SweeTech

Potentiostat-based Glucometer Development

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CBE 3300 - Final Demonstration
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Github Page

Github!

Project Overview

With diabetes on the rise, this project develops a potentiostat-based glucometer using amperometry for glucose detection.

Project Goals

01 Calibration

Development of sufficient redox-mediated calibration between glucose concentration and electrochemically produced measurement appropriate for instrumentation.

02 Hardware Development

Ensure compatibility between all components through various prototyping stages.

03 User-friendly Design

Design an easy-to-use, durable, portable glucometer.

04 Experimental Validation

Final product performs similarly compared to current available second generation glucometer.

Penn Engineering
UNIVERSITY of PENNSYLVANIA

Our Background

Paulina Bargallo

- **Main contributions:** GitHub documentation, Arduino GIGA and UI development

- No GitHub experience
- Minimal C++ exposure from 3300A (with Arduino Uno)
- Minimal serial communication exposure from 3300A

Theertha Vannemreddy

- **Main contributions:** Mechanical Design, Error grid generation and Display features

- CAD and Solidworks knowledge
- Introductory python knowledge
- Minimal C++ exposure from 3300A

Kayla Powell

- **Main contributions:** IO Rodeostat configuration and glucometer operation

- Beginner python user
- Minimal serial communication exposure from 3300A
- Signal processing novice

