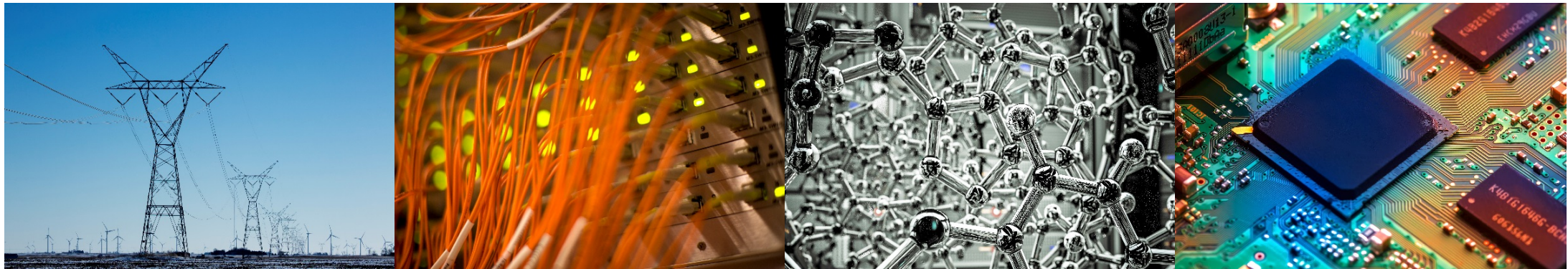


Low-Cost Thermal Cycler for LifeFoundry, Inc.

Yuanjiu Hu, Pei Liu, Shaoyu Meng

ECE 445 Fall 2017 Group 1



Introduction



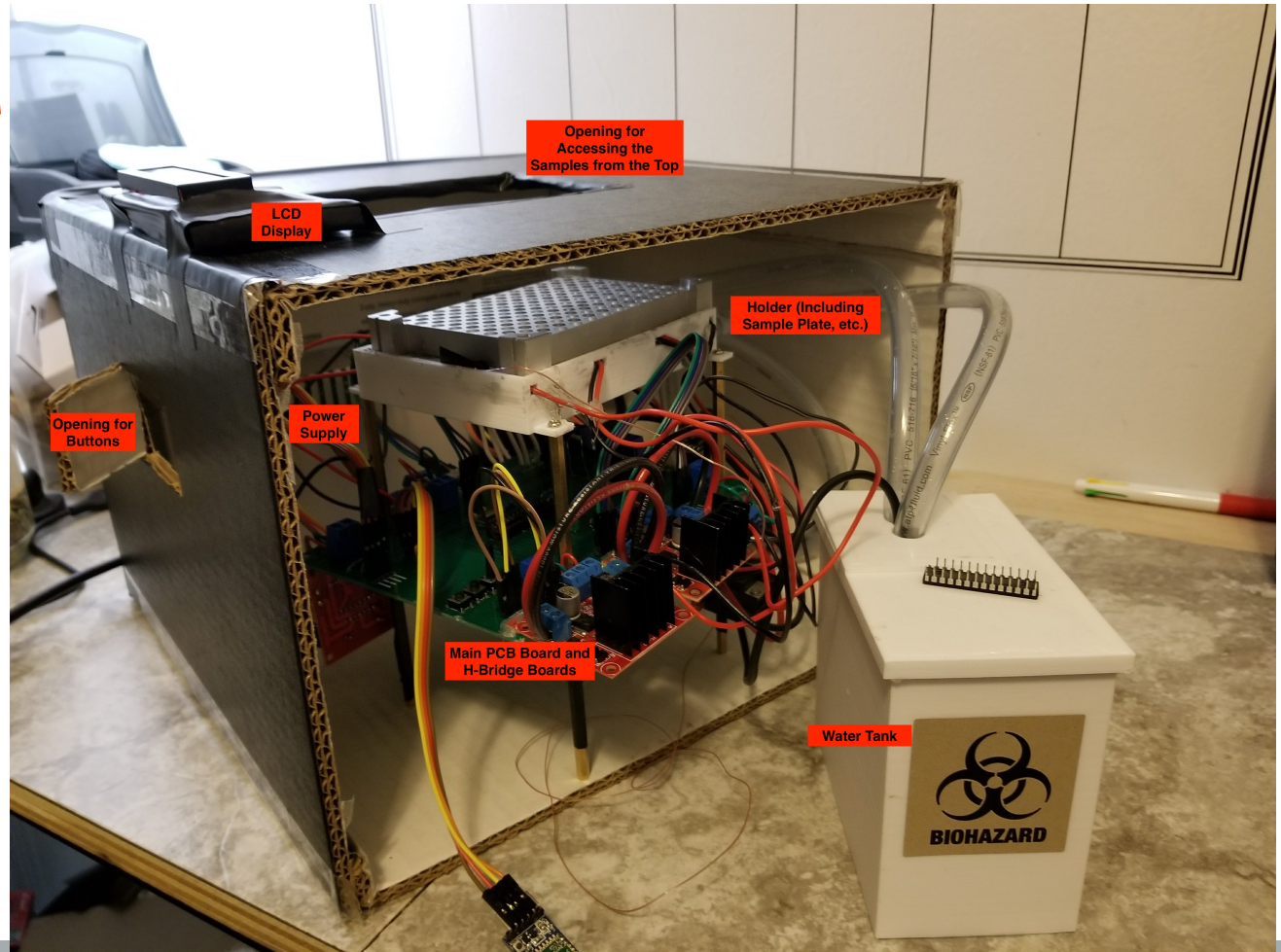
- Thermal cyclers are used to conduct polymerase chain reactions (PCR), a method to amplify DNA segments
- Current commercial thermal cyclers are very expensive, ranging from \$5,000 to \$10,000

