Design of a Wrist-Mounted Biometric and Ambient Sensor System

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***Abstract*—In environments where access to medical care is limited, real-time health monitoring is essential for ensuring personal safety and mission success. In order to address this issue I built a compact wrist-mounted module with specific sensors that allow remote monitoring of someone's general vitals. This is done using a variety of sensors: a pulse oximeter (MAX30101 & MAX32664), infrared temperature sensor (MLX 90614), galvanic skin response (GSR) sensor, and environmental sensor (BME680) inside a custom 3D printed casing. The key features of the device are remote monitoring for real time data as well as historical trends. The 3D printed casing and choice of sensors also allow for an economic price point. The device built is currently a proof of concept due to it still having certain flaws. While conducting this project it was important to be able to find solutions around many different issues that appeared such as I2C errors and difficulties setting up a real time database. This device is primarily designed for field researchers and people performing research in adverse environments.**

***Index Terms*—Wearable Sensors, Health Monitoring, Embedded Systems, Physiological Telemetry**

I. Introduction

People working in harsh environments often have very limited options for on site medical attention and monitoring. In addition to these factors others such as pricing and size constrain the type of equipment that workers are able to get access to. As field research becomes more prevalent it is more important than ever that researchers have access to simple modern technology where access to professional medical care is delayed or unavailable. Real-time monitoring and medical trends can be the difference between early intervention and critical health emergencies. Even basic physiological signals like heart rate or skin temperature, when monitored continuously, can reveal early signs of stress, dehydration, or illness before more serious symptoms appear. In addition real time measurements alone are not enough trend data over time provides the necessary context to assess whether a condition is worsening, stabilizing, or improving. Current existing solutions are either consumer products like a fit bit, more expensive specialized options such as NASA's bioharness or more traditional hospital medical systems. While all of these solutions are effective they each have their own limitations for performing well in the field. Fit bits are not modular or open source and they have a fairly limited number of sensors which are designed mostly for convenience and not medical accuracy. The bioharness software is excellent for some of these applications but is much too expensive for widespread use, often costing between $1,500-$4,000. The bioharness also primarily focuses on real time sensor readings and is not designed for analyzing long term trends. Lastly, traditional medical systems, while effective and a good choice for a base of operations, researchers in the field need a more portable solution and will most likely not be able to bring bulky equipment with them. To address these limitations, this paper presents a wrist-mounted wearable platform that combines biometric and environmental sensors into a compact, low-cost, and open-source system. Paired with software that uploads data to a central database this platform solves many of the limitations of alternative solutions.

II. Problem Statement

One of the most important mission directives for hazardous and remote missions is that of team safety and health. Health issues can escalate very quickly in the field especially without trained medical staff on site such as in polar expeditions and disaster zones. The project addresses the need for a compact, cost effective, wearable design that monitors physiological and environmental data in real time. By equipping workers with a multi sensor device that logs data remotely, the system enhances mission safety where conventional medical care is not practical.

III. NOVEL CONTRIBUTIONS OF THIS PAPER

Unlike existing commercial systems, this project emphasizes modularity and reproducibility using accessible, open-source tools. One of the core ideas of the project is that it is made with all off the shelf parts so it can be easily replicated by anyone with baseline skills in 3D printing and electronics. All of the 3D models and code files can be easily accessed online along with a parts list. In addition to the ease of replication, another aspect of the device monitors certain environmental conditions which could affect or influence the users health. Other similar platforms tend to focus solely on biometrics but neglect the fact that for people working in hazardous environments their surroundings could play a role in affecting their overall health. This combination of physiological, environmental monitoring, and replicability makes the system a practical and scalable solution for field researchers, educators, and humanitarian applications.

