Development of Non-Invasive Glucose Monitoring System

Integration of Spectroscopy, IoT, and Machine Learning for Real-Time Heath Insight

Supervisor: Vihtori Virta

Razib Hasan, Jinjing Yang

Background & Motivation

Diabetes affects over 800 million people 🌍 globally

Glucose monitoring is essential but current methods are invasive

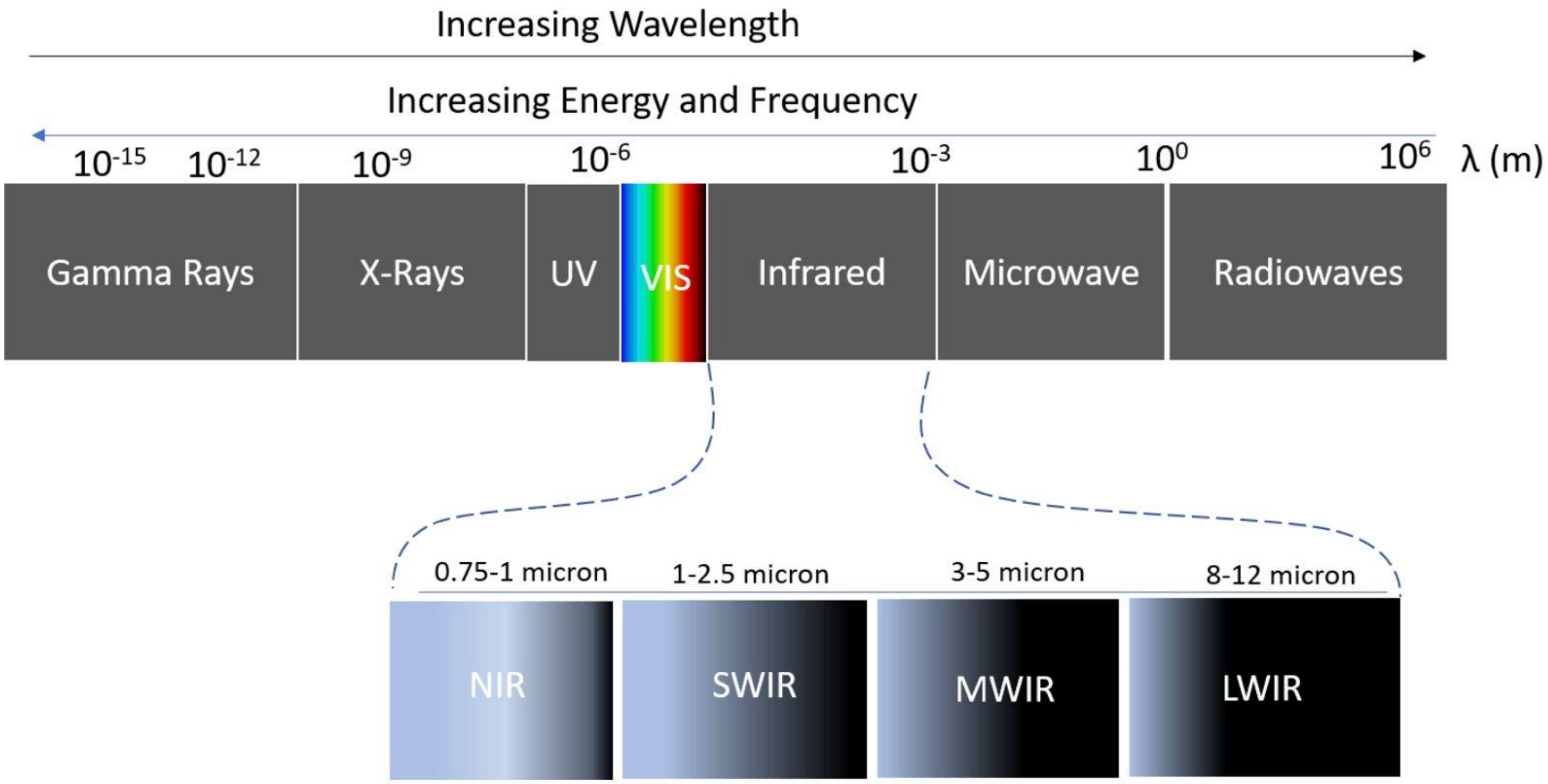
This project explores a **non-invasive**, real-time solution using infrared sensing + IoT + machine learning

Glucose Monitoring Methods

- **Invasive:** Finger pricks (accurate but painful)
- **Minimally invasive:** CGMs (continuous but costly)
- **Non-invasive (optical):** Promising but needs improvement on accurancy
- Challenges: weak glucose signals, water interference, skin variability

Objective

- Build a **low-cost, portable** glucose sensor
- Use **infrared light**, **ML**, and **mobile integration**



Increasing Wavelength
Increasing Energy and Frequency
10^{-15}
10^{-12}
10^{-9}
10^{-6}
10^{-3}
10^{0}
10^{6}
λ (m)
Gamma Rays
X-Rays
UV
VIS
Infrared
Microwave
Radiowaves
0.75-1 micron
1-2.5 micron
3-5 micron
8-12 micron
NIR
SWIR
MWIR
LWIR