Objectives

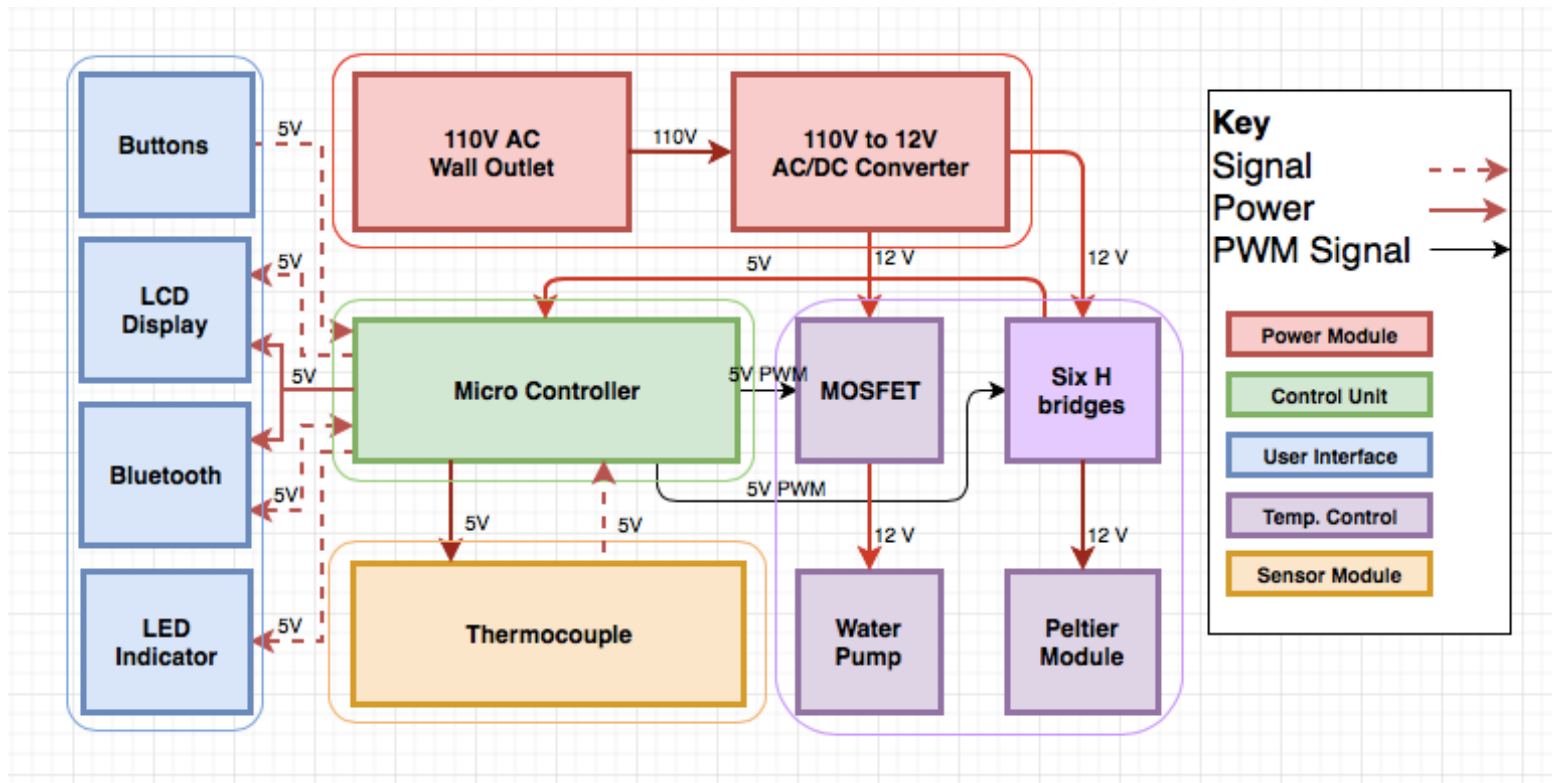
- Create a low-cost thermal cycler under a budget of **\$400**
 - Sponsored by LifeFoundry, Inc.
- Support **30** continuous cycles on **96** samples simultaneously
 - Commercial grade
- Use **water cooling** for superior heat removal efficiency
 - Scalable and end user ready