IV. RELATED WORK

Wearable health monitoring devices in recent years have become important tools for personal wellness, telemedicine, and long term disease management. These systems allow for real time tracking of key physiological metrics such as heart rate, temperature, and blood oxygen levels. Their ability to transmit data remotely is vital for situations where in person care is limited so users still have access to medical professional's advice. The widespread use of wearable devices help users do more than just ask advice from doctors. Users can detect symptoms early, track their personal health, care for elderly relatives, and measure athletic performance. The COVID-19 pandemic accelerated interest in no contact home based monitoring. Different systems have been proposed in recent research, focusing on new sensing methods and low-power data processing. This section reviews several representative studies that inform the design and scope of the present work.

One such study by Ahmed et al. explores a contactless monitoring system designed for continuous tracking of vital signs and human activity [1]. While their system eliminates the need for direct skin contact using radar based sensing, it highlights several challenges that contrast with the approach taken in this project. Their device primarily focuses on real-time monitoring of vital signs and activity using FMCW radar and AI algorithms for contactless data collection. The key components of their platform are the mmWave radar and deep learning to monitor respiration and heart rate. The advantages of a contactless system are that it eliminates the discomfort that some wearable devices can have for people with sensitive skin. The limitations of this system are that it is not portable and is fairly expensive. Our project offers a wearable, low cost system that can operate in changing environments. It also places a heavier emphasis on local sensing and direct biosignal access. Both devices have a focus in local data processing and do not make data uploading their main focus.

Another study by T. Carmo et al. presents a wearable respiration monitoring device developed for patients undergoing pulmonary rehabilitation [2]. Their system uses a fabric-embedded magnetic field sensor to track chest expansion and contraction in real time. This offers a non intrusive method for monitoring breathing patterns. The device they created focused on pulmonary rehab patients, especially post COVID-19. Data is transmitted wirelessly over bluetooth. While their device is accurate and comfortable for patients to use in motion it only focuses on collecting respiratory data and relies on the chest worn positioning which can be less versatile than wrist based devices. While our device differs from theirs and aims to be more multipurpose rather than specialized, both systems have similar goals of real time health data collection in wearable form.

Park et al. developed a custom biomedical AI processor optimized for low power operation in wearable health monitors [3]. Their system focused on real-time classification of physiological signals such as heart rate, oxygen saturation, and ECG using adaptive machine learning directly on hardware.

The custom processor they created focused on power efficiency and data analysis. While the resulting hardware is impressive there is not a focus on user feedback or cost efficiency. The system is not at a viable price point for being accessible for prototyping or low budget projects. Park et al.'s chip demonstrates a high end scalable version of what our device demonstrates in a prototype friendly form with affordable off the shelf components.

Martins et al. explored various implementation techniques for non intrusive CO sensing, aiming to support continuous respiratory monitoring in mobile health [4]. Their work evaluates several types of CO sensors small enough to fit into a wearable device. All of the sensors are transcutaneous and use various forms of sensing such as thermal conductivity, optical, and electrochemical sensing. The strengths of their research are that they offer an in depth review of practical design constraints in gas sensing wearables and how environmental sensors can be integrated into low profile wearable formats. The research only focuses on CO sensing and is more method comparative than implementation focused. Our work also incorporates environmental sensing via the BME680 sensor which tracks gas, humidity, and temperature. In addition both projects share similar goals around designing compact wearable devices which deal with sensor data and long term user comfort. While their sensors target CO our system shows how multi sensor integration can be achieved using more readily available components.

V. THEORETICAL IMPLEMENTATION OF THE SYSTEM

Prior to building the physical system of the wearable system a theoretical model was outlined to define functional requirements, optimize how sensors were integrated, and guide efficient development. This section presents initial design decisions that shaped both the hardware and software architecture.

The planned hardware design prioritized compactness, modularity, and compatibility with off-the-shelf components to ensure replicability by users and modified by others with basic prototyping skills. An ESP32-based microcontroller (Heltec LoRa V3.2) was selected due to its I²C compatibility, built-in OLED screen, and Wi-Fi support. The criteria for selecting the sensors is that they need to be compact, interact via I²C, and collect medically relevant signals. The form factor was focused on being wrist based for usability and comfort, with a pulse oximeter mounted in a finger clip. The casing for the device was planned to be 3D printed for rapid prototyping and modular sensor placement.

