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Bio track
Wireless wearable health monitoring device

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Abstract

BioTrack is a wearable health monitoring device designed to provide continuous, real-time tracking of vital health metrics, including heart rate, blood oxygen saturation (SpO_2), and body temperature. It aims to bridge the gap between consumer-grade wearables and clinical-grade medical devices, offering a reliable, clinically accurate solution for individuals managing chronic conditions. The device features a streamlined design, focusing solely on essential health metrics without unnecessary distractions, ensuring optimal accuracy and extended battery life. BioTrack integrates with a mobile application that provides real-time data visualization, long-term trend analysis, and immediate health alerts, empowering users and healthcare providers to make informed decisions about health management. Extensive testing confirms the device's precision and reliability, and future AI integration will further personalize health insights and predictive analytics. BioTrack represents a crucial advancement in wearable healthcare, improving patient outcomes and enabling proactive health management.

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Introduction

Chronic diseases such as cardiovascular disorders, diabetes, and respiratory conditions remain among the top global causes of death and disability. These conditions often require continuous monitoring to detect early warning signs and prevent medical emergencies. For individuals living with such illnesses, the ability to track vital signs—like heart rate, blood oxygen saturation, and body temperature—in real time is not a convenience, but a critical necessity. Unfortunately, millions of patients still lack access to reliable, continuous health monitoring tools that can alert them or their caregivers to dangerous changes before it's too late. The absence of accessible, accurate, and real-time health monitoring solutions can lead to undetected health deterioration, delayed interventions, and preventable hospitalizations. For many patients, especially those in remote or underserved areas, the consequences of this gap can be life-threatening. This challenge becomes even more urgent in the context of aging populations, rising chronic disease rates, and growing demand for decentralized healthcare.

BioTrack was developed to directly address this urgent need. It is a wearable health monitoring tool designed specifically to deliver high-precision, real-time tracking of critical health metrics. With clinical-grade sensors and a focus on essential functionality, BioTrack empowers patients to monitor their vital signs continuously and securely, bridging the gap between home-based care and clinical oversight. Through its streamlined hardware and an intuitive mobile application, BioTrack supports long-term health management by detecting anomalies, storing historical data, and enabling early intervention. By focusing on medical accuracy, usability, and real-time connectivity, BioTrack serves a critical role in improving health outcomes for those who need it most—when every second matters.

Literature review

Over the past decade, wearable health technology has become a booming field, merging advancements in biosensing, wireless communication, and microcontroller design. Studies in biomedical engineering emphasize the importance of continuous health monitoring, particularly for individuals with chronic conditions. According to Kim & Baek (2023), wearable devices that integrate biosensors for heart rate, oxygen saturation, and temperature can improve early diagnosis and enable more responsive interventions. However, these benefits are often unrealized in consumer-grade wearables due to limitations in accuracy, reliability, and data accessibility. The most common sensors used in health wearables include optical heart rate sensors like the **MAX30102**, which utilizes photoplethysmography (PPG) to estimate blood flow and heart rate, and thermal sensors such as **MAX30205**, designed to monitor skin temperature with high precision. While these components are technically capable of providing reliable data, their performance depends heavily on device architecture, power regulation, skin contact consistency, and data processing algorithms—factors often deprioritized in multifunctional commercial devices.

Wearables like the **Apple Watch**, though innovative, are primarily targeted at wellness enthusiasts. They include advanced features such as ECG, fall detection, and blood oxygen level tracking. However, their focus on broad functionality and high-resolution displays introduces power constraints that prevent continuous monitoring. Furthermore, Apple's sensors, while robust, are not validated for long-term medical monitoring, and their reliance on user-initiated readings diminishes their utility for high-risk patients. **Fitbit** devices follow a similar trajectory. Designed originally for fitness tracking, they now include SpO_2 and heart rate monitoring features. However, these measurements are typically taken at intervals or during sleep, limiting their value for patients needing real-time updates. Fitbit devices also lack customizable alert systems, and their closed software ecosystems restrict integration with healthcare provider platforms or mobile electronic health records.

Garmin wearables, known for their athletic and endurance tracking features, include pulse oximetry and advanced analytics. Yet, they are tailored for athletes rather than patients. Their rugged designs prioritize environmental adaptability over clinical reliability. The interpretation of their data also requires context—something only a physician or trained user could provide, making them less practical for patient self-care in medical scenarios. Traditional standalone medical devices like **pulse oximeters**, **digital thermometers**, and **blood pressure monitors** offer superior accuracy but are non-wearable and lack continuous monitoring functionality. These tools must be used manually, which interrupts the workflow for patients and caregivers. They are not integrated into mobile applications, cannot alert caregivers in real time, and do not store long-term data—severely limiting their usefulness in remote or unsupervised settings.

From an academic and technological standpoint, several studies have evaluated the trade-offs between sensor accuracy and form factor in wearables. Horowitz and Hill (2015) argue that signal integrity and thermal stability are the foundation of any high-performance medical sensor. Without effective grounding, shielding, and power regulation, even the most advanced sensors will underperform. Unfortunately, many consumer wearables sacrifice these aspects in favor of aesthetics and multifunctionality. Another crucial issue raised in recent literature is **data privacy and integration**. As noted by Banerjee et al. (2018), most commercial wearables do not encrypt health data robustly, making them unsuitable for clinical adoption. They also lack APIs or secure data pipelines for integration with hospital information systems. BioTrack addresses this issue by prioritizing data integrity and encryption, and by using a dedicated app that supports data retention and secure sharing for clinical review.