Finished Product

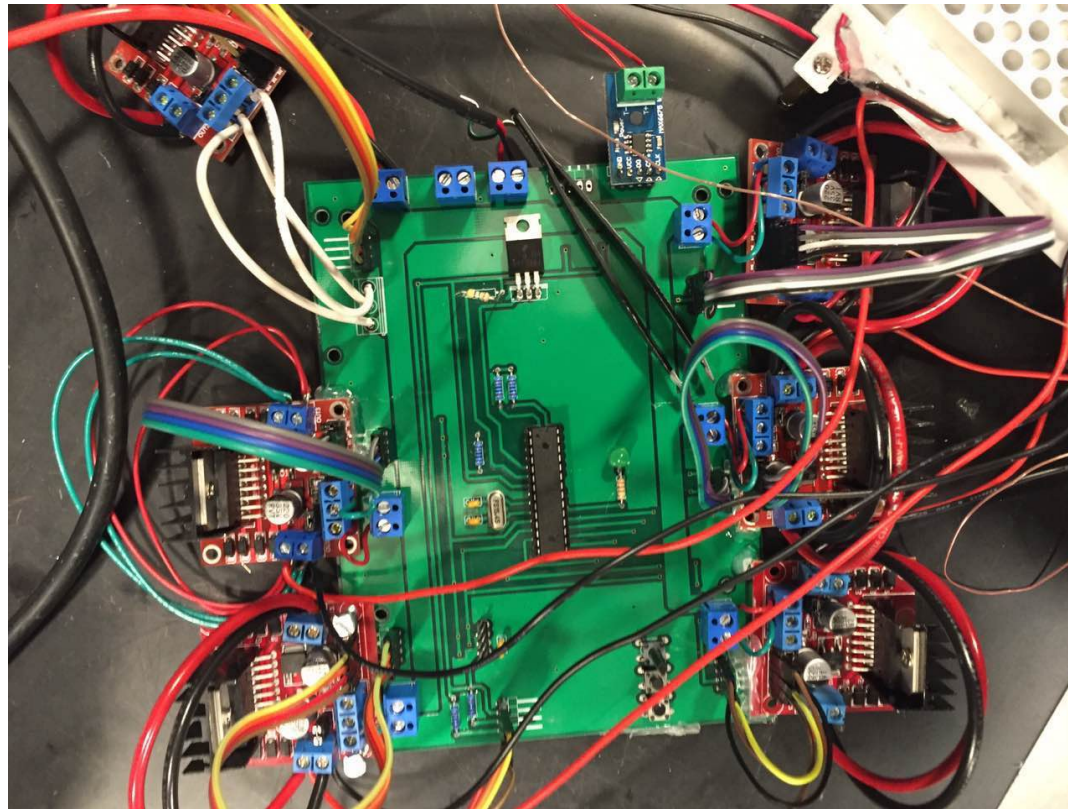
- Recycled cardboard casing
- Sample plate is put on the top
- LCD display is facing user
- Power supply is self-contained



Block Diagram

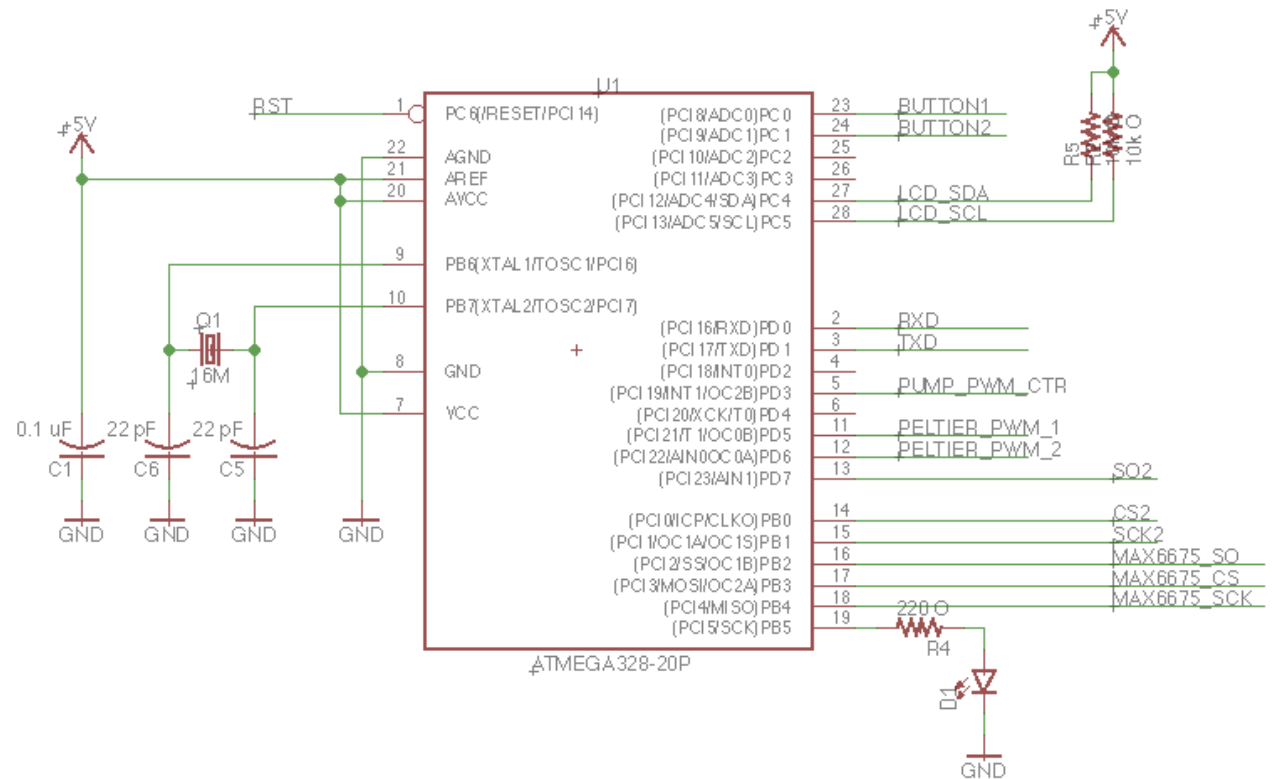


Hardware - Overview



Microcontroller ATmega328P

- Various communication protocol
- Pulse width modulation (PWM)
- Fast clock speed