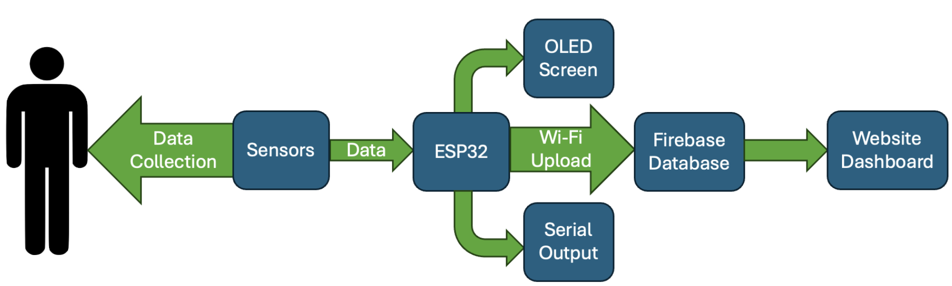


Figure 1. System architecture diagram.

On the software side, the system was designed to operate in real time, balancing sensor sampling, user interface feedback, and wireless data transmission while minimizing power consumption and ensuring reliability in field conditions. The general software model was designed to work on a polling based loop with different sampling rates per sensor because otherwise the system would encounter I^2C collisions. The microcontroller was also designed to output to an OLED screen for offline monitoring. The system in addition to the OLED output uploads via WiFi to a firebase database with a custom JSON format.

VI. Implementation and Validation of the Proposed System

The wearable system was developed through an iterative design process, integrating biometric and environmental sensors into a wrist-mounted platform controlled by an ESP32 microcontroller, with real-time data logging and remote database communication. The biometric and environmental sensors used in the platform are MAX30101 MAX32664 combination, galvanic skin response (GSR) sensor, MLX90614, and BME680. The MAX30101 MAX32664 sensors [5], [6] are on the same board and are placed inside a custom finger clip so that they will be able to sense pulse and blood oxygen levels effectively. The GSR sensor is screwed into the main casing and has sensors that fit around the user's fingers [7]. A small hole in the top of the casing is provided so that the wires can attach to the user's fingers while the platform is strapped to the user's forearm. The MLX90614 sensor is an infrared thermometer for measuring the user's temperature [8]. The sensor is mounted towards the front of the casing and pokes through a small hole in the bottom so that the infrared beams can reach the user's skin. Lastly the BME680 sensor focuses on environmental factors such as barometric pressure and ambient temperature [9]. The BME 680 is able to get a fresh supply of air through small vent holes in the front of the device. All the sensors are connected through shared power, ground, SCL, and SDA buses on a custom soldered PCB connection board. All wires connecting shared connections were created so that they would be small enough to keep the device at a manageable size. All the sensors are connected to a LORA Heltec V3.2 ESP32 arduino [10] which connects to each sensor through shared connections on the PCB. The ESP32 is powered by a LiPo battery back which rests underneath it and connects to the bottom of it through a power and ground wire. The ESP32 additionally has a builtin SSD1306 OLED screen which is utilized to improve the user experience by giving a simple readout of the most important metrics. The screen is configured over a second I^2C bus so as not to create conflicts with the external sensors. The screen displays real-time sensor readings including heart rate, SpO, skin temperature, and ambient conditions. The display allows the user to verify that the system is functioning as intended in the field even without an internet connection.