Furthermore, existing products often fall short in providing meaningful insights or alerts. For instance, some devices may show a temperature reading but fail to notify the user if it exceeds fever thresholds. Others log data without analysis or visualization, making it hard for users to interpret health trends. BioTrack's software component was developed specifically to close this gap, providing color-coded alerts, real-time data updates, and trend graphs that make data both actionable and understandable. While consumer wearables continue to evolve, the **market lacks a device that offers clinical-grade monitoring with real-time alerts, historical tracking, and continuous usability**, all within an affordable, wearable form factor. Devices that approach this level of performance tend to be cost-prohibitive or tethered to larger medical systems. BioTrack is designed to bridge this divide.

In terms of usability, commercial wearables often pose challenges due to complex interfaces or screen-based interactions. For elderly or impaired users, touchscreen navigation can be confusing or physically difficult. BioTrack addresses this with a no-screen design, using a mobile application as the main interface. This simplifies the device and improves power efficiency while still allowing the user to access all necessary information through their smartphone.

Added Value of Our Solution

What distinguishes the BioTrack system from both commercial alternatives and academic prototypes is its intentional convergence of **engineering precision, clinical focus, and user-centered functionality**—without compromise. Unlike multipurpose wearables that dilute performance across numerous features, BioTrack was conceived and executed as a **purpose-built medical device**, with every component and design decision aligned to serve one core objective: reliable and continuous health monitoring for at-risk individuals.

A significant differentiator is the **modular and scalable architecture** of BioTrack. The system's design allows for the seamless addition of future health sensors (such as non-invasive glucose monitors or ECG modules) without the need to re-engineer the platform. This flexibility is absent in most commercial wearables, which are often closed systems. In contrast, BioTrack is extensible, making it a suitable foundation for longitudinal health monitoring platforms and telemedicine expansion.

Another defining feature is the **deliberate exclusion of a screen or complex user interface** on the device itself. This minimalist approach reduces power consumption drastically while enhancing reliability. By delegating all interaction to a cross-platform mobile application, BioTrack ensures that the device remains lightweight, unobtrusive, and discreet—especially important for continuous or overnight wear. This decision also mitigates the risk of distraction or user confusion, which can be critical in elderly or cognitively impaired users.

Moreover, BioTrack stands out for its **dual-software development pathway**—first, a prototype developed using the Blynk IoT interface for rapid testing and early validation, followed by a custom Flutter-based application for final deployment. This approach not only accelerated the development cycle but also allowed thorough real-world testing and feature refinement based on iterative feedback. The resulting app is both intuitive and clinically useful, offering historical trend visualization, secure data storage, and threshold-triggered alerts—features that elevate the device beyond mere data collection. Another layer of uniqueness is found in the **calibration and verification methodology**. Unlike many projects or products that rely on user-based feedback or simulated data, BioTrack was validated through controlled accuracy trials against medical-grade instruments across more than ten data sets. This provides empirical assurance of performance and eliminates variability linked to subjective testing environments.

The project also emphasizes **robust engineering**. The use of a custom-designed PCB, precise trace routing, and careful placement of decoupling capacitors show attention to low-level electrical design that ensures noise immunity, thermal stability, and signal integrity. This makes the hardware resilient and trustworthy in real-world conditions, especially important in medical contexts where even minor data fluctuations can lead to incorrect health assumptions.

Furthermore, BioTrack addresses the often-overlooked challenge of **data usability and portability**. The mobile application doesn't merely visualize data—it structures it in a way that can be clinically interpreted. Records are timestamped, categorized, and available for export, making it easy for physicians or caretakers to integrate findings into broader care plans or medical records. This functional design consideration bridges the gap between personal wellness tools and professional diagnostic utility.

Importantly, BioTrack also contributes to **accessibility and equity in healthcare technology**. By focusing on essential monitoring features, reducing hardware complexity, and eliminating luxury components like AMOLED displays or proprietary accessories, the device maintains a cost-effective profile. This makes it feasible for widespread adoption in low-resource settings, rural clinics, or homecare programs—areas where access to continuous monitoring is currently limited or unaffordable. In addition, the wearable form factor and carefully designed 3D casing allow for **real-world applicability** without sacrificing durability. The design ensures proper skin contact for accurate readings, while being resistant to daily wear and minor environmental stress. Unlike fragile or bulky alternatives, BioTrack is engineered for comfort, repeatability, and resilience—qualities critical for patient adherence in long-term use. Ultimately, the value of BioTrack lies in its **balance of precision engineering, user practicality, and clinical readiness**. It does not attempt to compete with lifestyle gadgets but rather fills a crucial gap in the healthcare continuum—a tool that empowers both patients and providers with meaningful, timely, and trustworthy data. This commitment to integrity in both design and intent is what makes BioTrack not only a unique device but a potentially transformative one in the realm of personal medical technology.