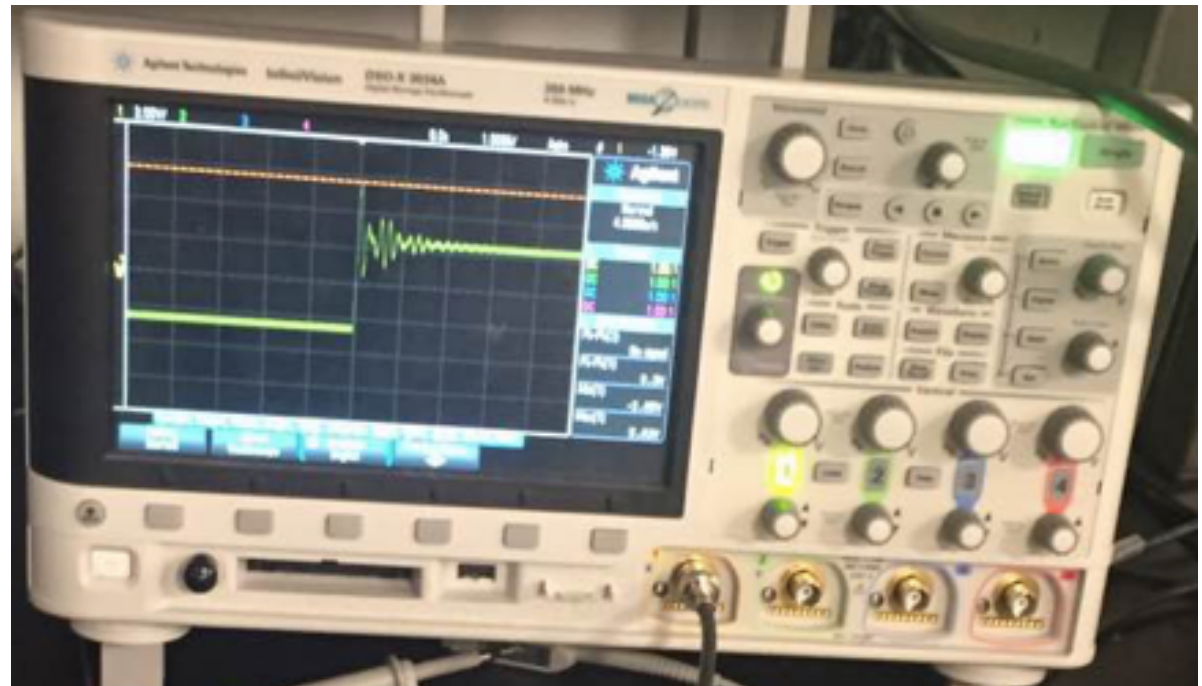
Microcontroller - Challenge

- Low memory to store large program
- Solution:
 - Compress program by using shared function
 - Reduce total number of variables

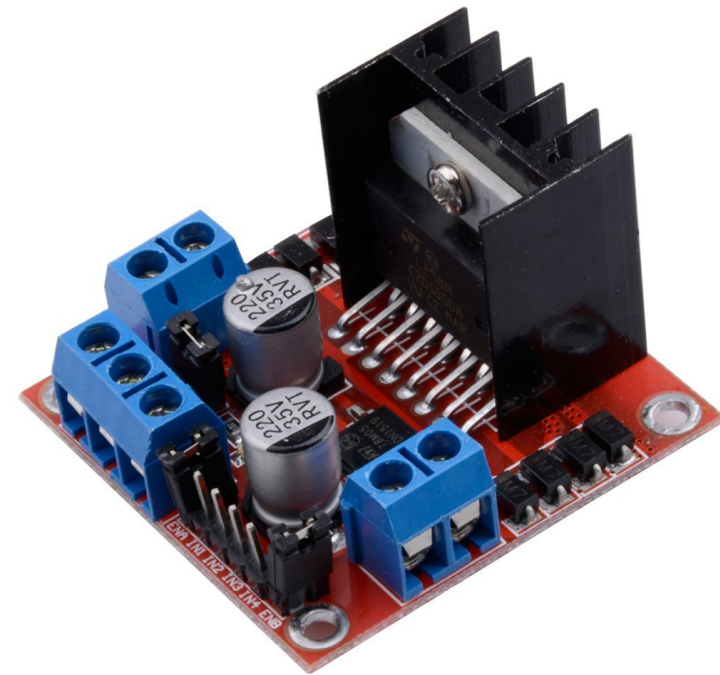
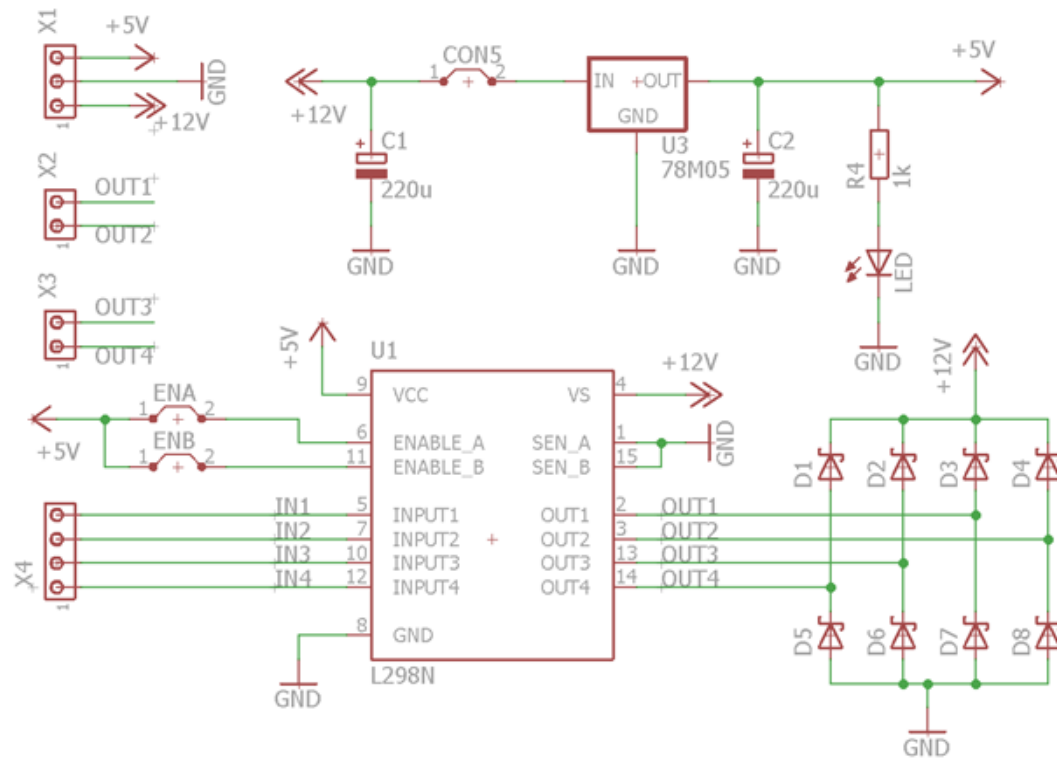
PWM Signal