Background

Market Landscape

537M

Adults have diabetes globally

1/10

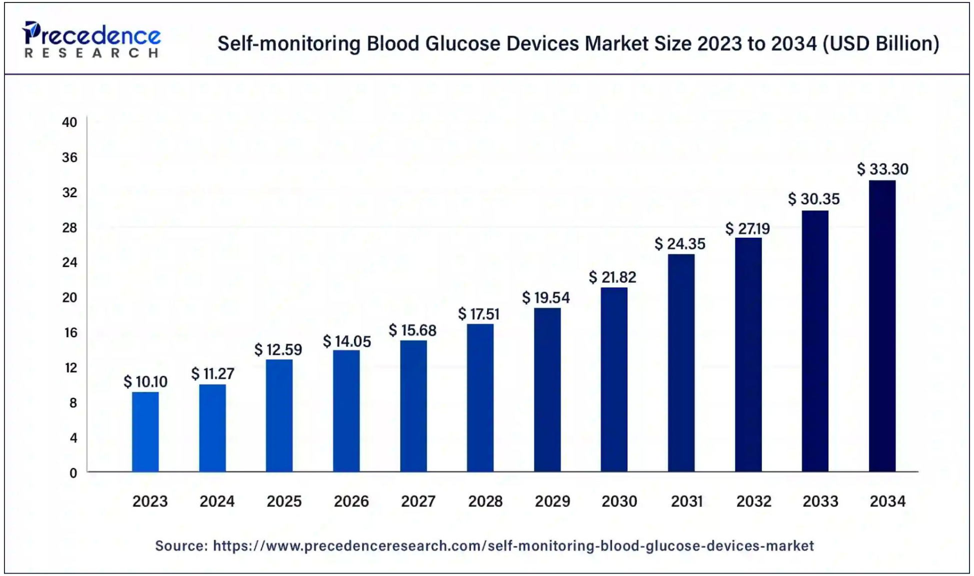
Adults need regular glucose monitoring

1.5M +

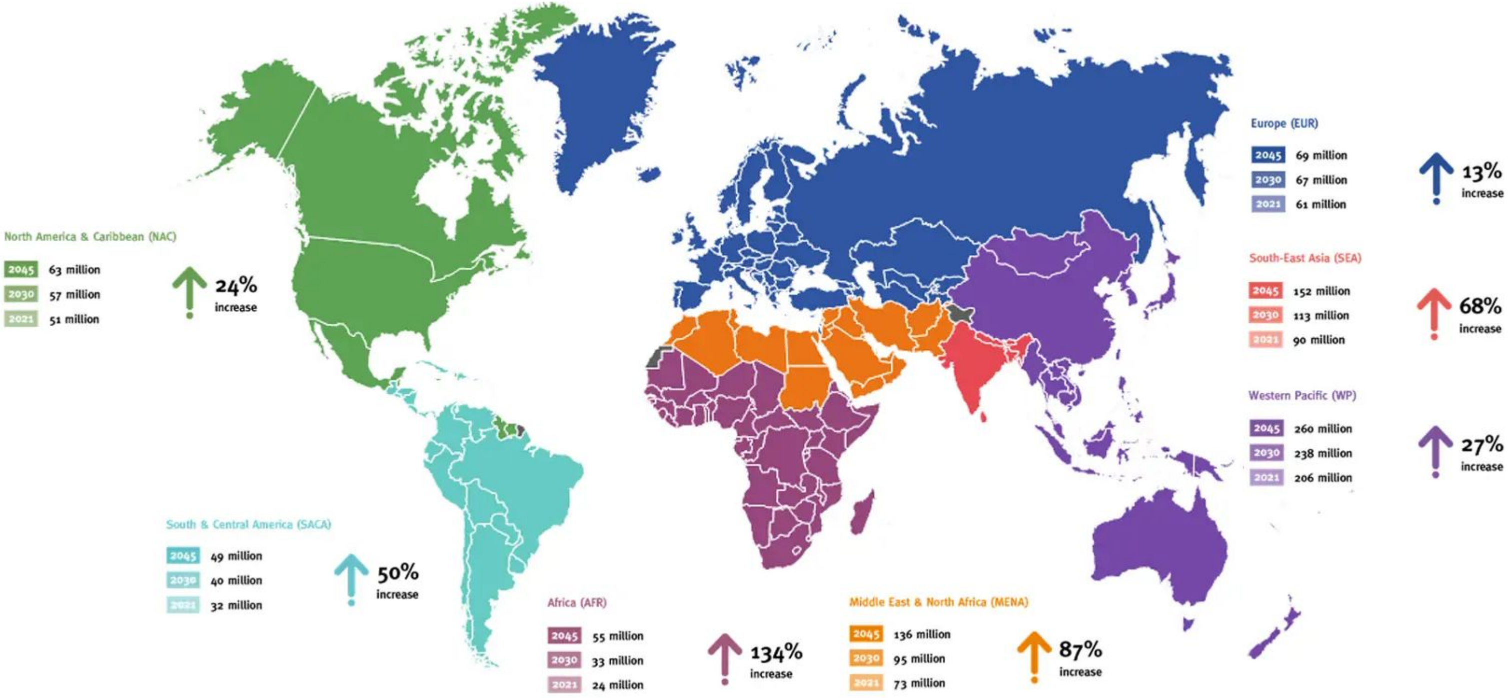
Deaths annually due to diabetes

$12.6B

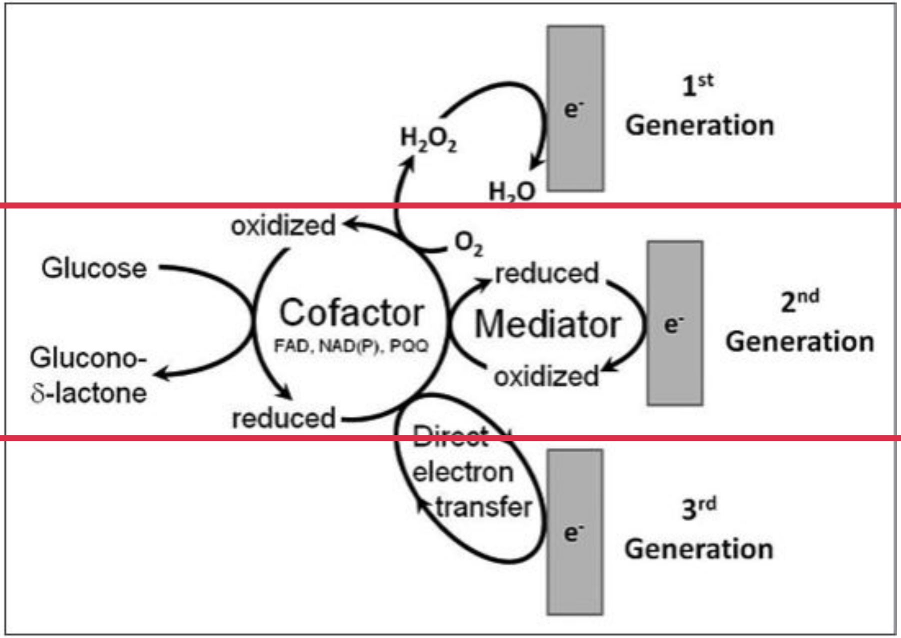
Global Market Size (2025)



Global glucose monitoring market trends



How do glucometers work?