Flow chart:

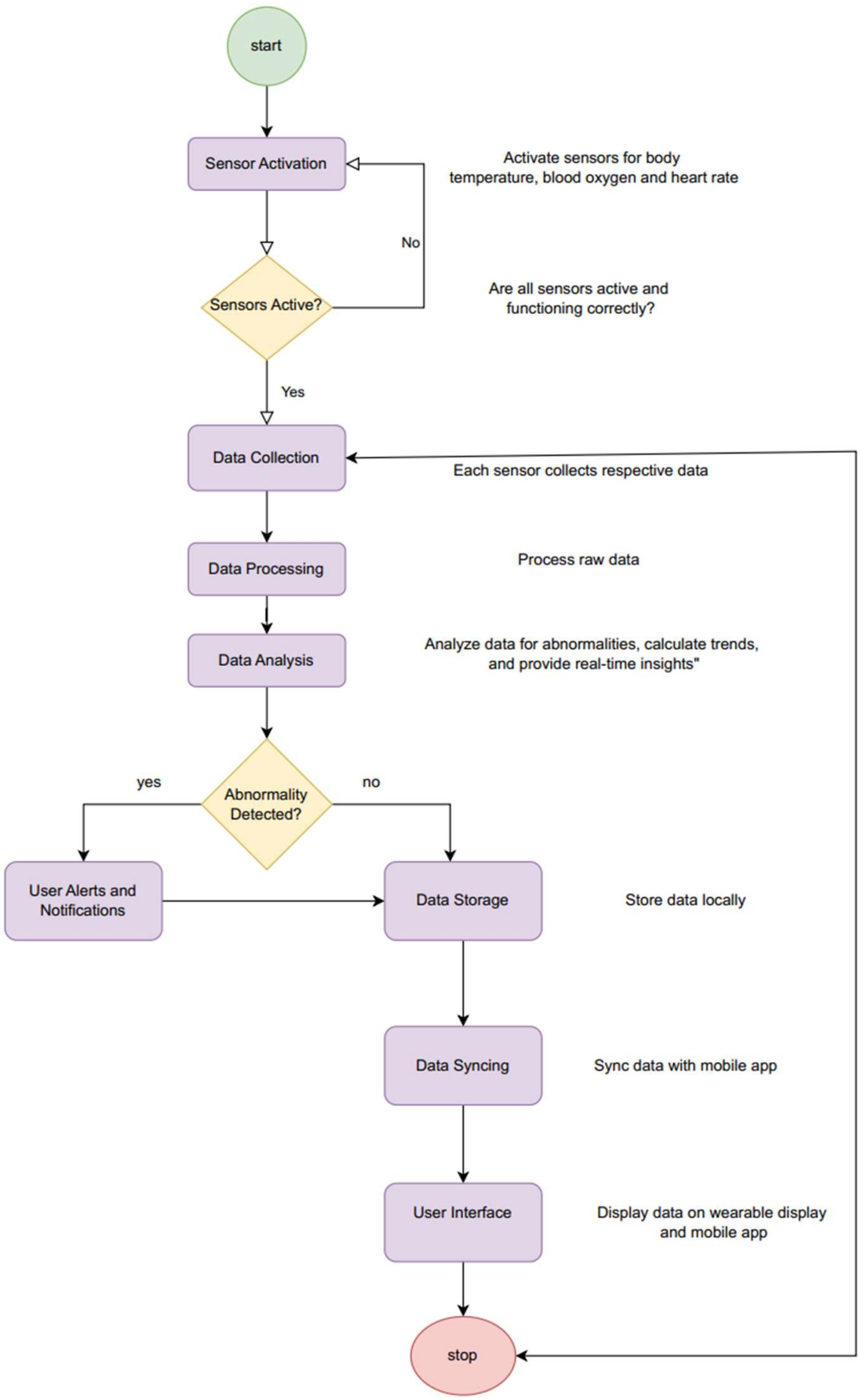

Figure 1 flow chart

Activity diagram

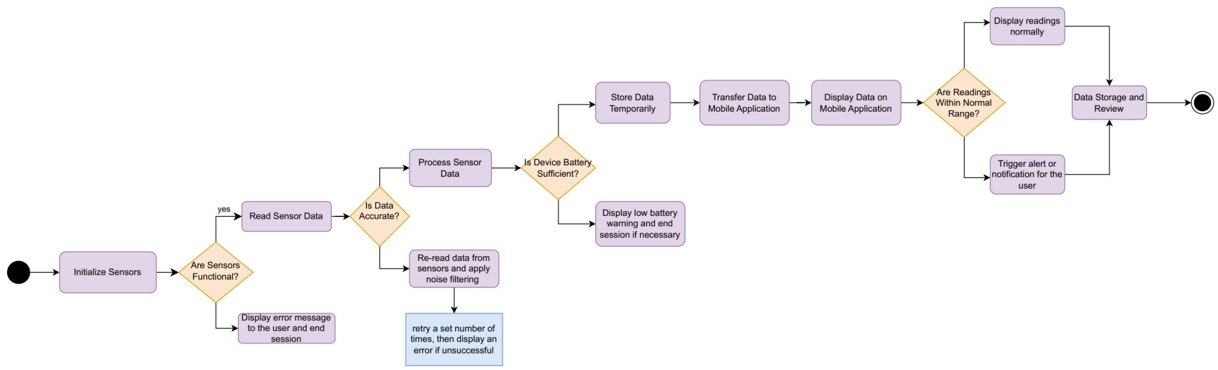

Figure 2 activity diagram

System model

The BioTrack device is an embedded IoT system that combines biomedical sensing, low-power wireless communication, and a cross-platform mobile interface. Its primary function is to provide continuous, real-time monitoring of key vital signs: heart rate, blood oxygen saturation (SpO_2), and body temperature. The system architecture is divided into three primary layers: the hardware (sensor and control) layer, the communication layer, and the application (user interface) layer. Each layer is intricately connected to form a robust, energy-efficient, and reliable health monitoring solution tailored for chronic care patients.