Figure 3 shows the system-level flow of data through the platform, from user experience to visualization, showing how software and hardware components interact in real time. The software of the device ties all of the sensors together and through local home wifi is able to upload data to an external database which then is accessible through a custom webpage. Data is collected from each sensor at a frequency of approximately 1–5 Hz, depending on the sensor's internal update rate and Wi-Fi upload speed. This allows for real-time monitoring while keeping bandwidth and power usage within practical limits. Each sensor samples data every 100 loop cycles, except the pulse oximeter which only adds new sensor data when it detects the user's finger inside the finger clip. After collecting sensor data, the device sends the data over serial output, if connected, and to display on the OLED screen. The data is then sent by wifi to the firebase database system in a custom JSON format. The JSON is structured with this data: heartRate, confidence, oxygen, status, gsr, temp, humidity, pressure, gas, skinTemp. The confidence and status are information from the pulse oximeter which are used to screen whether or not the data should be sent. However this data will only be sent if the confidence level of the pulse

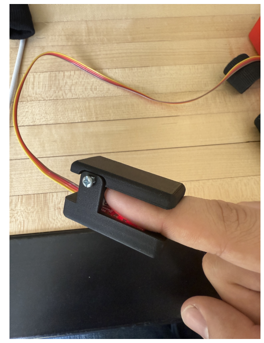


Fig. 1: Custom 3D-printed finger clip housing the MAX30101 pulse oximeter.

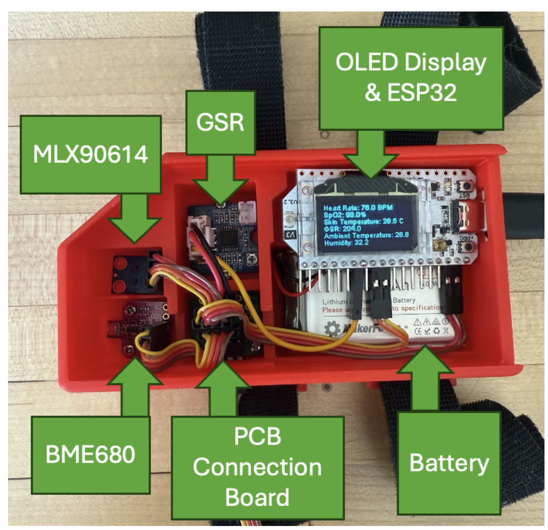
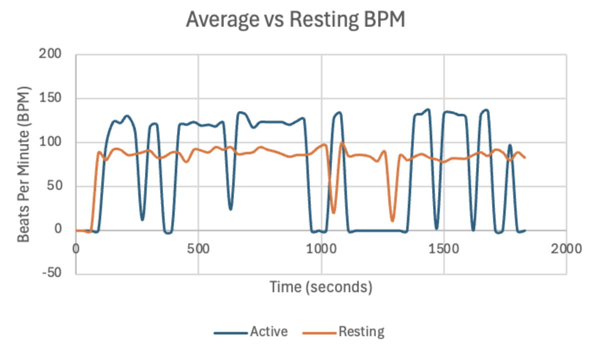
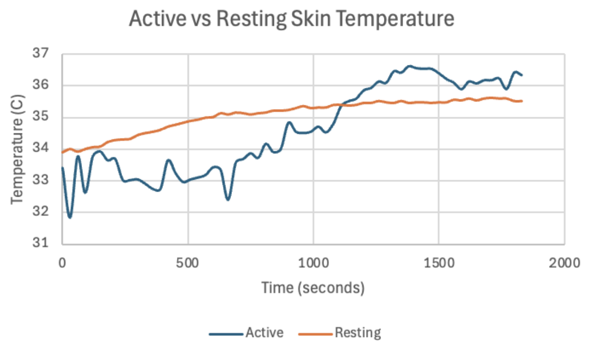


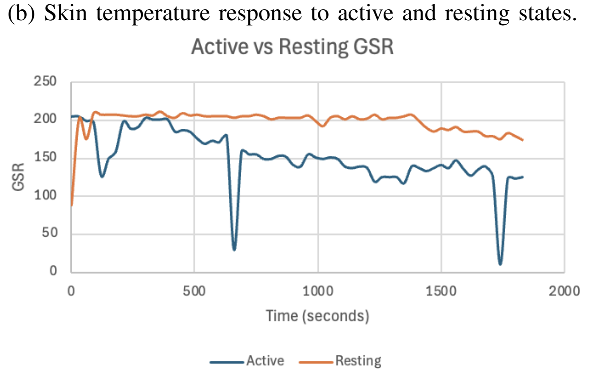
Fig. 2: Top-down view of the wearable system showing sensor placements and wiring.