Converting current to concentration

- Electrochemical reactions occur on biosensor
- Redox-mediated electron transfer introduced to improve efficiency, accuracy
- Chronoamperometry for selective re-oxidation of mediator
- Signal analysis using **Cottrell equation**

$$i = \frac{nFAc_j^0\sqrt{D_j}}{\sqrt{\pi t}} \longrightarrow i \; \alpha \frac{1}{\sqrt{t}}$$

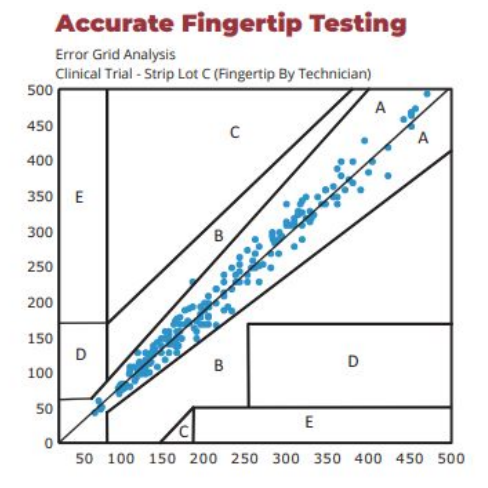
  - Current depends on diffusion rate
  - Ideal for simple redox events
  - slope → concentration calibration
  - Relate [Mediator] ~ [Glucose]

AimStrip® Plus Glucose Meter and Strips

Important meter functions

- Reliable, Accurate Results in 10 Seconds
- Only 1µL Blood Sample Required from Fingertip or Forearm Testing
- Single Code Chip for the Life of the Meter
- Memory Allows up to 300 Records with Date and Time
- English & Español Instructions

Diagnostic performance



The AimStrip® Plus Blood Glucose Test Strips is stored in a sealed vial with desiccant. Each test strip contains the following chemicals:

Glucose Oxidase	**CAS Number:** 9001-37-0	**Concentration:** <25IU
Mediator	**CAS Number:** 13746-66-2	**Concentration:** <30µg

← GOx with $K_3[Fe(CN)_6]$

Development Process

Analysis Flowchart

Data Analysis Workflow

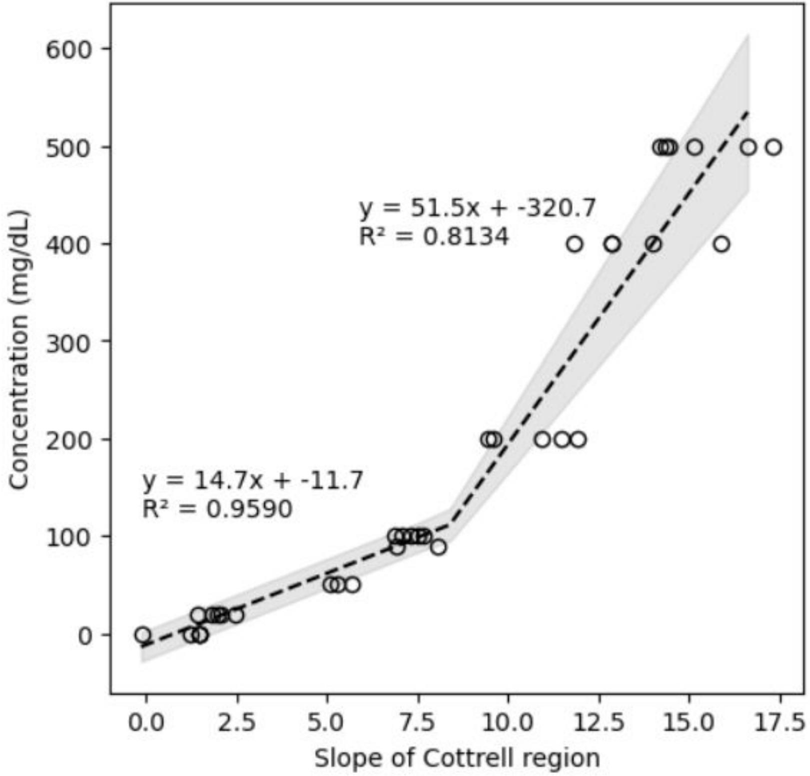
1. Import chronoamperometry data (time, voltage, current).
2. Mask and smooth current post-step application.
3. Detect Cottrell behavior via regression on current vs 1/√t.
4. Identify best-fit region (highest R^2) and extract slope.
5. Test calibration models: linear, polynomial, and piecewise.
6. Validate accuracy using Clarke Error Grid.