Multi-Wavelength Proposal

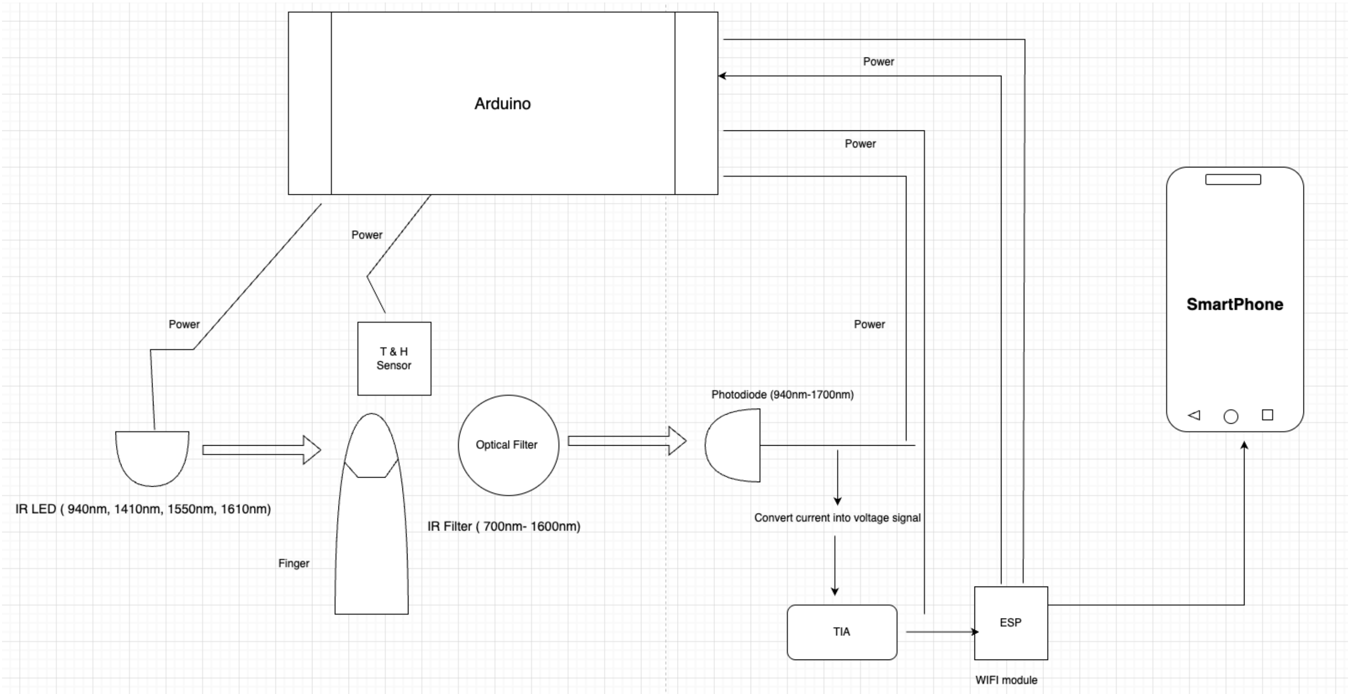
Wavelength	Function
940 nm	Deep tissue reference
1410 nm	Hydration interference compensation
1550 / 1610 nm	Glucose-specific absorption

- 940 nm
  - NIR region (700-1400 nm)
- 1410, 1550, and 1610 nm
  - SWIR range (1400-2500 nm)

- Improves accuracy and robustness
- Combines **reference, correction**, and **signal detection**

System Design

- Two-unit architecture:
  - **Arduino**: LED control, signal sampling
  - **ESP32**: Wireless transmission
- **Sensing path:** IR LED → finger → photodiode
- 40-second sensing cycle per session



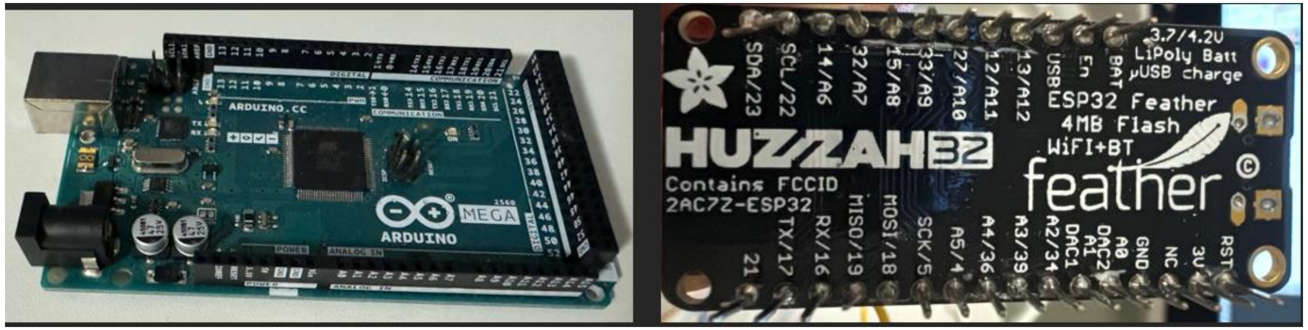
System Design Diagram

Components Used

- All components chosen for **biomedical compatibility and safety**
- Ensured skin safety with:
  - Limited current (20–30 mA)
  - Pulse-mode emission
  - Matte black enclosure

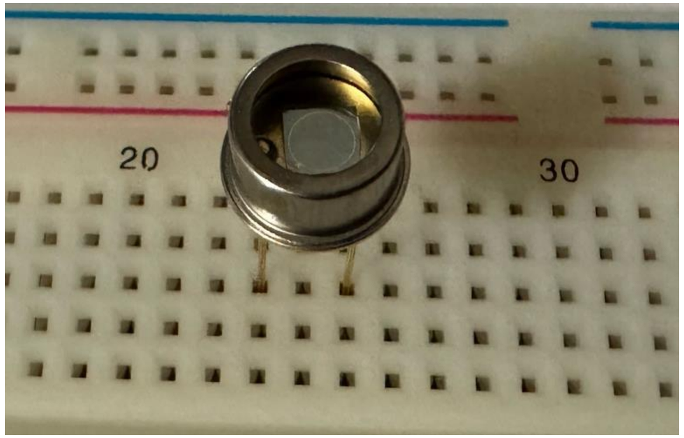
Component	Function
IR LEDs (4)	Emit specific wavelengths
Photodiode	Detect transmitted light
Optical filter	Block ambient light
TIA Circuit	Convert current to voltage
Env Sensor	Record temperature & humidity
ESP32	Send data wirelessly