- Oscilloscope displays output accordingly as the MCU sends PWM with different duty cycle

$$V_{\text{rms}} = \sqrt{\frac{1}{T} \int_0^T (V(t))^2 dt}$$

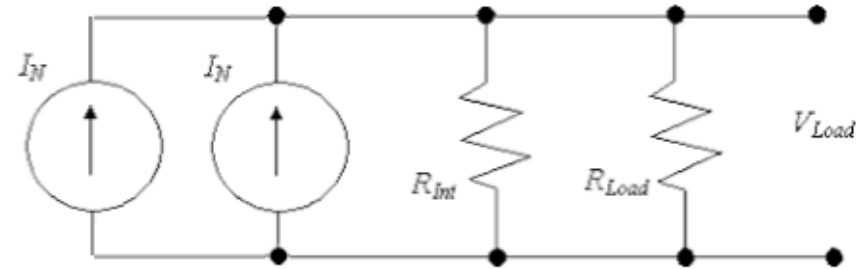


H Bridge L298N



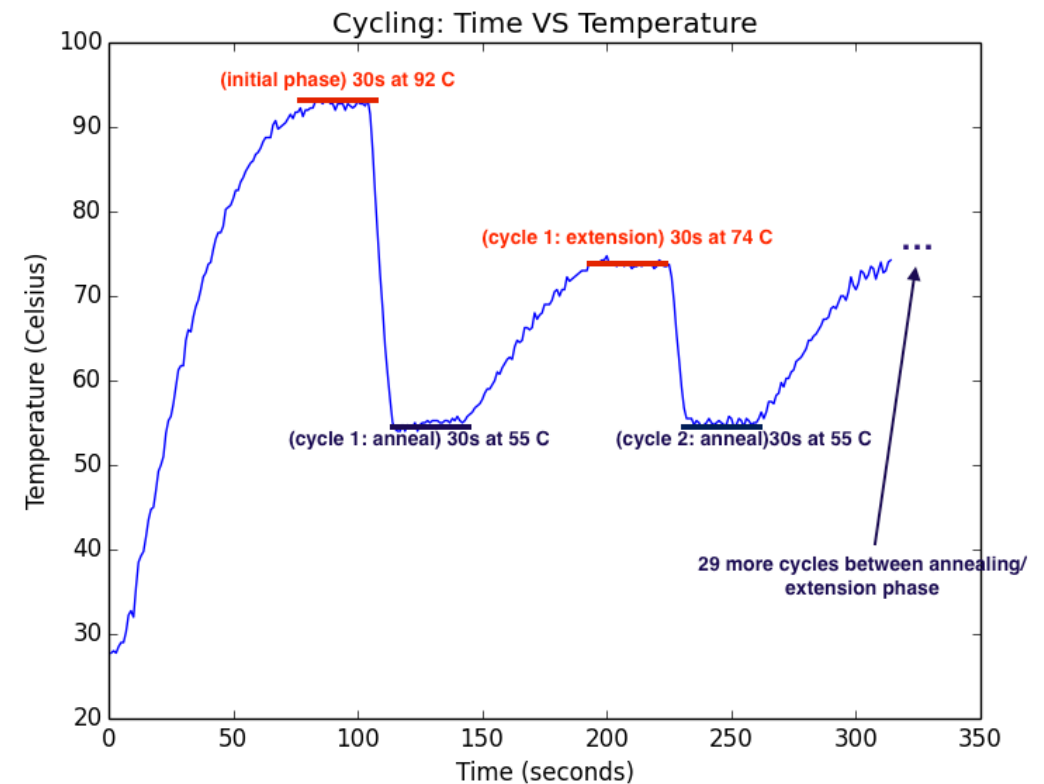
H Bridge - Challenge

- No large enough current supported
- Solution:
 - Parallelize inputs and outputs
 - Use H bridge support large current