Validates diffusion-controlled CA testing conditions

Analytical Method

Final methodology:

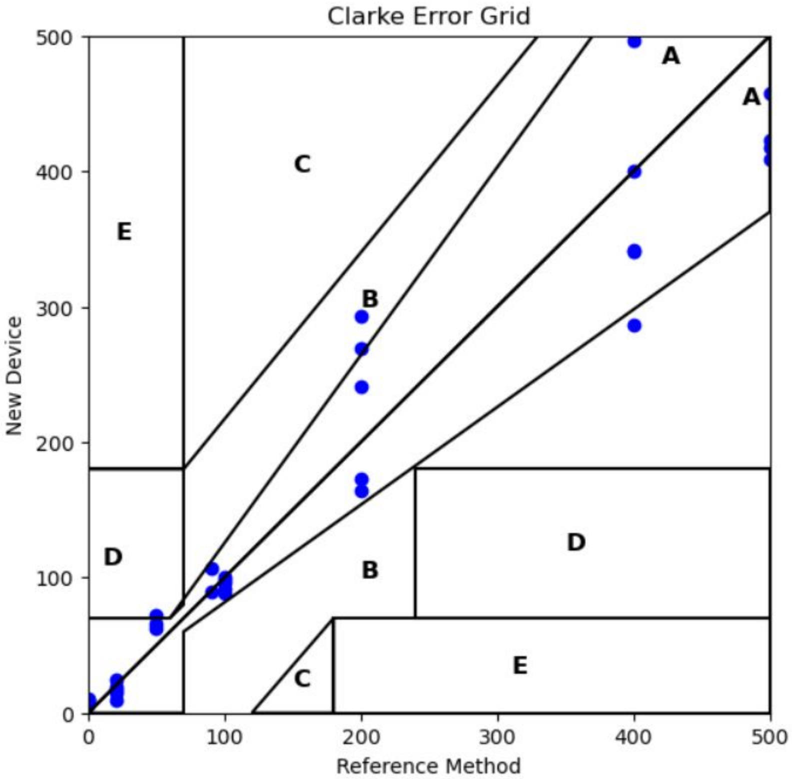
1. 6 second quiet time
2. 200 mV constant potential step
3. Collect data once step is applied
    a. Sample rate 10 Hz
    b. 50 ms after step
    c. 500 ms window
4. Smooth data, get linear regression of i vs 1/√t
5. Apply piecewise calibration (slope → glucose concentration)
6. Store data in excel workbook
7. Send glucose reading to Arduino



Accuracy Standards

- **ISO 15197:2013** (user performance evaluation for 95% of samples)
  - <100 mg/dL: ± 15 mg/dL
  - ≥100 mg/dL: ± 15% error

- **Clarke Error Grid**
  - Compares new device to reference device
  - Plasma vs whole blood calibration
    - Buffered glucose samples
    - HPLC as reference
  - Still useful calibration validation tool during developmental stages



Our Glucometer Design

IO Rodeostat: Open Source Potentiostat

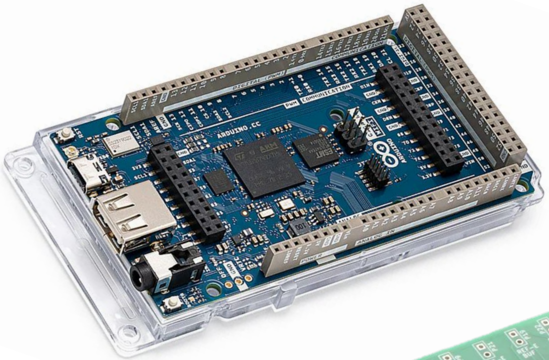
- Digitally-controlled with python Potentiostat library
- Supports chronoamperometry
- Supported by **Adafruit ItsyBitsy M4**