Components Used

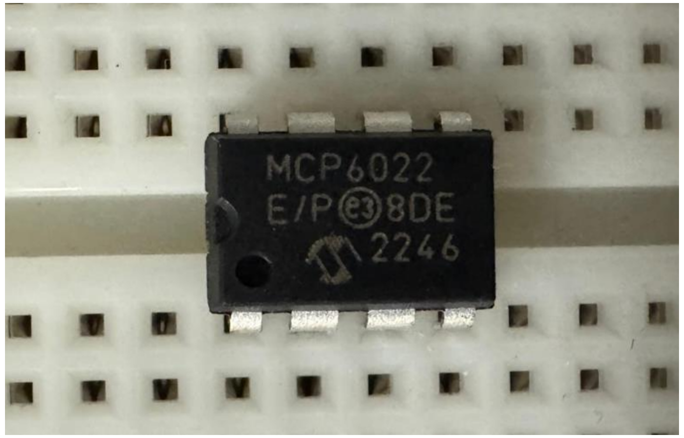


Arduino mega & ESP32

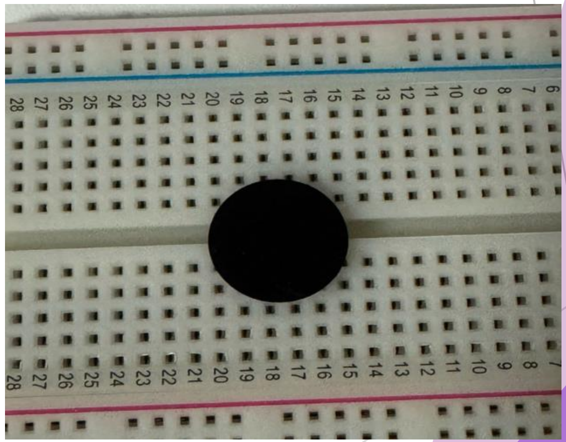
THD Sensor



Photodiode

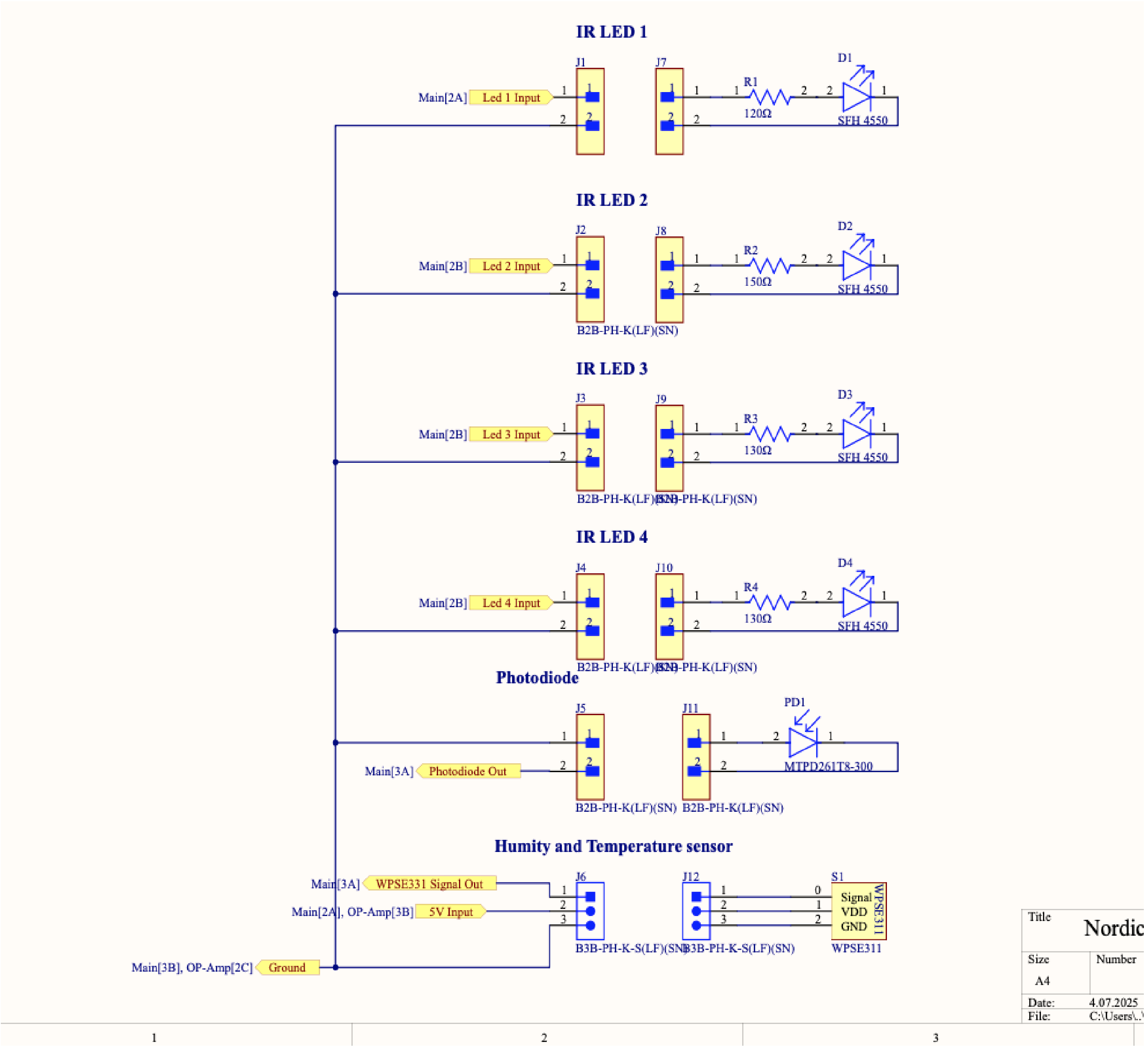


Op-amp

