Project Overview

**Product**
A smartwatch that monitors health metrics and environmental conditions

**Project**
Design a smart wearable device to monitor user health

**Goal**
To improve the well-being of all users
Team Members

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Project Features

Sensors
- Pulse oximetry
- Body temperature
- Motion
- Noise level
- Weather

Outputs
- Medical metrics
- Air quality and environmental safety
- Step counting
- Alerts

User Interface
- Wearable:
  - LCD display
  - Rotary encoder
- Mobile application:
  - Data visualizations
  - Databasing
Wearable Block Diagram

- **TMP117**: Body temperature sensor
- **BME688**: Temperature, pressure, humidity, & AQI sensor
- **TMP17**: Body temperature sensor
- **LSM9DS1**: Accelerometer, gyroscope, & magnetometer sensor
- **VC0834B011F**: Haptic motor for notifications
- **PES12**: Rotary encoder for on-device user input
- **ST7789V**: LCD display driver
- **LM393**: Analog-output noise sensor
- **MAX30101 & MAX32664**: Optical heart rate sensor & data processor
- **nRF52840 Microcontroller**: Central processing unit
- **GPIO**: General-purpose input/output
- **I2C**: Inter-Integrated Circuit
- **SPI**: Serial Peripheral Interface
- **ADC**: Analog-to-Digital Converter
- **DC**: Direct Current
Microcontroller

Specifications

- On-board Bluetooth Low Energy (BLE)
- Low-power operation
- I2C, SPI, UART, ADC and GPIO capabilities
Weather Sensor

BME688

Sensor Details
- I2C communication
Measures:
- Temperature
- Pressure
- Humidity
- Gas resistance
Medical Thermometer

- nRF52840 Microcontroller
  - I2C-compatible
  - Measures temperature via contact with skin
  - Medical-grade

Sensor Details

TMP117

BME688

PES12

ST7789V

I2C

GPIO

SPI

ADC

BME688

I2C

SPI

ADC

DC

MAX30101

MAX32664
Inertial Measurement Unit (IMU)

**nRF52840 Microcontroller**
- SPI communication
- Contains an accelerometer and gyroscope
- Provides data for step counting

**Sensor Details**
- SPI communication
- Contains an accelerometer and gyroscope
- Provides data for step counting
Heart Rate / Blood Oxygen Sensor

**MAX30101**
- Optical heart rate sensor
- Collects raw data using onboard LEDs
- Receives commands from and transmits data to MAX32664 using I2C for analysis

**MAX32664**
- Biometric sensor hub
- Receives raw data via I2C
- Computes and transmits heart rate and blood oxygen saturation values

**nRF52840 Microcontroller**

**MAX30101 & MAX32664**
Volume Sensor

Sensor Details

- Microphone that measures sound level
- Outputs noise intensity as analog voltage
- Omnidirectional

nRF52840 Microcontroller

LM393
Display Module

Sensor Details

- SPI communication
- 18-bit color depth
- Compatible with LCD displays up to 240x320 resolution
UI Components

- **nRF52840 Microcontroller**
  - EN10
  - GPIO
  - ST7789V
  - SPI
  - I2C
  - ADC
  - DC

- **Rotary Encoder**
  - 2-pin GPIO interface
  - Compact & lightweight
  - Tactile feedback

- **Haptic Motor**
  - VC0834B011F
  - GPIO (1 pin)
  - Allows device to notify user or prompt them for action

- **GPIO**
  - EN10
  - ST7789V
  - SPI
  - I2C
  - DC

- **DC**
  - MAX30101 & MAX32664

- **I2C**
  - BME688
  - LSM9DS1

- **SPI**
  - IPS17

- **ADC**
  - MAX30101 & MAX32664
PCB Design

- 6-layer design and dimensions of 35 x 50 mm

1. Top Component Layer
2. Upper GND Plane
3. Inner Routing Layer
4. PWR Plane
5. Lower GND Plane
6. Bottom Component Layer

6-layer stackup
PCB Design

- 6-layer design and dimensions of 35 x 50 mm
- EMI shielding with GND planes
6-layer design and dimensions of 35 x 50 mm

- EMI shielding with GND planes

**Embedded capacitance:**
- Alternative to decoupling capacitors for noise reduction
- Utilizes capacitance between PWR and GND planes
PCB Design

- 6-layer design and dimensions of 35 x 50 mm
- EMI shielding with GND planes
- Embedded capacitance
  - Alternative to decoupling capacitors for noise reduction
  - Utilizes capacitance between PWR and GND planes
- **Reference planes**
  - Provides a direct return path for currents from signal layers
  - Helps to reduce EMI output and further mitigate noise
PCB Layout

- Noise sensor
- Weather sensor
- IMU
- Display connector
- Microcontroller
- BT Antenna
- Battery connector
- Body temperature sensor
- Heart rate & pulse oximetry sensor
Hardware Construction
Enclosure Design