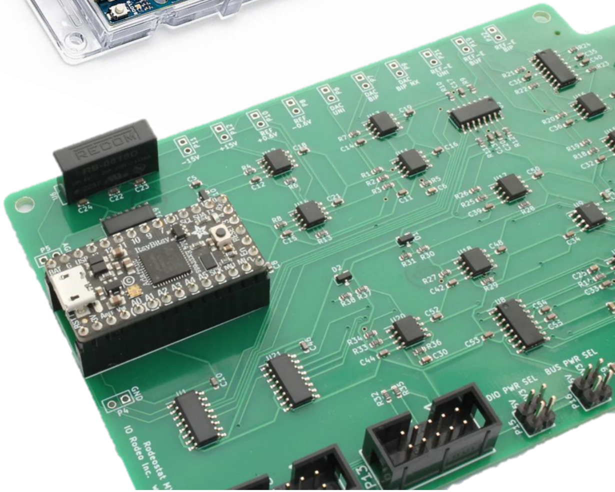
Hardware selection

- **Arduino GIGA R1 w/ Display Shield**
  - High resolution and touch-screen function
  - Python support for integration
  - 2 MB internal flash memory

3D printing

- Test strip connection
- Sturdy design for practical use and secure integration of components





Arduino GIGA Set-up

Hardware

- **Arduino GIGA R1 WiFi Board**: Serves as the main microcontroller.
- GIGA Display Shield: Features a 3.97" 480x800 RGB touch screen, mounted on the bottom side of the GIGA R1 WiFi board.

Software

- 'Arduino Giga Display' libraries.
- Test Examples:
    - RGB LED Test
    - Touch Screen Test
    - LCD Screen Test
    - LVGL Demo: Demonstrates interactive UI elements.

2. Development of our own UI based on test samples and our requirements

Display Logic Overview

Data Processing

Arduino: Analog to digital conversion

Apply serial communication
 to get mg/dL values

Python Integration

Python generates CSV → Sends via serial

Arduino receives and updates display

Displaying Data

Show concentration value as text

Depending on the value we have a color coding on what the value means for the user.

User Interface

Touchscreen buttons/sliders with LVGL

Usher selection

Display of concentration

Return to home page and new reading

Concentration Display

The glucose concentration display dynamically changes color based on real-time sensor readings. The background of the info panel adjusts to reflect risk zones, providing immediate visual feedback to the user:

- 🟡 Under 70 mg/dL: Hypoglycemia warning (yellow)
- 🟢 70–99 mg/dL: Normal fasting (green)
- 🟠100–125 mg/dL: Prediabetic risk (light red)
- 🔴 126–250 mg/dL: Diabetic range (deep red)
- ⚠️ Over 250 mg/dL: Critical level alert (dark red)

User Interface Workflow

Workflow

1. User starts of the display and selects user or creates new user.

   Dips test strip into solution.

   Run python on computer

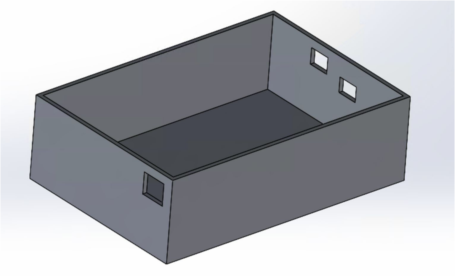
2. Glucose Concentration Received by Arduino

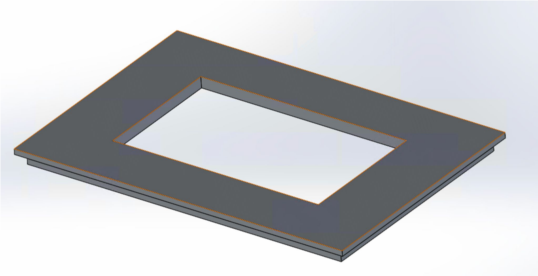
3. Process Data for Display (formatting, units, range checks)

4. GIGA Display Shield Outputs Concentration Value and Interprets the Value through colors

Packaging Design Process

1. CAD the two parts using SolidWorks.
2. Convert the CAD files into 3D-printable formats (e.g., STL, 3MF).
3. Send the files to a 3D printer and fabricate the part with PLA
4. Make necessary design adjustments based on evaluation feedback. *(7 iterations)*
5. Continue the cycle as needed for further refinement.