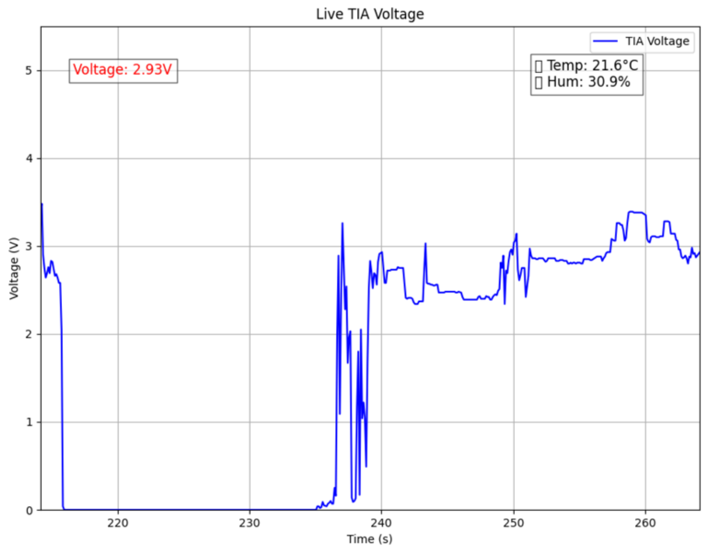


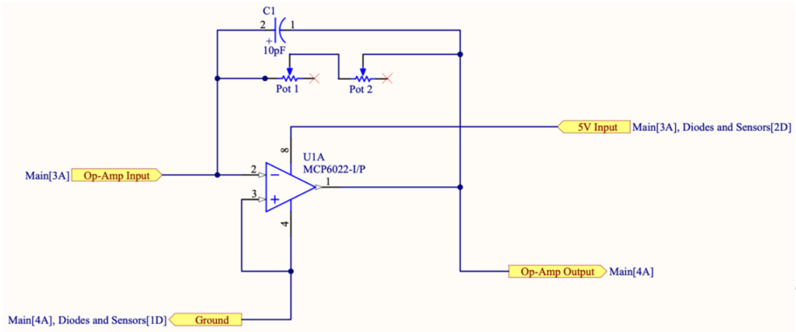
Long cut optical filter

IR LEDs and Env-sensor

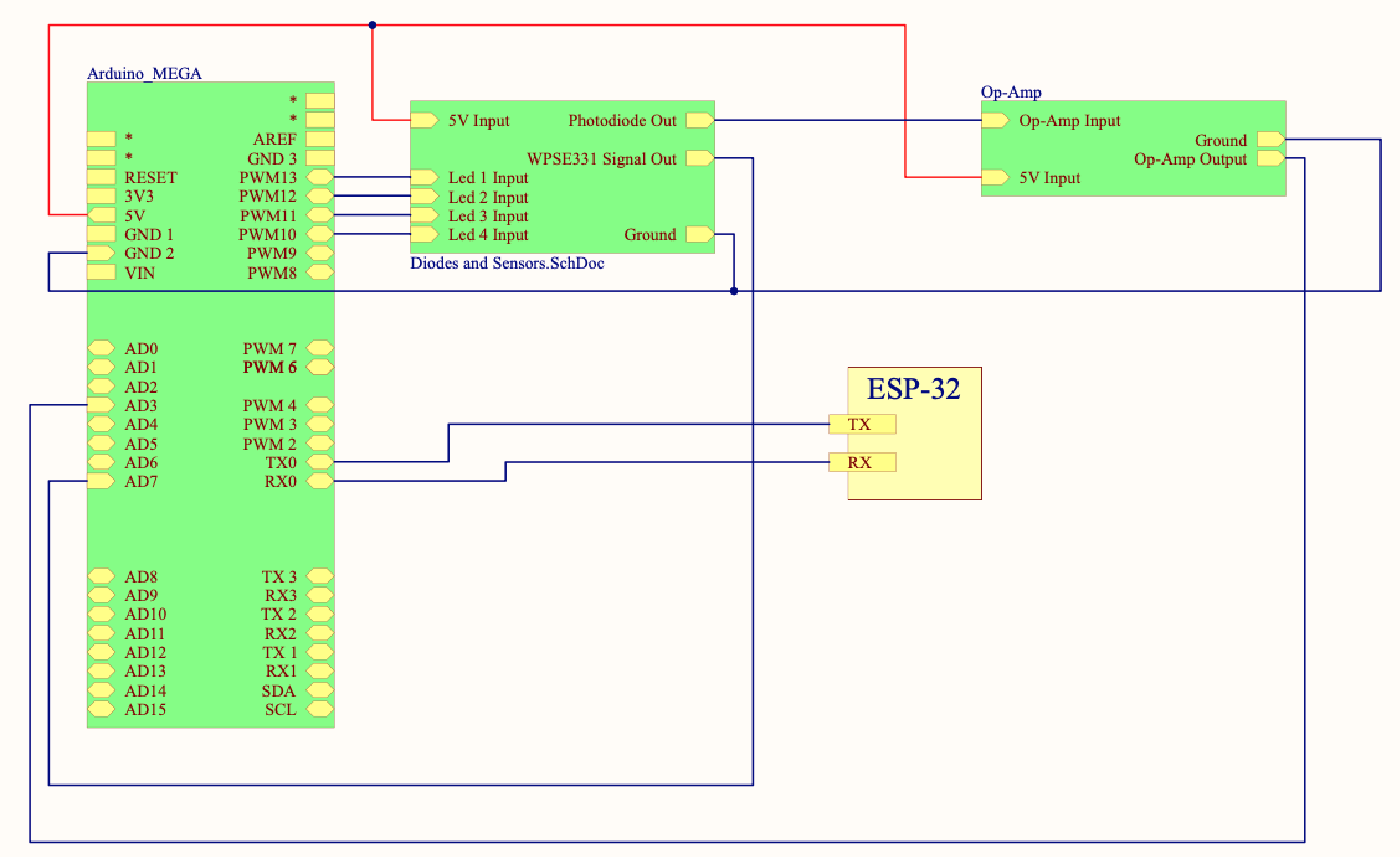


Transimpedance Amplifier (TIA)