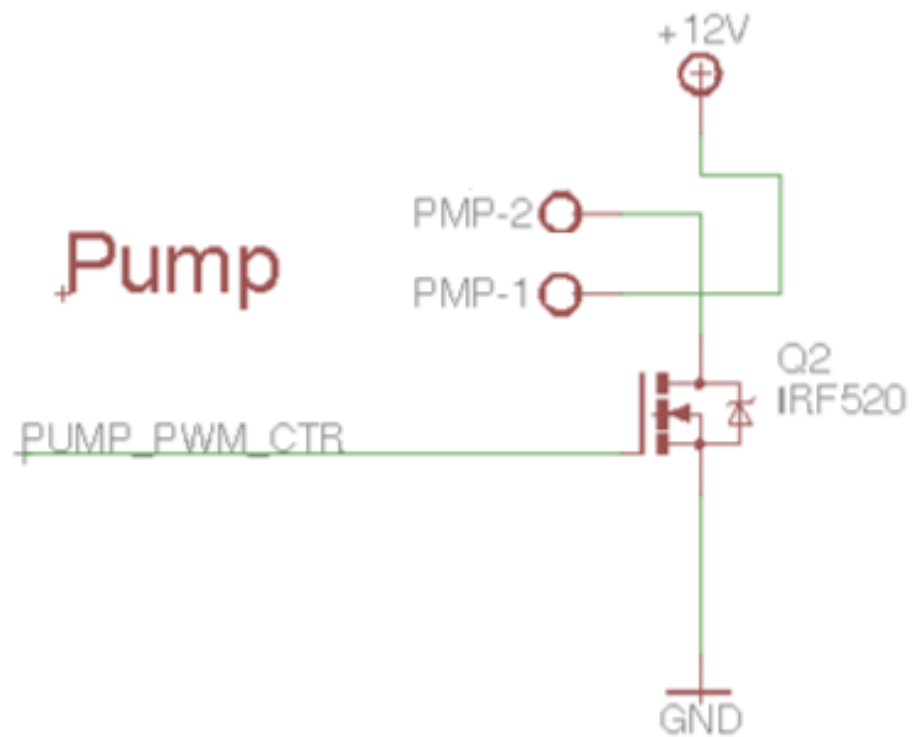


Peltier Target Temperature - Verification

- Heat to 92 °C with ~100% duty cycle
- Maintain 92°C with ~95% duty cycle
- Cool down with reversed signal direction