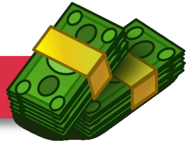


Comparison and Feasibility

Cost Analysis

Component	Cost
IO Rodeo Rodeostat	$240
Arduino Giga R1 Wifi	$73
Arduino GIGA Display Shield	$64
Wires + 3D printing estimates	$25
Needs a Laptop	$1000**
Total Cost of SweeTech	~$402

Cost of Industry Glucometer

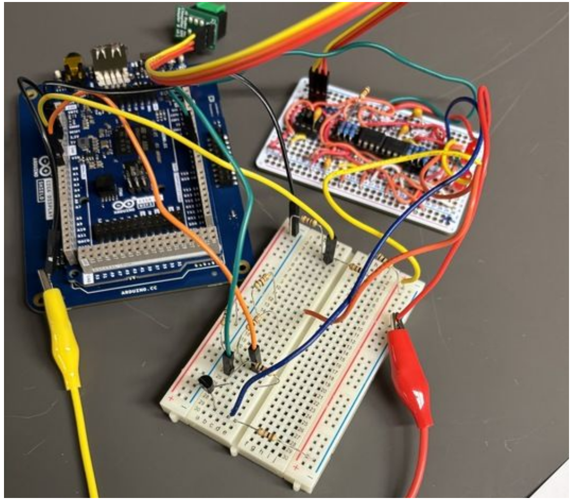


~$20

Clearly, we are not anywhere close to an industry standard device, but that is okay. We did learn a lot though :)