Circuit Diagram



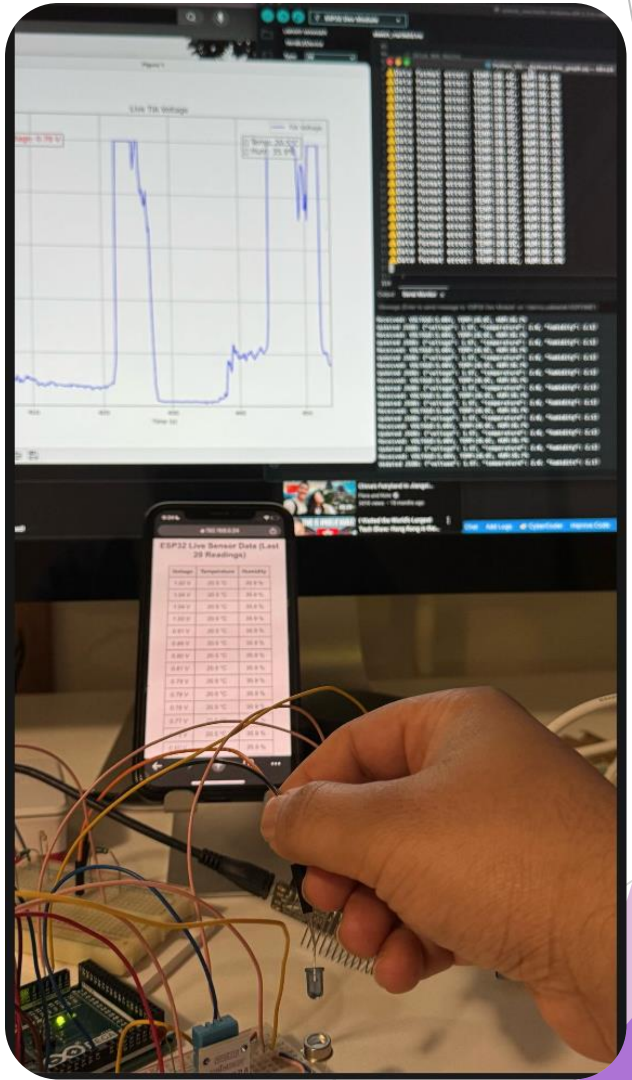
Initial System Testing

5:47

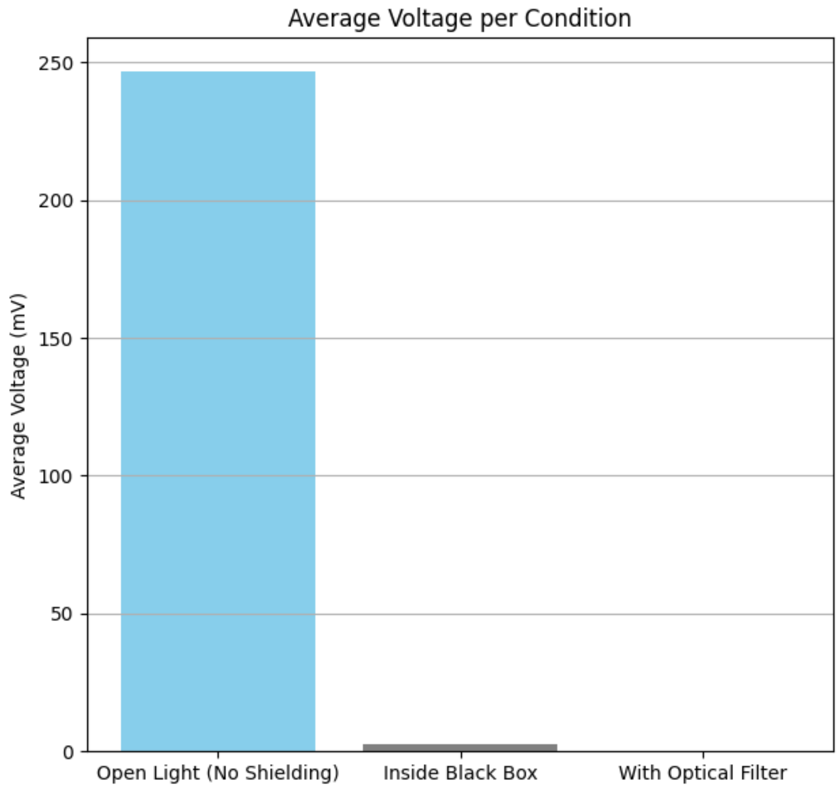
192.168.0.24

ESP32 Live Sensor Data (Last 20 Readings)