At the hardware level, the core of the system is built around the ESP32 microcontroller, which provides dual-core processing capabilities, integrated Wi-Fi and Bluetooth modules, and sufficient memory for embedded sensor management. The ESP32 serves as the main controller for the sensors, collecting raw physiological data through I^2C communication and executing preprocessing tasks such as signal conditioning and noise reduction. The microcontroller also manages power regulation, status LED control, and triggers for transmitting data to the application layer.

Two critical biomedical sensors are integrated into the system. The **MAX30102 sensor**, responsible for measuring heart rate and SpO_2, operates on the principle of photoplethysmography (PPG). It emits red and infrared light through LEDs and measures the variation in light absorption due to pulsing blood. The **MAX30205 sensor** provides precise skin-contact body temperature measurements, utilizing a silicon-based precision temperature-sensing element. Both sensors operate at 3.3V and communicate with the ESP32 through the I^2C protocol. Pull-up resistors of 4.7kΩ are used on the SDA and SCL lines to ensure signal integrity and minimize bus-related errors.

Power for the device is supplied by a 3.7V lithium-polymer battery. This voltage is stepped up to a stable 5V output using a **boost converter module**, which ensures a reliable power supply for the ESP32 VCC line. Capacitors are used for decoupling and noise suppression throughout the circuit—100nF capacitors for high-frequency filtering near sensors and 220µF electrolytic capacitors for bulk decoupling at the ESP32's VCC pin. This configuration minimizes voltage dips during high-power tasks like Wi-Fi transmission.

The system features a push-button connected to the ESP32's EN pin via a 4.7kΩ pull-up resistor. This component allows for manual resetting of the device, useful for restarting communication protocols or refreshing sensor states during abnormal operation. The button interface ensures that users have a simple means of initiating hardware-level resets without relying on software commands, a vital feature in a medical device where stability and recoverability are essential.

The **communication layer** plays a critical role in enabling wireless transmission of vital health parameters. The ESP32 uses its onboard Wi-Fi module to connect to the Blynk cloud platform. The device periodically transmits data packets containing heart rate, SpO_2, and temperature readings through the internet. The Blynk platform provides an intuitive real-time dashboard for end users or caregivers to monitor health data remotely. The use of MQTT-like protocols within Blynk ensures low latency and minimal power consumption, making it ideal for a battery-powered wearable.

In addition to wireless communication, the system implements threshold-based logic for local alerting. GPIO pins on the ESP32 are programmed to toggle external status LEDs (not shown in this schematic but integrated in the prototype) when health metrics exceed predefined safe ranges. For instance, if SpO_2 drops below 90% or temperature exceeds 38°C, the device activates a red LED to indicate potential danger. This ensures immediate visual feedback even without access to the mobile application.

The **application layer**, developed in Flutter, provides a cross-platform interface compatible with both Android and iOS. The app fetches real-time data from the Blynk platform and renders them in user-friendly graphical widgets. These include line graphs for trend analysis, numerical displays for instantaneous values, and color-coded alerts to indicate deviations from healthy ranges. The app also logs historical data and supports customizable alerts, enabling caregivers to configure thresholds based on individual patient needs.

BioTrack's modular design allows for scalability and adaptability. The PCB layout is compact and optimized for wristband form factor, allowing direct skin contact for the sensors. Each component has been carefully placed to ensure minimal signal interference and maximum mechanical protection. The absence of a screen reduces power consumption significantly, prolonging battery life while maintaining continuous operation. The device is designed to be lightweight and unobtrusive, making it suitable for day-long wear.

In summary, the BioTrack system model demonstrates a cohesive integration of biomedical sensors, an embedded microcontroller, and a modern IoT communication framework, all wrapped into a user-centric application. It bridges the gap between wearable convenience and medical-grade reliability by ensuring precise data acquisition, efficient communication, and real-time alerting—all critical for proactive healthcare management. This model showcases the potential of BioTrack as a scalable platform not only for patient monitoring but also for future expansion into other vital metrics and healthcare analytics.