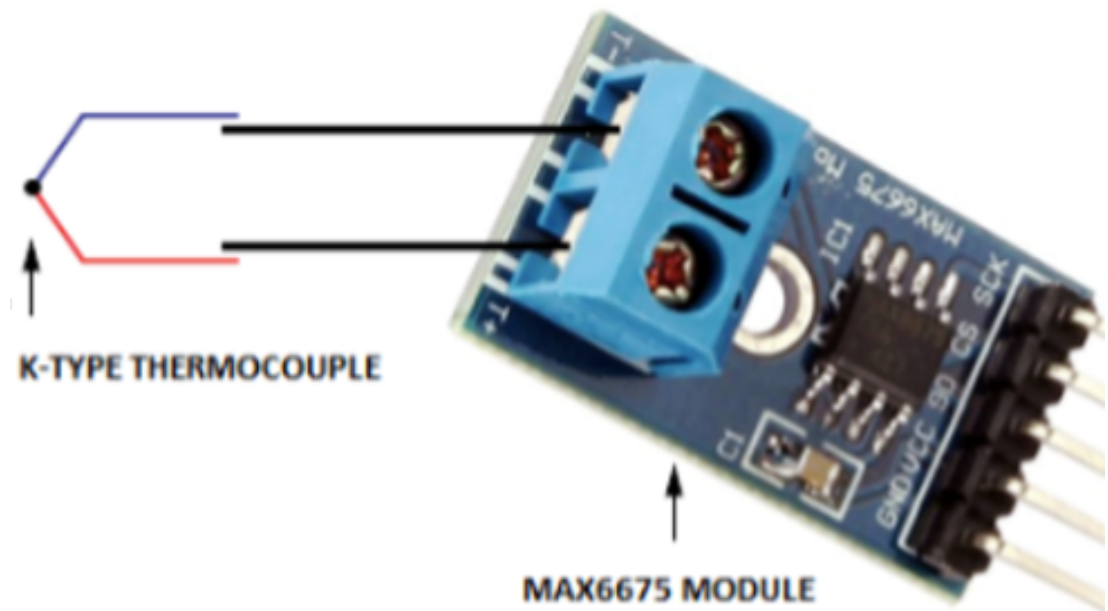
Water Pump



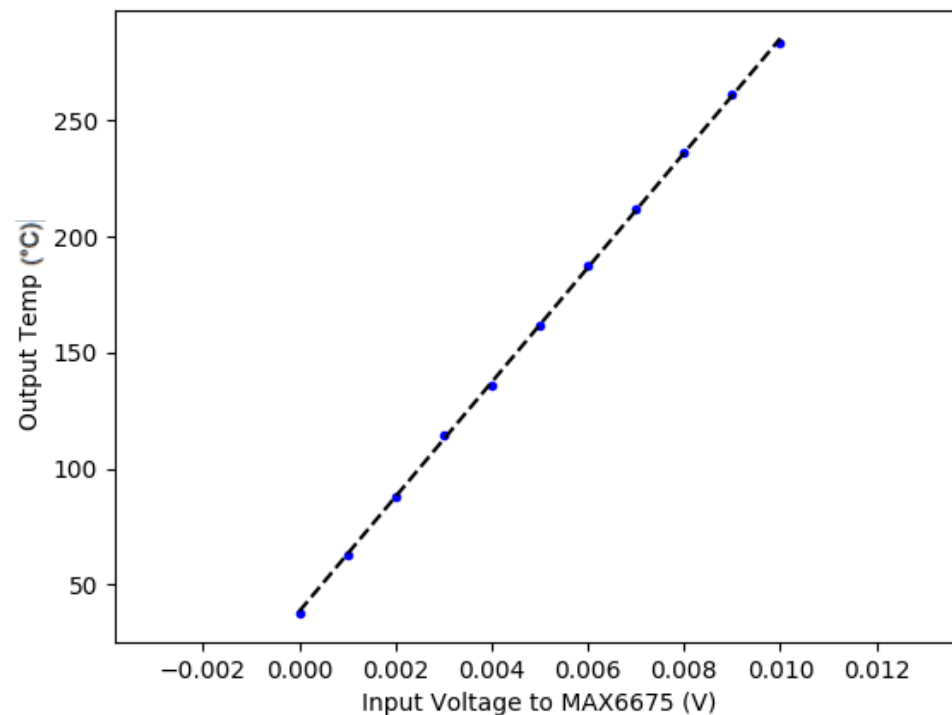
Thermocouple and MAX6675 ADC

Goal:

- LCD and app displays temperature information
- Reading error between IR thermometer and thermocouple is less than 5°C
- Able to detect disconnect