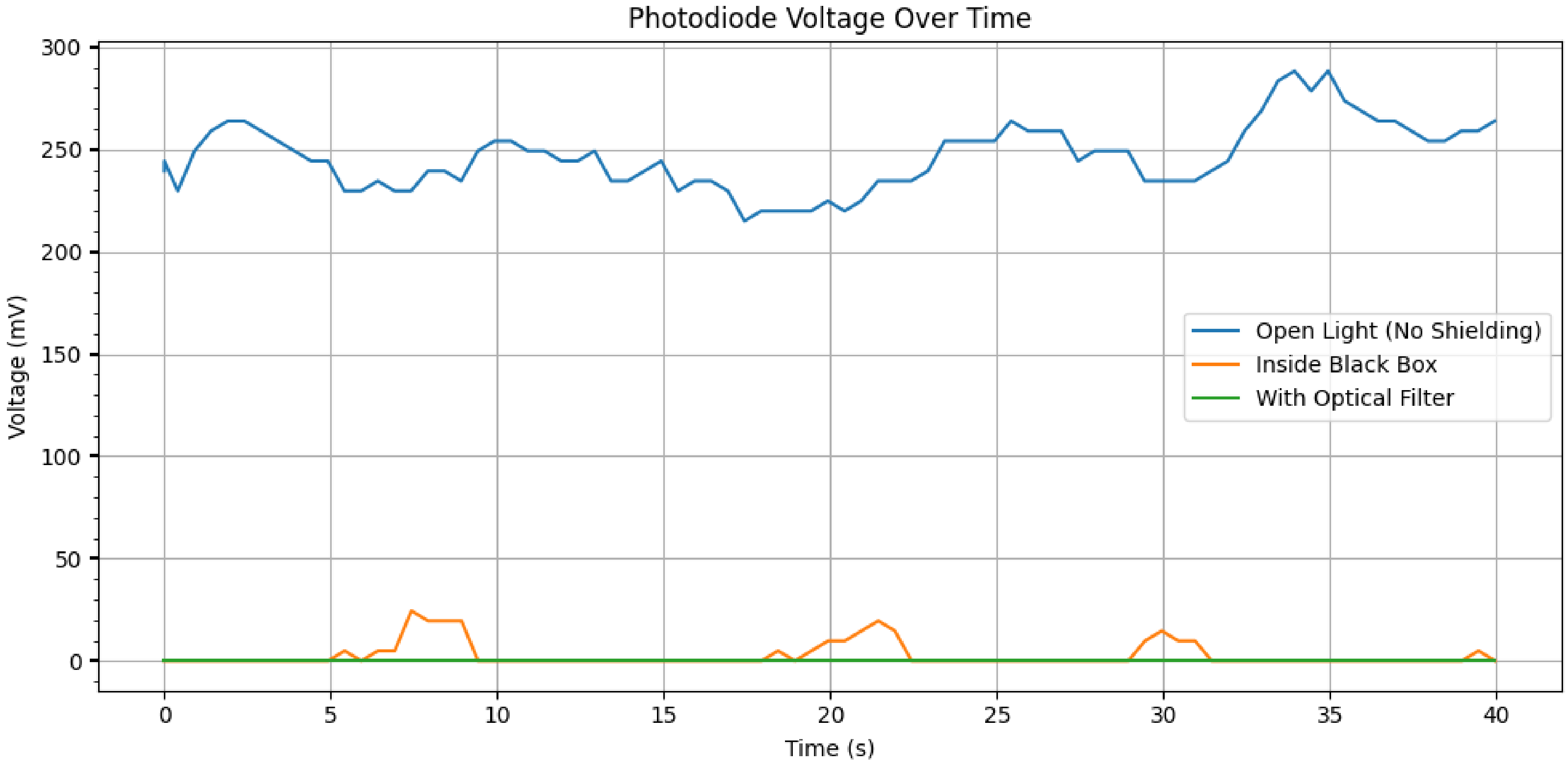
Voltage	Temperature	Humidity
1.54 V	20.1 °C	36.9 %
1.64 V	20.1 °C	36.9 %
1.51 V	20.1 °C	36.9 %
1.54 V	20.1 °C	36.9 %
1.56 V	20.1 °C	36.9 %
1.54 V	20.1 °C	36.9 %
1.67 V	20.1 °C	36.9 %
1.72 V	20.1 °C	36.9 %
1.95 V	20.1 °C	36.9 %
2.01 V	20.1 °C	36.9 %
2.24 V	20.1 °C	36.9 %
1.86 V	20.1 °C	36.9 %
1.86 V	20.1 °C	36.9 %
1.89 V	20.1 °C	36.9 %
2.06 V	20.1 °C	36.9 %
2.1 V	20.1 °C	36.9 %
2.48 V	20.1 °C	36.9 %



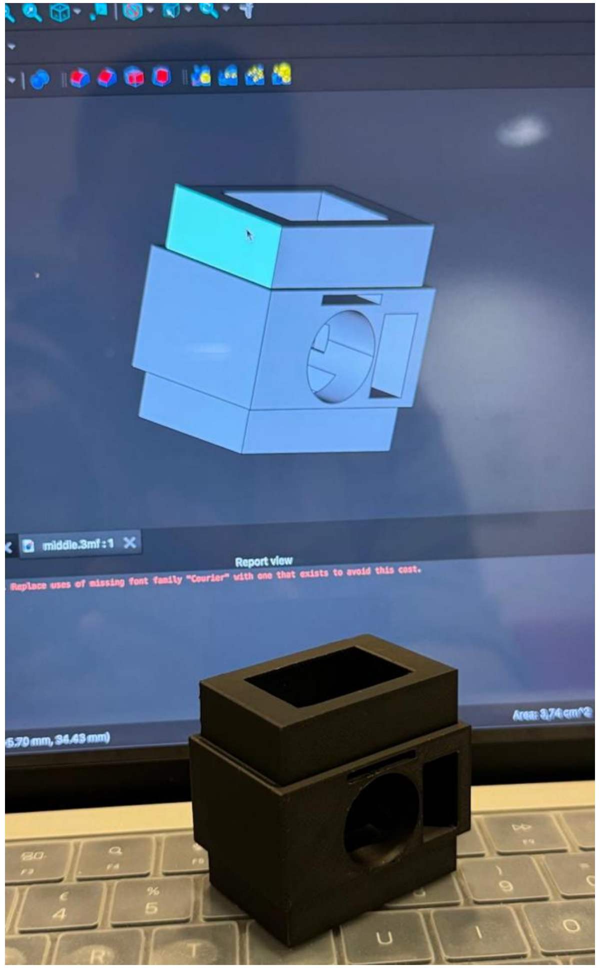
Improved Signal Accuracy via Optical Isolation and Filtering