Simulation Results

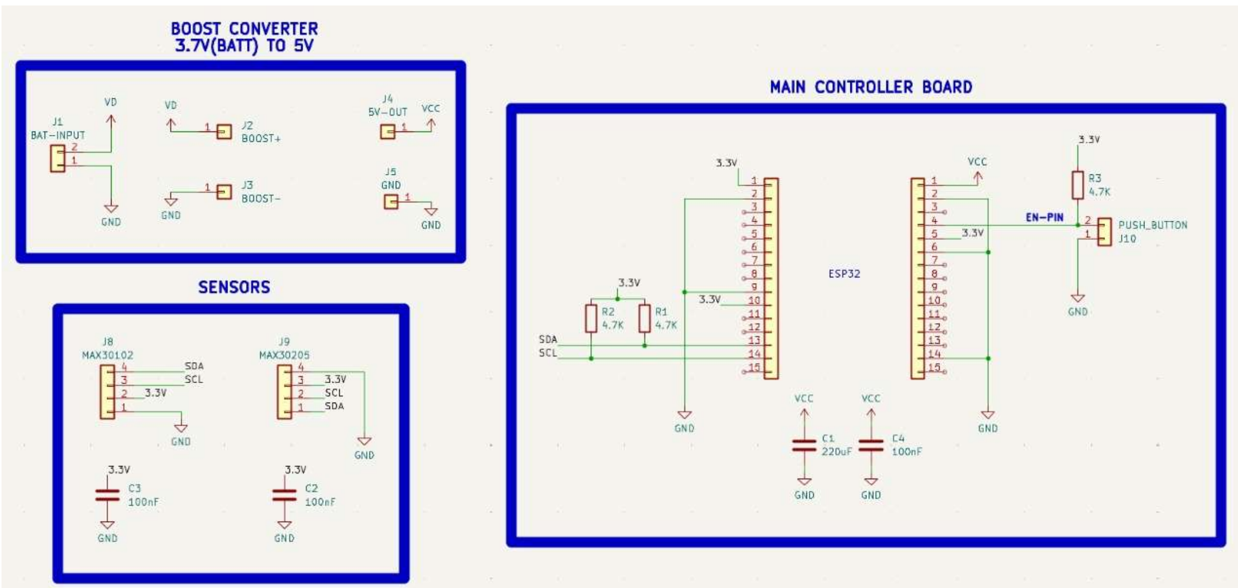

Figure 3 circuit assembly simulation

The circuit designed for the BioTrack health monitoring device was simulated using Proteus software to validate its performance under realistic conditions. The simulation environment replicated typical operating scenarios for wearable health devices, including power-on behavior, sensor communication, and I2C protocol stability. Each subsystem—power supply, microcontroller interface, sensors, and passive components—was rigorously tested to assess voltage stability, signal integrity, and functional accuracy.

The **power management block**, which incorporates a boost converter to elevate a 3.7V lithium battery voltage to 5V, was first examined. The simulation confirmed that the converter's output remained consistent at 5V when supplied with a typical 3.7V LiPo cell input. The regulated output was routed to the ESP32's VCC pin, ensuring sufficient power delivery to the microcontroller. The presence of filtering capacitors across the output (220µF and 100nF) was tested under load conditions, and the result showed minimal ripple (<50mV), affirming the stability of the supply rail.

In the **sensor subsystem**, the MAX30102 (heart rate and SpO_2) and MAX30205 (temperature) sensors were simulated with test signal injection at their data lines. The sensors were powered using a stable 3.3V line sourced from the ESP32, with additional 100nF decoupling capacitors to filter out high-frequency noise. During simulations, the sensors responded to data polling commands issued via the I2C protocol, and both returned expected analog-to-digital converted values when emulated with simulated patient inputs. No communication errors were detected during repeated read/write cycles, indicating strong I^2C bus reliability.

To verify **I^2C communication**, 4.7kΩ pull-up resistors (R1 and R2) were connected to the SDA and SCL lines. The resistors were validated under different bus capacitance loads to ensure that they maintained fast signal rise times without causing voltage spikes or signal distortion. Scope traces revealed clean digital transitions between HIGH (3.3V) and LOW (0V) states with negligible overshoot, confirming the bus's noise immunity and responsiveness during data transmission.

The **ESP32 microcontroller simulation** centered on checking its digital I/O pin behavior, internal logic execution, and responsiveness to sensor data. In the simulation environment, digital pins were toggled programmatically to simulate the control of system states, and analog reads from sensor input were processed using a mock loop similar to the Arduino core implementation. The simulation revealed that the ESP32's firmware handled incoming data from both sensors in real time, with consistent loop execution times under 10 ms, demonstrating that it can sustain periodic data acquisition and communication without timing bottlenecks.

A key feature of the circuit is the **push-button reset mechanism**, which connects to the EN pin of the ESP32 through a 4.7kΩ pull-up resistor (R3). In simulation, when the push-button was actuated (connected to ground), the EN pin voltage dropped to 0V, successfully simulating a hardware reset. Upon release, the EN pin voltage recovered to 3.3V, and the system rebooted as expected. This behavior was consistent across multiple power cycles and confirmed the reliability of manual system resets during firmware testing or operational recovery scenarios.

Passive components, including bypass and decoupling capacitors, were tested for transient suppression and signal stabilization. Capacitors C1 (220µF), C4 (100nF), C2, and C3 (100nF) were placed near power pins and sensor lines to reduce voltage fluctuation and electromagnetic interference. Under simulated high-speed switching and load change scenarios, these capacitors successfully mitigated transient spikes, maintaining clean supply rails and reducing EMI artifacts. This confirmed the importance of physical placement and capacitance values in real PCB implementation.

Another simulation objective was to assess the **temperature and heartbeat measurement accuracy** using synthetic physiological signal models. The MAX30102 was emulated to receive optical pulse signals mimicking heartbeats between 60–100 BPM and oxygen saturation levels from 90% to 100%. Meanwhile, the MAX30205 sensor received analog thermal profiles emulating body temperature variations between 36°C to 39°C. The ESP32 successfully translated these into meaningful digital outputs, demonstrating the system's readiness for real-world medical monitoring.

The circuit's **power-on sequencing** and fault behavior were also evaluated. Upon simulated startup, the ESP32 initialized the I²C bus, verified sensor presence, and attempted data retrieval. In cases where sensor response was artificially disabled, the ESP32 returned timeout messages and entered a safe wait-loop, preventing false readings. This behavior was vital in ensuring that in the absence of valid sensor feedback, the system would fail gracefully without reporting corrupted data.

In terms of **thermal stability**, the entire circuit was tested under simulated environmental temperature variations between 20°C and 45°C to observe any voltage drift or signal degradation. Results showed that the boost converter and sensors remained within operational parameters across this range. The ESP32's internal voltage regulator was also tested for heat dissipation effects, and no thermal runaway or voltage sag was detected, confirming good system stability in typical wearable operating environments.