(a) Heart Rate (BPM) during active and resting periods.



(b) Skin temperature response to active and resting states.



(c) Galvanic Skin Response (GSR) signal during different states.

Fig. 3: Sensor readings during 30-minute active and resting trials.

oximeter is either 0%, meaning a finger is not detected, or above 85% which ensures that the pulse and blood oxygen levels will be reliable when used in the database. A dashboard website was also created to visualise the real time and historical data stored in the database. The initial prototype version of the website was created using Vercel to streamline the front end setup. Overall, the software enables seamless integration between data collection, local user interface, and cloud-based monitoring. While the system performs reliably in short-term use, long-term logging and data verification will be further explored in future iterations.

VII. Results and Discussion

To evaluate the performance of the wearable platform, a 30-minute session of light physical activity (walk at a quick pace on a treadmill) was conducted, followed by a 30-minute resting period while seated. Data was collected continuously from the heart rate (BPM), skin temperature, and galvanic skin response (GSR) sensors and is presented in Figure 4 above. The active data for the BPM shows frequent spikes between 110-130 which is consistent with mild exertion. The resting heart rate is stable around 75-85 BPM. The spikes and drops in the data are due to movement because the finger clip has trouble tracking BPM when the user's hand is moving excessively. The data showing more drops in the data in the active portion relative to the resting portion is consistent with this statement. The pulse oximeter is shown to me most consistent when the user is able to stay relatively still during the data collection. For the skin temperature there is a gradual increase in temperature during the active phase likely due to increased circulation. Similar to the BPM readings the skin temperature readings were much more consistent and in addition had a higher baseline reading during the resting phase of the data collection than the active phase. Small fluctuations in the readings are expected and verify the device is collecting data at the intervals expected. The last chart shows the GSR reading in both the active and resting sessions similar to the previous charts. Resting GSR values remain high and steady (around 200) which reflects lower skin gland activity. In the active phase the GSR readings are lower, between 110-180, likely reflecting increased perspiration or stress due to being more active. Overall these results demonstrate the device's ability to detect and differentiate between active and resting states in real time across multiple biometric parameters.

VIII. Conclusions and Future Research

This project successfully developed a compact, low cost wearable device capable of collecting, displaying, and uploading real time biometric and environmental data. Through the integration of multiple sensors the platform has demonstrated the ability to distinguish between active and resting states based on the biometric data collected. The addition of a built-in OLED screen and Firebase data pipeline sets this platform apart from prior conceptual and prototype research. Compared to systems such as the HOT watch and Sharma et al.'s proposed design, the device discussed in this paper offers improved usability, form factor, and autonomy. After careful analysis the results showed consistent repeatable patterns in all tracked signals, not just the charts provided for the paper. This confirms the sensor suite and data handling are effective for real world applications. For future work several directions are promising. With a custom manufactured PCB the sensor suite could fit into a much smaller casing because they would not need a breakout board. The form factor could also be improved, while the current casing is effective and comfortable the straps are difficult to stay still as is plugging in the GSR sensor's connecting wire. Other areas for improvement include different types of activities for sampling as well as expanding the system's connectivity for example adding bluetooth as an option for data uploading. In summary this project demonstrates the potential of integrated, real time wearable monitoring systems built from accessible components. It lays the groundwork for further exploration into affordable, personalized health tracking technologies.

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