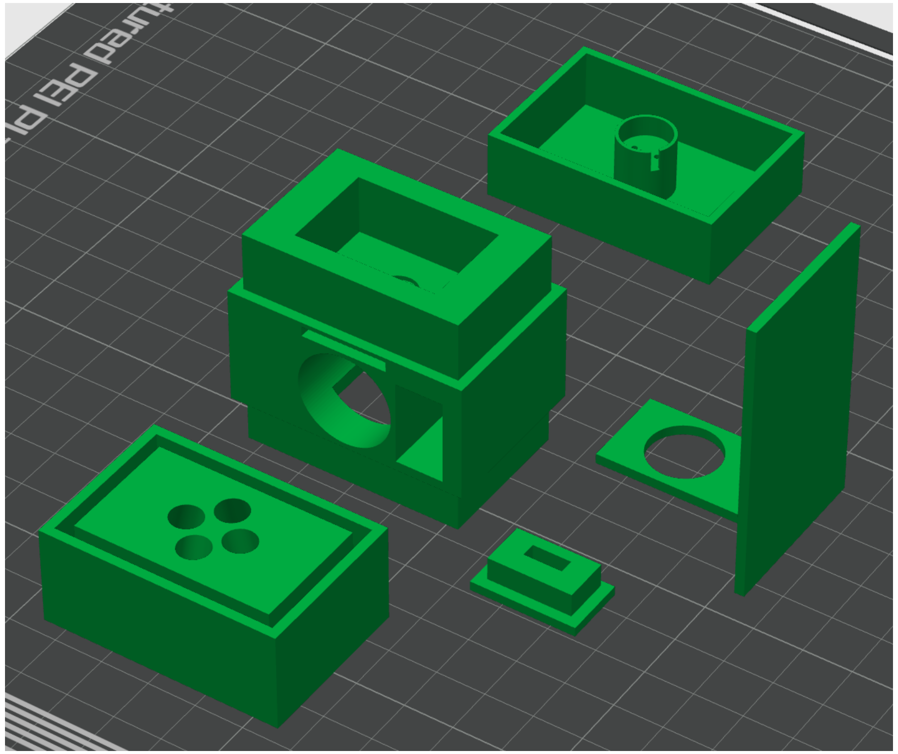



```
□ Estimated Light Reduction:

□ Open → Black Box:     98.89%
□ Black Box → Filter:  100.00%
□ Open → Filter:       100.00%

□ Min & Max Voltage Observed (mV):
- Open Light (No Shielding):
   Min = 215.05 mV
   Max = 288.37 mV
- Inside Black Box:
   Min = 0.00 mV
   Max = 24.44 mV
- With Optical Filter:
   Min = 0.00 mV
   Max = 0.00 mV
```



Black Box Enclosure





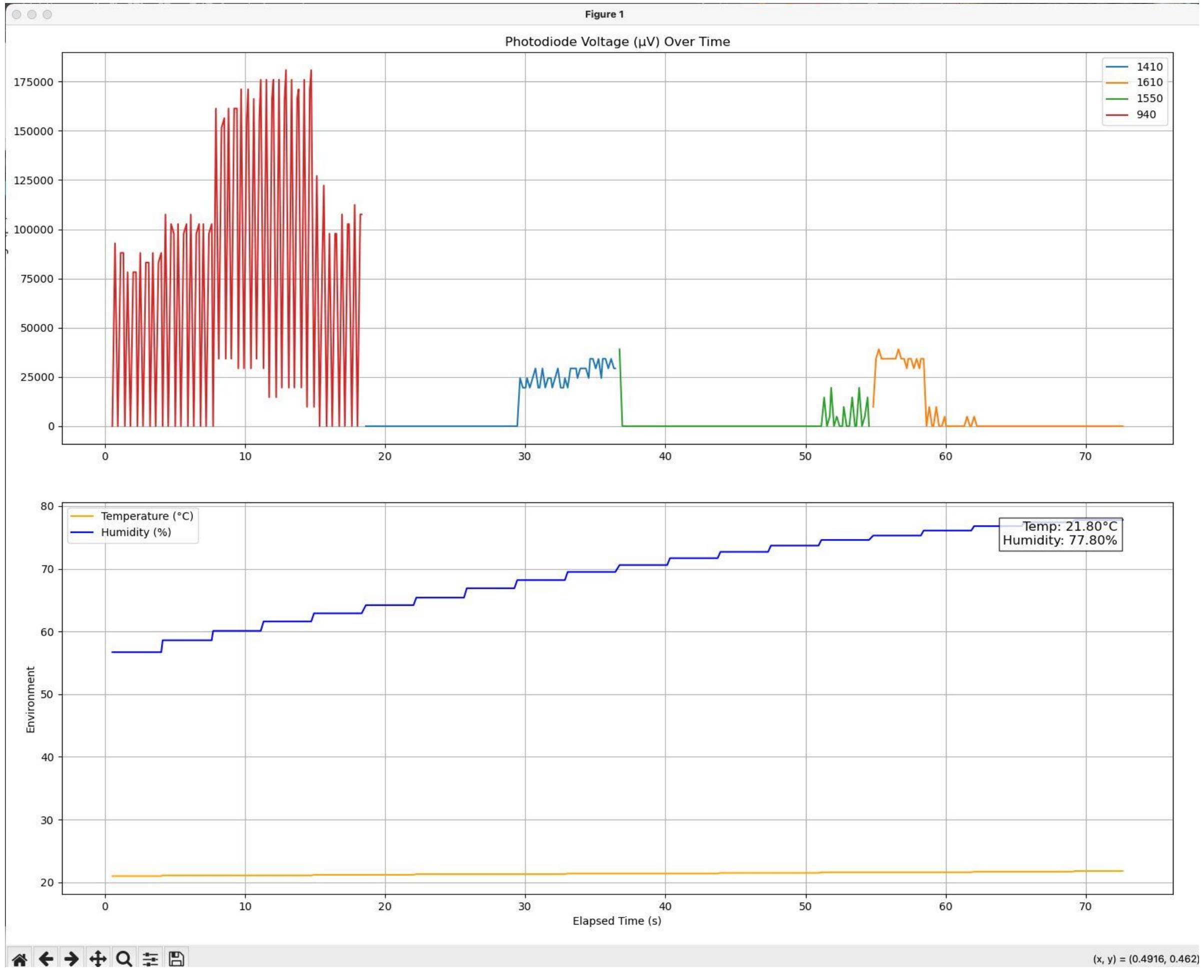


Figure 1
Photodiode Voltage (μV) Over Time
1410
1610
1550
940
Temperature (°C)
Humidity (%)
Temp: 21.80°C
Humidity: 77.80%
Environment
Elapsed Time (s)
(x, y) = (0.4916, 0.462)