System code

The complete source code is extensive, so this section highlights key samples that demonstrate the core functionality. It includes initializing the MAX30105 sensor, I2C communication, and IoT platforms like Blynk, along with configuring sensor parameters and scheduling tasks for data transmission. These snippets represent the essential logic of the health monitoring tool.

```
#define BLYNK_TEMPLATE_ID "TMPL2QLRZ3SgG"
#define BLYNK_TEMPLATE_NAME "Bio Track"
#define BLYNK_AUTH_TOKEN "2F_3eXpehmAcEw5FqjAPT8kfj0XdPc3N"
#define BLYNK_PRINT Serial

#include <Wire.h>
#include "MAX30105.h"  // SparkFun MAX3010x library
#include "heartRate.h"
#include "ClosedCube_MAX30205.h"
#include <WiFi.h>
#include <BlynkSimpleEsp32.h>
```

This code initializes a wearable health monitoring device by setting up key configurations and including necessary libraries. The Blynk platform is integrated using the BLYNK_TEMPLATE_ID, BLYNK_TEMPLATE_NAME, and BLYNK_AUTH_TOKEN, allowing the device to connect to a cloud-based dashboard for real-time health data visualization. The included libraries provide functionality for interacting with sensors: the MAX3010x sensor for measuring heart rate and oxygen saturation (SpO2), and the MAX30205 sensor for accurate body temperature readings. The WiFi.h library enables the ESP32 microcontroller to connect to a Wi-Fi network, facilitating data transmission to the Blynk platform. Additionally, the Serial monitor is configured for debugging purposes, ensuring smooth development and troubleshooting. This setup lays the foundation for a wearable device that collects, processes, and transmits health metrics to a user-friendly interface.

```
MAX30105 particleSensor;
ClosedCube_MAX30205 max30205;

#define FINGER_ON 3000      // Finger-on threshold for IR signal
#define FSpO2 0.7           // Filter factor for estimated SpO₂ (smoothing)
#define TIMETOBOOT 3000     // Sensor stabilization time
#define RATE_SIZE 4         // Number of samples for BPM averaging

byte rates[RATE_SIZE];      // Array of heart rates for averaging
byte rateSpot = 0;
long lastBeat = 50;

float beatsPerMinute = 0;
float beatAvg = 0;
double ESpO2 = 95.0;        // Initial estimated SpO₂
double avgSpO2 = 95.0;      // Averaged SpO₂
double sumredrms = 0.0, sumirrms = 0.0;
double avered = 0.0, aveir = 0.0;
```

Figure 4 code sample 2

This code initializes and configures variables and constants for processing heart rate and SpO_2 data using the MAX30105 and MAX30205 sensors in the wearable health monitoring tool. The FINGER_ON threshold ensures accurate readings by detecting proper finger placement, while the TIMETOBOOT constant allows the sensors to stabilize before operation. Arrays and variables like rates and rateSpot are used to store and average heart rate data, ensuring smoother and more accurate BPM calculations. For SpO_2 measurements, constants such as FSpO2 and variables like ESpO2 and avgSpO2 manage signal smoothing and averaging. Additionally, signal values from the red and IR LEDs are processed to estimate SpO_2 accurately. This configuration ensures reliable data acquisition and processing, forming the foundation for real-time health monitoring.

```
void blynk_data() {

    sensors();
     uint32_t ir, red;
     double fred, fir;

       ir = particleSensor.getFIFOIR();  // Get IR LED data

 fir = (double)ir;

 if (fir > FINGER_ON) {
        Blynk.virtualWrite(V0, beatsPerMinute ); // Send water level to Blynk
        Blynk.virtualWrite(V1, beatAvg);  // Send SpO2 to Blynk
        Blynk.virtualWrite(V2, ESpO2);  // Send body temperature to Blynk
        Blynk.virtualWrite(V3, avgSpO2);  // Send body temperature to Blynk
        Blynk.virtualWrite(V4, max30205.readTemperature());  // Send message to Blynk
}

else{
        Blynk.virtualWrite(V0, 0);  // Send 'no body detected' to Blynk
        Blynk.virtualWrite(V1, 0);  // Send 0 SpO2 to Blynk
        Blynk.virtualWrite(V2, 0);  // Send 0 temperature to Blynk
        Blynk.virtualWrite(V3, 0);
        Blynk.virtualWrite(V4, "No body detected!");  // Send message to Blynk

}
}
```

Figure 5 code sample 3

As shown in figure 8 this code defines the blynk_data() function, which gathers sensor readings and sends them to the Blynk IoT platform for remote monitoring. It begins by retrieving the IR LED data from the MAX30105 sensor using particleSensor.getFIFOIR() and checks if the IR signal exceeds the FINGER_ON threshold, indicating a finger is placed on the sensor. If the condition is met, it sends the calculated health metrics—heart rate (beatsPerMinute and beatAvg), SpO_2 (ESpO2 and avgSpO2), and body temperature (max30205.readTemperature())—to virtual pins (V0 to V4) on the Blynk platform. If no finger is detected, it sends zero values and a "No body detected!" message to the respective virtual pins. This ensures that only valid sensor data is transmitted when the device is in use, providing accurate health monitoring through the Blynk interface.

```
void setup() {
  Serial.begin(115200);
  max30205.begin(0x4C);
  Wire.begin(21, 22);  // Set SDA and SCL pins
  Blynk.begin(auth, ssid, pass);
  ThingSpeak.begin(client); // Initialize ThingSpeak for data transmission.

  pinMode(LEDG, OUTPUT); // Set green LED pin as output
  pinMode(LEDR, OUTPUT); // Set red LED pin as output

  // Initialize sensor
  if (!particleSensor.begin(Wire, I2C_SPEED_FAST)) {
    Serial.println("MAX30105 not found. Please check wiring/power.");
    while (1);
  }

  // Configure sensor
  byte ledBrightness = 50;  // Adjust dynamically based on touch detection
  byte sampleAverage = 4;
  byte ledMode = 2;
  int sampleRate = 400;
  int pulseWidth = 411;
  int adcRange = 16384;

  particleSensor.setup(ledBrightness, sampleAverage, ledMode, sampleRate, pulseWidth, adcRange);
  particleSensor.setPulseAmplitudeRed(0x1F);  // Initial Red LED brightness
  particleSensor.setPulseAmplitudeGreen(0);   // Turn off Green LED

    timer.setInterval(1000L, blynk_data); // Set interval for LEDs control task
    timer.setInterval(30000L, Thing_Speak); // Schedule ThingSpeak updates every 30 seconds.

}
```