Charging port

Vent hole

Rotary encoder mount

Apple Watch band connector

HR/SpO2 and body temperature sensor cutouts

Mounting holes for display
Embedded Software Design
Embedded Software Flow

Start

Initialize Bluetooth and peripherals

Start threads

Bluetooth

Maintain BLE connection & send updated data
Embedded Software Flow

1. Start
2. Initialize Bluetooth and peripherals
3. Start threads
4. Collect data from I2C sensors
5. Maintain BLE connection & send updated data
Embedded Software Flow

Start

Initialize Bluetooth and peripherals

Start threads

Bluetooth

Maintain BLE connection & send updated data

I2C

Collect data from I2C sensors

IMU

Poll IMU, filter, and perform step tracking & fall detection

\[ V_{out}[n] = \frac{T}{T + RC} V_{in}[n] + \frac{RC}{T + RC} V_{out}[n - 1] \]

f(c)=5Hz
cutoff frequency
Embedded Software Flow

Start

Initialize Bluetooth and peripherals

Start threads

I2C

Bluetooth

Collect data from I2C sensors

IMU

Maintain BLE connection & send updated data

Poll IMU, filter, and perform step tracking & fall detection

User Interface

Poll rotary encoder and operate LCD display
UI State Machines

Rotary encoder debouncing

Wearable user interface
Wearable User Interface

- Heart Rate: 65 BPM
- Body Temp: 98.6°F
- Total Steps: 8072
- Distance: 4.0 mi
- Air Temp: 98°F
- Air Quality: 257
- High Temp: None
- Humidity: 20%
- Pressure: 6.5 inHg
- Alert: Fall Detected
Custom Display Drivers

- Optimize pixel drawing with buffers
- Customizable font with digit/text drawing
- Parametric equations to draw shapes

\[ x = 16 \sin^3 t \]
\[ y = 13 \cos t - 5 \cos(2t) - 2 \cos(3t) - \cos(4t) \]
Android Application

Weather Data:
- Temperature: 99.00°F
- Barometric Pressure: 21473 Pa
- Relative Humidity: 20.68%
- Gas Resistance: 5684.0

Medical Data:
- Heart Rate: 61 BPM
- Heart Rate Confidence: 0%
- Blood Oxygen Saturation: 98.8%
- Body Temperature: 98.3°F

Analog Inputs:
- Step Count: 8072
- Accelerometer Y: -0.83
- Accelerometer X: -0.00
- Accelerometer Z: -0.00

Temperature: 67.3°F
Pressure: 974.9 hPa
Humidity: 46.5%
Gas/VOC Level: Good
Air Quality: Good

Pulse Waveform

Heart Rate: 61.5 BPM

Application Launched
Scan for Bluetooth Devices
Connected?
No
Yes
Data Received?
No
Yes
Upload to Cloud Database
Firebase

(sensorData)

- Start collection
  - sensorData

- Add document
    - bloodOxygen: 0
    - bodyTemperature: 78.26
    - gas: 8012
    - heartRate: 71
    - humidity: 60.2
    - pressure: 89310
    - temperature: 77.96

- Start collection
Thank You!

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Questions?
Operating Characteristics

• Power consumption:
  • HR sensor and LCD display OFF: 0.15 W
  • LCD display OFF: 0.22 W
    - LCD power draw would be cut by 33% if run of 3.3V instead of 5V
  • All peripherals ON: 1.48 W

• Battery life:
  • 30 minutes with everything enabled
  • Numerous potential improvements

• Operating temperature:
  • ~110 °F on average

Total capacity: 2 * 0.555 Wh = 1.11 Wh
Marketability

• Modular → easily repairable

• Medical focus provides superior data without unnecessary features
  • No calibration required

• Total cost per device: $145.34
  • PCB parts: $46.74
  • HR/SpO2 sensor: $40.00
  • PCB manufacturing and assembly: $58.60
  • Easy improvements: Include HR sensor on PCB, use cheaper IMU, eliminate some weather data, order larger batches of both PCBs and parts

• Seamless databasing and data viewing by medical personnel
float get_body_temp() {
    uint8_t BT_ADDR = 0x48;
    uint8_t write_data1[1] = {0x00};

    // Writing 2 bytes to the sensor
    int ret = i2c_write(i2c0_dev, write_data1, 1, BT_ADDR);
    if (ret < 0) {
        return 0; // Error writing to sensor
    }

    // Reading 2 bytes from the sensor
    uint8_t data_buffer[2];
    ret = i2c_read(i2c0_dev, data_buffer, sizeof(data_buffer), BT_ADDR);
    if (ret < 0) {
        return 0; // Error reading from sensor
    }

    // Raw temp output
    uint16_t temperature = (data_buffer[0]<<8)+(data_buffer[1]);
    float final_temp_F = (temperature / 128.0)*1.8 + 32;

    return final_temp_F;
}
Difficulties and Future Plans

• Including HR/SpO2 sensor on PCB proved too expensive
  • Total PCB cost was ~$500 when soldering sensor on
  • Directly using SMD components would cost $2000 minimum

• Operating temperature can exceed comfortable values
  • Microcontroller has limited power
  • HR/SpO2 sensor and display are drawing more power than necessary

• Potential improvements:
  • Make all components SMD
  • Remedy noise sensor sensitivity issues
  • Add heat management components
  • Reduce size of PCB and enclosure