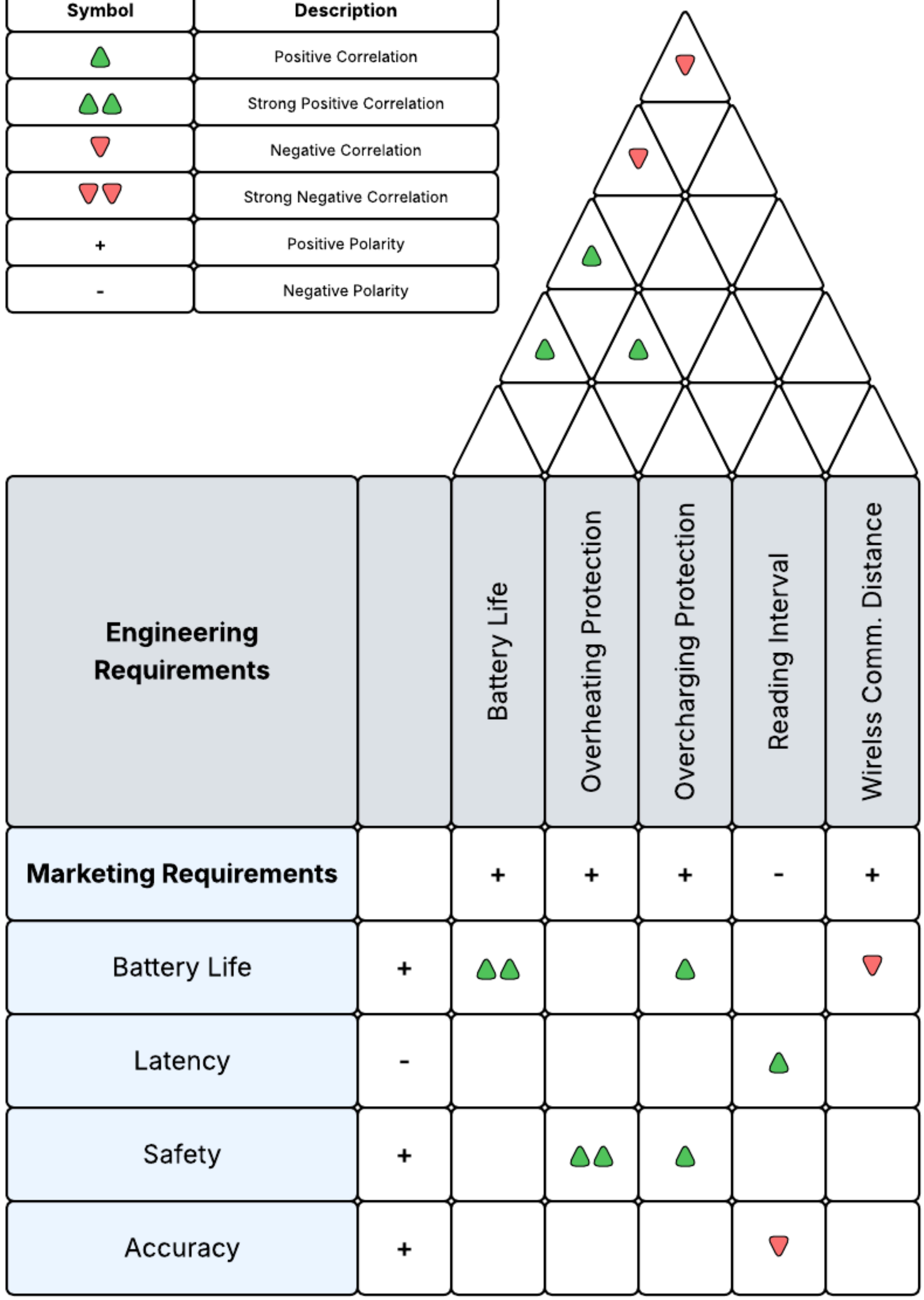
Tyler Takimoto will be responsible for the software development. Kai Ford will assist with providing necessary algorithms.