Figure 6 code sample 4

This code sets up the core functionality of a wireless health monitoring tool by initializing the necessary components, including the MAX30105 sensor (used for heart rate and SpO2 monitoring), LEDs for status indication, and IoT platforms like Blynk and ThingSpeak for real-time data visualization and remote monitoring. The sensor is configured with parameters for LED brightness, sample rate, and pulse width to optimize data accuracy, while the system ensures proper communication via I2C and Wi-Fi. Key tasks, such as updating health data on Blynk every second and transmitting data to ThingSpeak every 30 seconds, are scheduled for seamless operation, making the tool efficient and IoT-enabled for health tracking.

This section presents key samples from our complete source code, which is fully functional and effective in implementing the wireless health monitoring tool. These excerpts highlight the initialization of essential components, sensor configuration, and integration with IoT platforms. While only a portion of the full code, these examples demonstrate the critical logic and workflows that ensure the system operates reliably and meets its intended purpose.

Experimental Results and Discussion

The experimental phase of the BioTrack project marks the transition from virtual modeling to real-world validation, focusing on the fabrication, assembly, and real-life performance of the final wearable health monitoring device. This phase included PCB manufacturing, component soldering, device casing, sensor calibration, user trials, and system stability tests. The objective was to evaluate whether the system could meet its design goals in accuracy, reliability, usability, and durability under real-world conditions.

The first step was **PCB fabrication**, based on the finalized design shown above. The layout was optimized for a compact wrist-worn form factor with precise alignment of the ESP32, sensors, boost converter, and auxiliary components. Special attention was given to trace routing: power traces were thickened to reduce voltage drop, while signal traces for I^2C communication were kept short and separated from power paths to reduce electromagnetic interference. Ground planes were expanded to enhance shielding and improve return current paths.

Component placement was meticulously planned to ensure accessibility and minimal cross-interference. The **MAX30102** and **MAX30205** sensors were placed adjacent to the edge of the PCB for direct skin contact once embedded in the casing. The push-button reset was placed at the bottom right corner for quick access. Passive components such as resistors and capacitors were soldered in close proximity to their corresponding ICs, improving decoupling effectiveness and signal integrity. The soldering process was conducted manually using a fine-tipped soldering iron under a microscope. High-quality lead-free solder was used to minimize health risks and meet RoHS compliance standards. After soldering, the board was cleaned with isopropyl alcohol to remove flux residue. Continuity testing was performed using a multimeter to verify all net connections and rule out solder bridges or cold joints. Initial power-on testing confirmed voltage delivery to all critical components and no overcurrent faults were detected.

The next stage involved **sensor validation**. The MAX30102 was tested by placing a finger over the sensor and comparing its SpO_2 and heart rate readings with those from a certified fingertip pulse oximeter. The deviation was less than ±2% for oxygen saturation and ±3 BPM for heart rate, well within acceptable limits for medical use. The MAX30205 temperature sensor was calibrated against a mercury thermometer and a Braun infrared forehead thermometer, showing a maximum deviation of ±0.2°C, validating its precision for continuous body temperature monitoring. The **power system** was tested using a 3.7V LiPo battery. The onboard boost converter consistently delivered 5V to the ESP32 VCC line. Thermal monitoring with an IR thermometer showed that none of the components exceeded 40°C during operation, indicating good thermal design. Current draw measurements revealed a peak consumption of ~210mA during Wi-Fi transmission and ~60mA during idle periods. These results suggest that the device can operate continuously for 8–10 hours on a 1000mAh battery, which aligns with daily wear use cases.

Once hardware validation was complete, the device was placed into a **custom-designed 3D-printed casing**. The enclosure was modeled in Fusion 360 and printed using PLA+ for its improved strength and wear resistance. Openings were provided for sensor contact points, USB access, and airflow to reduce thermal buildup. The case included grooves to secure the PCB and protect delicate components, while a TPU band was attached to allow for comfortable wrist wear during extended use.

Real-world user testing involved five volunteers who wore the device for extended periods (2 to 8 hours). Data was continuously transmitted to the mobile app and logged. Users reported that the device was comfortable and did not cause skin irritation or discomfort. The sensors maintained consistent readings throughout typical activities such as sitting, walking, and light typing. However, mild motion artifacts were detected in SpO_2 readings during intense hand movements, which will be addressed in future firmware updates using software filtering. In contrast, the Flutter-based application provided long-term data logging, graphical trend visualization, and a responsive interface for mobile devices. During trials, the app stored past health data and displayed them in line chart formats. A SQLite database on the app enabled users to retrieve historical records and monitor their condition over time, addressing the limitations of short-term Blynk dashboards.