Web Dashboard (hosted on ESP32) : user-friendly data collection

- Start/stop measurement
- Countdown timer
- Live voltage, temp, humidity

Non-Invasive Glucose Monitoring

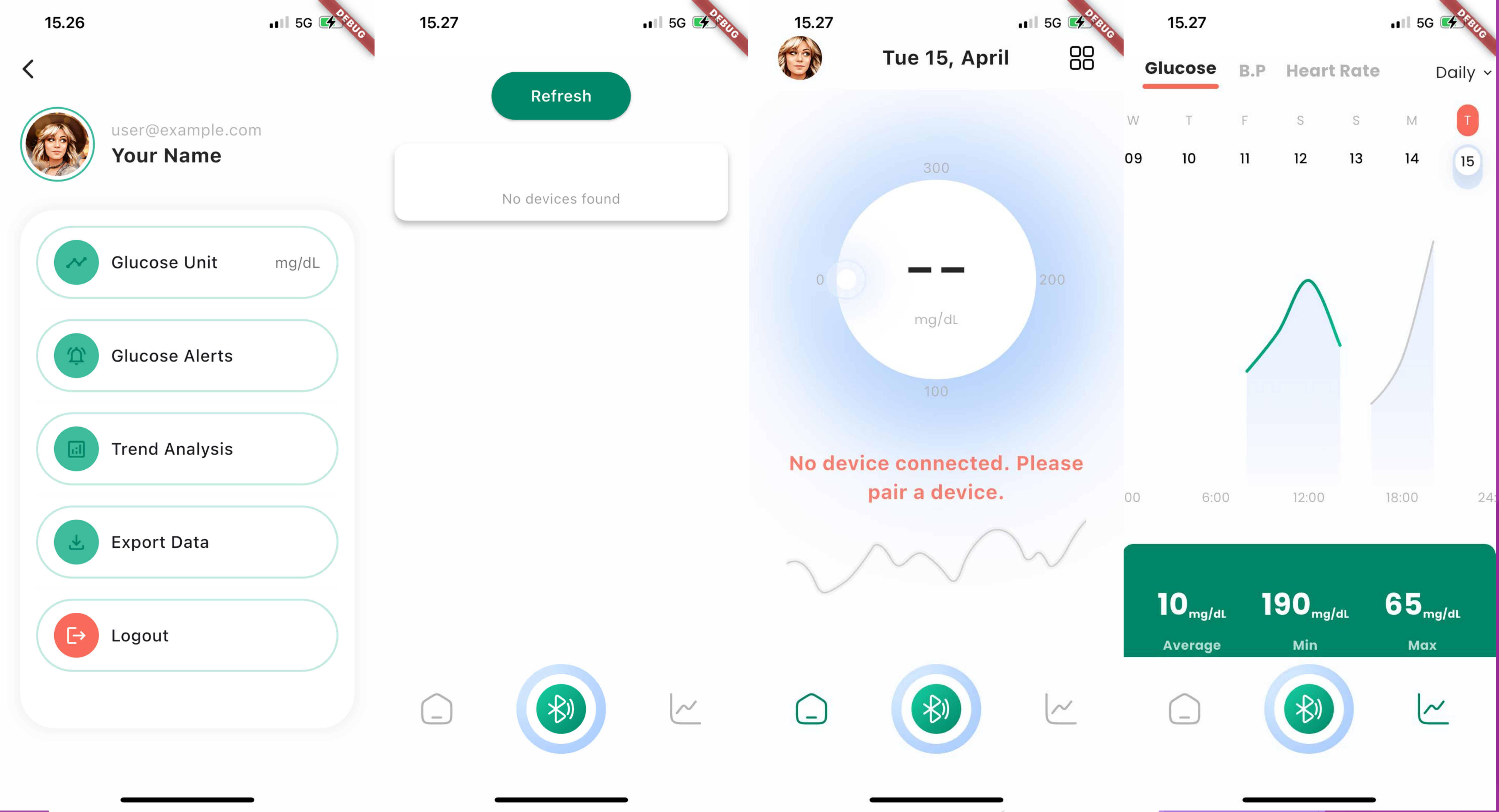
Start Measurement

00:00

Voltage	Temp (Â°C)	Humidity (%)
0.06V	21.6C	61.5%
0.00V	21.6C	61.5%
0.01V	21.6C	61.5%
0.00V	21.6C	61.5%
0.00V	21.6C	61.5%
0.07V	21.6C	61.5%
3.28V	21.6C	61.5%

Mobile App (Flutter)

- User settings
- BLE device pairing
- Real-time glucose animation
- Trend analysis



15.26
5G
DEBUG
user@example.com
Your Name
Glucose Unit
mg/dL
Glucose Alerts
Trend Analysis
Export Data
Logout
15.27
Refresh
No devices found
15.27
Tue 15, April
300
0
200
100
– –
mg/dL
No device connected. Please pair a device.
15.27
Glucose
B.P
Heart Rate
Daily
W T F S S M T
09 10 11 12 13 14 15
00
6:00
12:00
18:00
10 mg/dL
Average
190 mg/dL
Min
65 mg/dL
Max

Machine Learning Plan

System-Captured Raw Data:

- **Voltage from 4 wavelengths**
- **User data** (age, weight, skin tone, meal state)
- **Environmental data** (temp, humidity)

Engineered Features:

- Ratio: V_{1610} / V_{940}
- Subtraction: $V_{1550} - V_{1410}$

Real-World Considerations

Human tissue = more complex:

- Scattering, absorption, motion
- Need better **signal processing** and **correction**

Factors to monitor:

- Water absorption
- Temperature/humidity
- Skin type differences

Future Work

Test	Test on real tissue or blood
Train	Train ML model with real human data
Integrate	Integrate into wearable device (e.g. finger clip or ring)

Thank you!