Conclusion and Lessons Learnt

Homemade Potentiostat Vs. IO Rodeo Potentiostat



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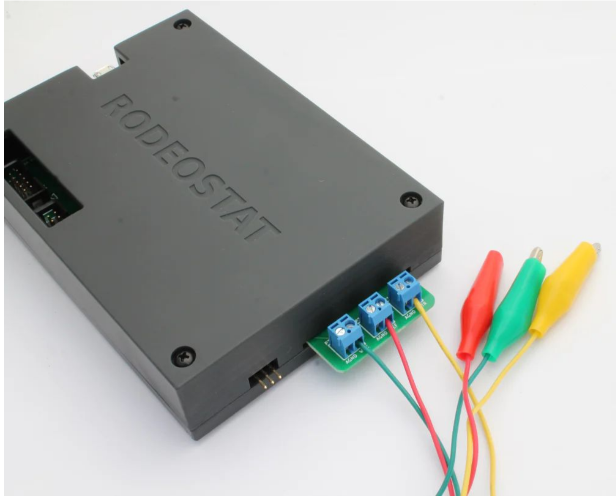
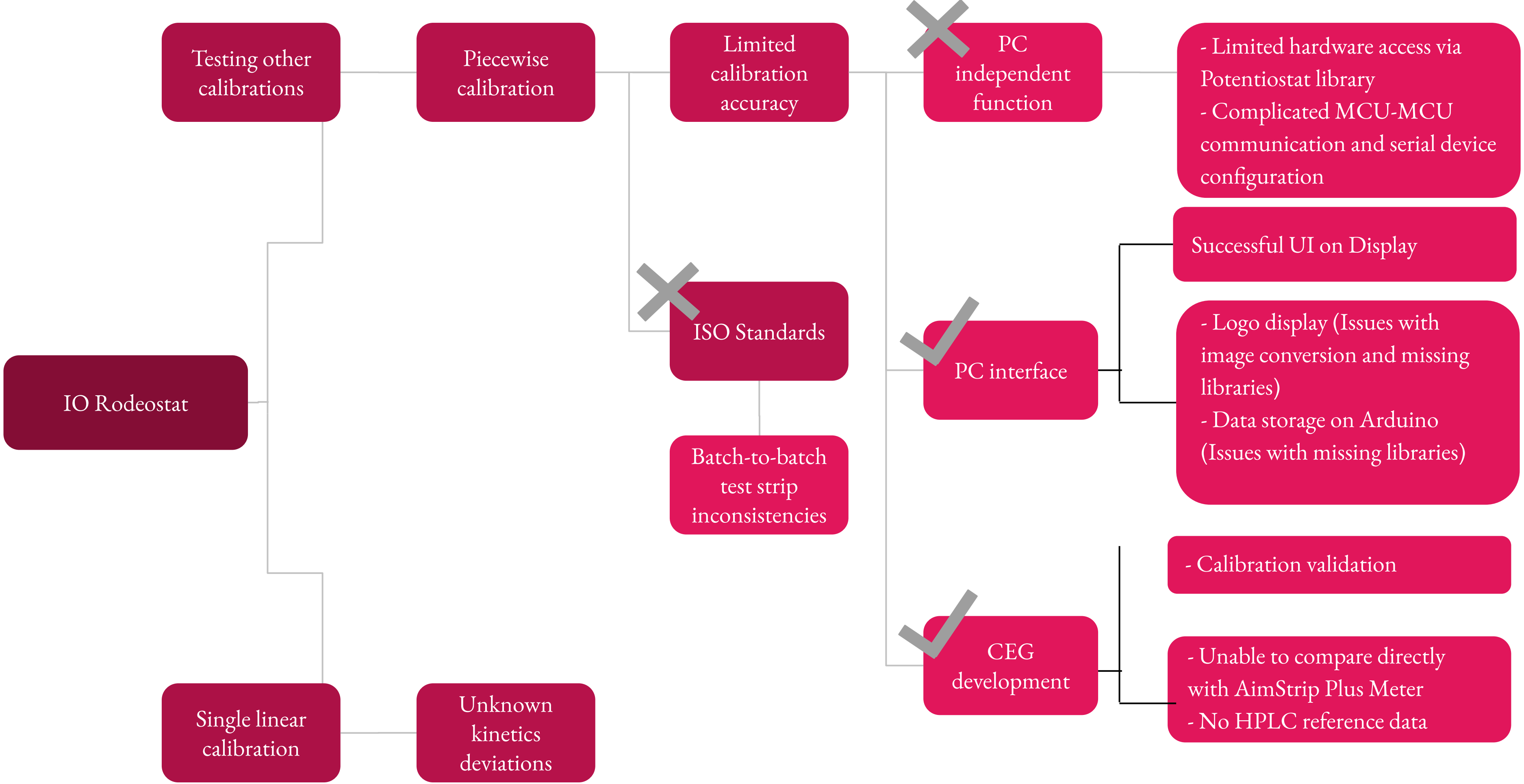


Challenges We Faced and Design Choice Workflow

Homemade Potentiostat

Conversion from Arduino UNO R3 to Arduino GIGA R1

- Complicated adjustments to the original circuit
- Too many Arduino code modifications


IO Rodeostat
Testing other calibrations
Piecewise calibration
Limited calibration accuracy
PC independent function
- Limited hardware access via Potentiostat library
- Complicated MCU-MCU communication and serial device configuration
ISO Standards
Batch-to-batch test strip inconsistencies
PC interface
Successful UI on Display
- Logo display (Issues with image conversion and missing libraries)
- Data storage on Arduino (Issues with missing libraries)
CEG development
- Calibration validation
- Unable to compare directly with AimStrip Plus Meter
- No HPLC reference data
Single linear calibration
Unknown kinetics deviations

Conclusion

A potentiostat CAN be used to create a glucometer ✓

Innovative Design

- Developed glucometer using a potentiostat and CA for real-time glucose detection.
- Integrated electrochemical sensing for improved sensitivity

Feasibility and Scalability

- Ideal for academic settings.
- Not currently scalable for consumer use due to manual operation, bulkiness, and lack of automation.

Impact

- Valuable as a learning tool
- Encourages multidisciplinary thinking by blending hardware design, coding, and analytical chemistry.

Improvements

- Get rid of need for a laptop
- Miniaturize hardware
- Automate workflow
- Calibrate to blood
- Include flash memory storage

Potentiostat-Based Glucose Meter

Thank You!

Any Questions?

CBE 3300
Team SweeTech