6. PROTOTYPE ILLUSTRATION

7. BUDGETING EVALUATION

7.1 House of Quality

Symbol	Description
▲	Positive Correlation
▲▲	Strong Positive Correlation
▼	Negative Correlation
▼▼	Strong Negative Correlation
+	Positive Polarity
-	Negative Polarity



7.2 Estimated Costs Table

Subsystem	Component(s)	Cost
Power	Power Supply	$20
Power	Battery	$20
Power	Battery Circuitry	$25
Power	Regulator Circuitry	$25
Sensor	Sensor	$10
Sensor	Sensor Circuitry	$25
Software/Hardware	MCU	$5
Software/Hardware	Screen	$15
RF	RF Module + Antenna	$80
RF	RF Circuitry	$25
General	Shipping	$50
General	Tools + Supplies	$30
	TOTAL	=$330

7.3 Preliminary Budget Allocation Table

Student	Allocation
Kai Ford	$82.50
Tyler Takimoto	$82.50
Benjamin Will	$82.50
Ethan Denner	$82.50
TOTAL	=$330

8. PROJECT MILESTONES

8.1 Senior Design I

Week	Milestone
1-2	Form a group and brainstorm project ideas
3	Begin research, develop Divide and Conquer document and form a committee
4	Meet with advisor, finalize Divide and Conquer document and research specific components
5	Begin 60-page draft, order specific components and begin preliminary circuit design/simulations
6	Acquire components
7	Begin basic testing of individual components (sensors, batteries, etc.)
8	Begin circuit prototype testing using breadboard and microcontroller development board, submit 60-page draft
9	Acquire feedback on 60-page draft, finish up breadboard experiments and begin PCB design
10-11	Continue PCB design and start on 120-page document
12	Order PCB and continue making progress on 120-page document
13	Continue to work on 120-page document
14-15	First PCB arrives; solder components and test the board
16	Submit 120-page document

8.2 Senior Design II

Week	Milestone
1	Make edits to 120-page document as directed
2	Troubleshoot any issues with PCB design: fix them in software and reorder
3-4	Model and 3D-print the housing for the prototype

5	Prototype PCB arrives; solder components and test the board
6-8	Research solutions to any malfunctions
9	Implement solutions
10	Test prototype with implemented solutions
11-15	Test, optimize processes, etc.
16	Demonstrate prototype

APPENDICES

Appendix A - References

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[2] Amazon, "Owlet Accessory Monitor with Base Station (Sensor Not Included)." Amazon. [Online]. Available: https://www.amazon.com/Owlet-Accessory-Monitor-Station-Included/dp/B08R5CHF5P/. [Accessed: Sep. 2, 2025].

[3] Google, "Gemini 2.5 Flash." Google. [Online]. Available: https://gemini.google.com/. [Accessed: Sep. 4, 2025].

[4] Morgenthaler, A. B., T. H. E. L. I. T. L. E., S. S. J. C. K. S. O. N. M. B., N. G. R. E. A. S. O. N. S. U. G., L. L. Y. D., C. I. N. G. O. L. F. N. S. O. N., L. P. L., and M. D. E. A. R. S. U. G. "The performance of 11 fingertip pulse oximeters during hypoxemia in healthy human participants with varied, quantified skin pigment." *eBioMedicine*, vol. 102, March 2024, Art. no. 105051.

[5] "Onyx® Vantage 9590 Finger Pulse Oximeter: Instructions for Use-English," Nonin Medical, Inc., Plymouth, MN, document no. 113634-001-01, 2019. [Online]. Available: https://www.nonin.com/wp-content/uploads/113634-001-01_ENG.pdf. [Accessed: 5 Sep. 2025].

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[10] "ScanWatch 2," Withings. [Online]. Available: https://www.withings.com/us/en/scanwatch-2. [Accessed: 5 Sep. 2025].

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Appendix B - Acknowledgements

Google's free AI tool, Gemini [3], was utilized to quickly learn and gather widely available conceptual information (used instead of the traditional "Google search"). OpenAI's ChatGPT was utilized for the same purpose [11]. The information gathered using these tools was paraphrased, and any sections of the document that significantly utilized information curated by an LLM was cited with an in-text citation. If text generated by Gemini was explicitly used, it was placed in direct quotes. If a specific prompt led to certain information, it was indicated with a reference to the appropriate appendix; otherwise, assume information was obtained using a wide variety of different prompts where documenting them does not provide practical benefit.

Gemini [3] and ChatGPT [11] were also utilized to help format the reference list to IEEE citation standards.

Project logo illustrated by Rylee M. Galilei.