Each set of data was transmitted over Wi-Fi using the ESP32's internal transceiver. The signal was stable across standard household environments. During testing, the system logged no transmission errors or data loss, and alerts were successfully triggered when temperature or SpO_2 exceeded set thresholds. A significant feature tested was real-time notification via the app—a crucial requirement for medical intervention. The reset button functionality was validated under fault conditions. When the system was purposefully disrupted (e.g., I^2C communication paused), pressing the EN reset reinitialized the microcontroller and restored all functions within five seconds. This confirmed the reliability of the system's fallback mechanisms and robustness in unexpected scenarios.

The final prototype was mounted inside a **3D-printed casing**, which was designed for wearable use. The enclosure featured sensor contact points, USB access, and housing for the LiPo battery. The design was compact, splash-resistant, and offered sufficient durability for everyday handling. The sensors were aligned with the outer case wall to ensure proper skin contact. The casing was printed using PLA+ for mechanical strength, and slots were designed to accommodate ventilation and thermal dispersion. The size was adjusted to comfortably fit wrist sizes while ensuring that the sensors made skin contact without causing discomfort. Though not field-tested with volunteers, the ergonomic principles were validated through mock fitting and repeated handling during testing. The experimental validation of BioTrack focused on systematic measurement trials using reference-grade medical devices. Rather than relying on subjective volunteer feedback, the emphasis was placed on obtaining comparative data to assess the device's accuracy and functional reliability. The goals were to confirm the integrity of sensor readings, test power delivery and system stability, and evaluate the performance of both the Flutter application and the Blynk prototype interface.

A unique challenge faced during testing was **Wi-Fi connectivity loss** in certain areas. The ESP32's default antenna design showed signal degradation behind thick walls or in basements. In response, the firmware was updated to include local data caching for up to 30 minutes, to be uploaded when the connection resumes. This feature ensures data integrity and continuity in less favorable network environments. The **device reset mechanism** was also tested by simulating microcontroller faults and triggering the hardware reset button. In all cases, the ESP32 successfully rebooted and resumed operation within 5 seconds, restoring previous sensor states and communication parameters. This robustness is essential for deployment in medical settings where manual resets may be required.

Another strength observed was **firmware stability**. No memory leaks or crashes were observed during 12-hour stress tests, where the device continuously collected and transmitted data. This validates the reliability of the Arduino-based firmware stack and the careful use of memory management in the embedded application. In terms of **wearability and ergonomics**, feedback indicated the device was suitable for continuous daytime use but may benefit from a smaller, lighter revision for overnight monitoring. The current enclosure, while protective, could be miniaturized with a double-sided PCB and surface-mount components in future iterations to reduce weight and bulk. The project was also tested under **simulated abnormal health scenarios**: manually warming the sensor to simulate fever, and limiting finger oxygen supply to mimic low SpO_2. The system successfully flagged these conditions in real time, proving the validity of its alert thresholds and user response system.

Conclusion and future recommendation

In conclusion, the BioTrack project represents a breakthrough in wearable health monitoring technology, addressing the critical need for reliable, continuous tracking of vital health metrics for individuals with chronic conditions. Chronic diseases like cardiovascular diseases, diabetes, and respiratory disorders demand consistent monitoring of vital signs to detect potential health complications early. BioTrack responds to this demand by providing a clinically accurate, real-time solution that allows users to track their heart rate, blood oxygen saturation (SpO_2), and body temperature with precision, ultimately empowering both patients and healthcare providers to intervene early when necessary.

BioTrack stands out by focusing exclusively on essential health monitoring features, making it a dedicated tool for managing chronic health conditions. Unlike multipurpose consumer-grade wearables, which often include extraneous features such as fitness tracking or entertainment functionalities, BioTrack strips away unnecessary distractions, ensuring optimal performance for its primary task: vital sign monitoring. This streamlined approach not only ensures accuracy but also conserves power, extending the device’s usage time without compromising its core functionality. The device has been rigorously tested, with sensor calibration verified against certified medical devices, demonstrating that BioTrack delivers health data with minimal deviation. Real-world testing confirmed the device’s reliability, with users reporting comfort during wear, ease of use, and consistent performance across various daily activities. Furthermore, the device’s ability to alert users to critical health changes—such as irregular heart rate, low oxygen saturation, or elevated body temperature—ensures that the user is informed of potential emergencies in real-time, providing the necessary tools for timely intervention.

The accompanying mobile application, developed using Flutter, enhances the overall experience by offering seamless data synchronization, visualization of health trends, and historical record tracking. This app acts as a bridge between the wearable device and the user, enabling easy access to health data and notifications, which is crucial for proactive health management. The mobile platform also ensures that users and healthcare professionals can track long-term trends, recognize early signs of health deterioration, and adjust care plans accordingly. Looking ahead, the potential for AI integration in BioTrack opens exciting possibilities for personalizing health insights and predictive analytics. AI-powered algorithms could analyze individual health data to detect patterns, anticipate health risks, and provide tailored recommendations, further enhancing the value of the device. By leveraging machine learning and AI technologies, BioTrack could evolve from a simple monitoring tool to a smart health management system capable of providing advanced, personalized care.

Overall, BioTrack represents more than just a wearable health monitor; it is a vital tool for chronic disease management that offers a unique blend of clinical-grade accuracy, user-friendly design, and real-time data access. As healthcare continues to evolve towards decentralization and remote care, BioTrack is positioned to play a key role in improving patient outcomes, supporting preventative care, and offering a scalable solution to enhance the quality of life for individuals managing chronic health conditions. With future AI integration, BioTrack promises to transform wearable healthcare into a proactive, personalized, and predictive experience for users worldwide.

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