MAX6675 ADC - Testing

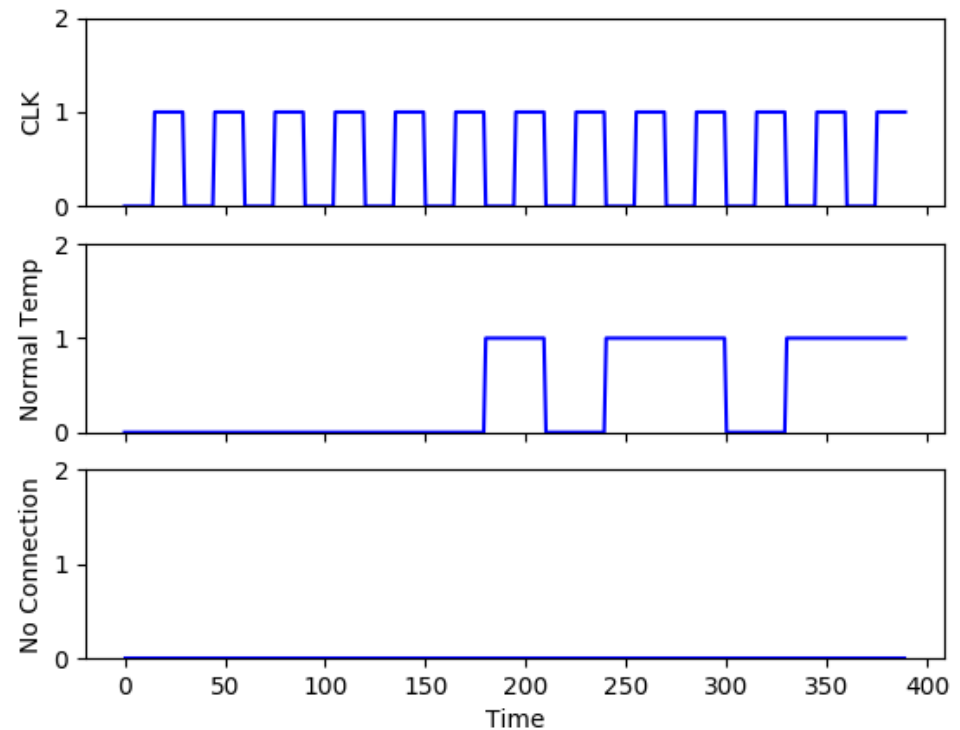


Attribute	Value
R^2	0.99
Slope	24677.27
Intercept	38.47

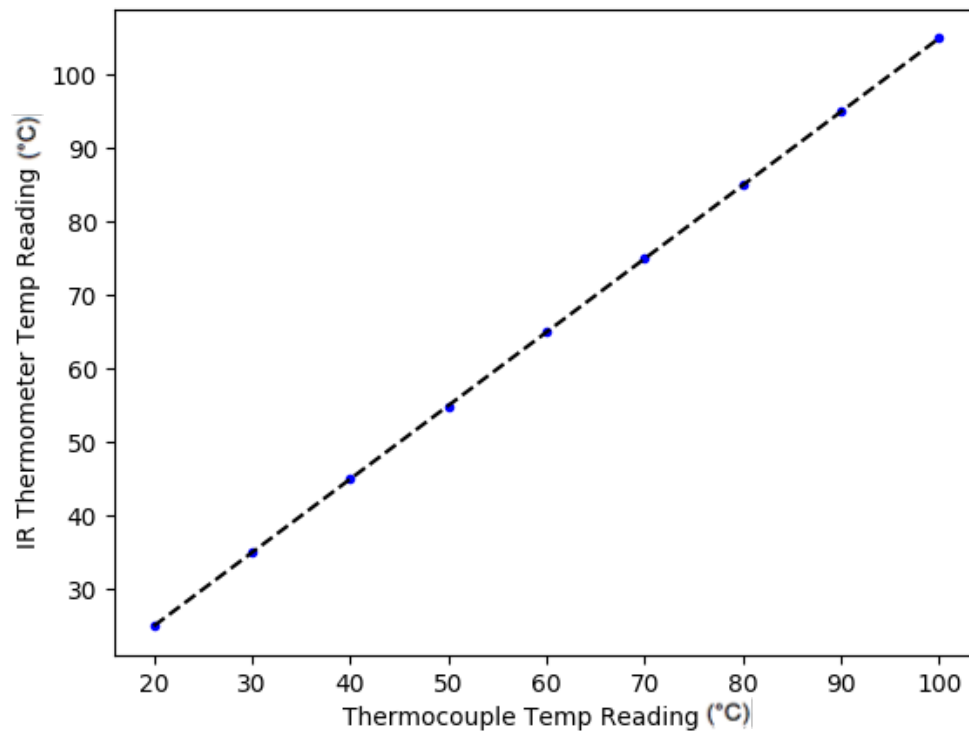
MAX6675 - Verification

Two digit precision

- 22.75 is 010110.11 in binary form
- Not connected is flat zero

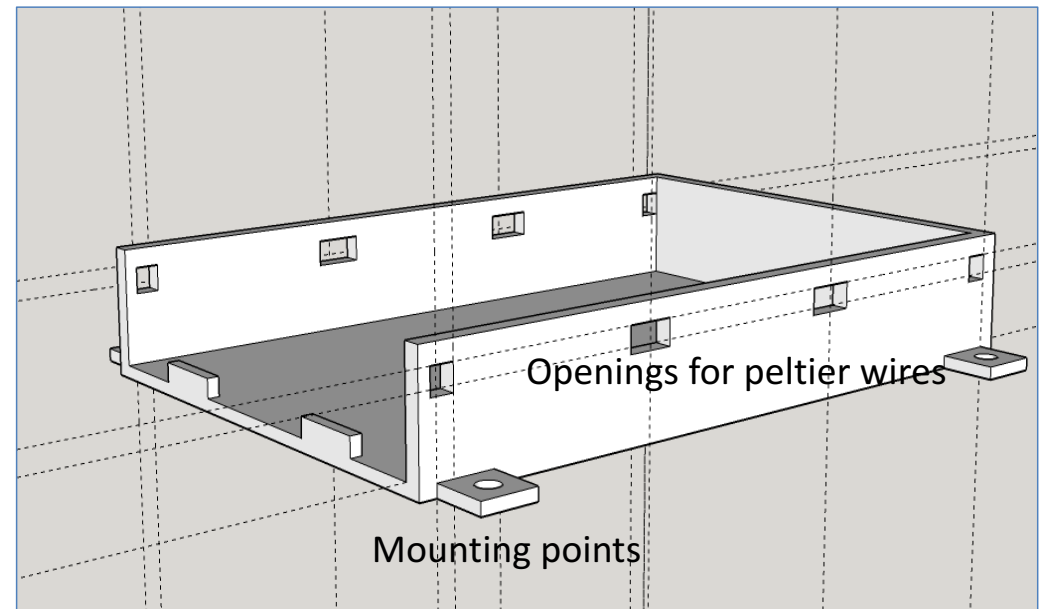
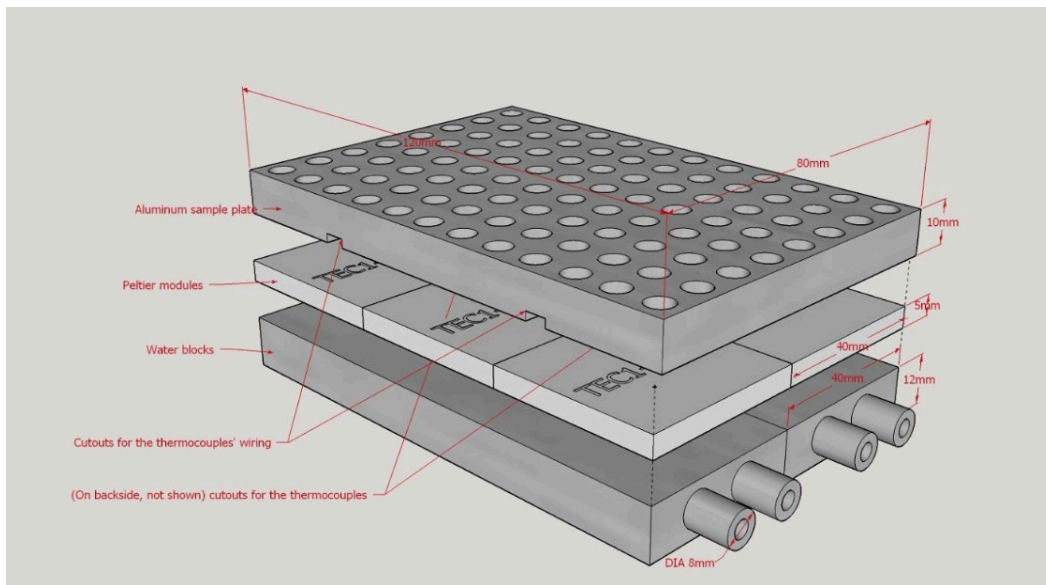


MCU Offset - Adjustment

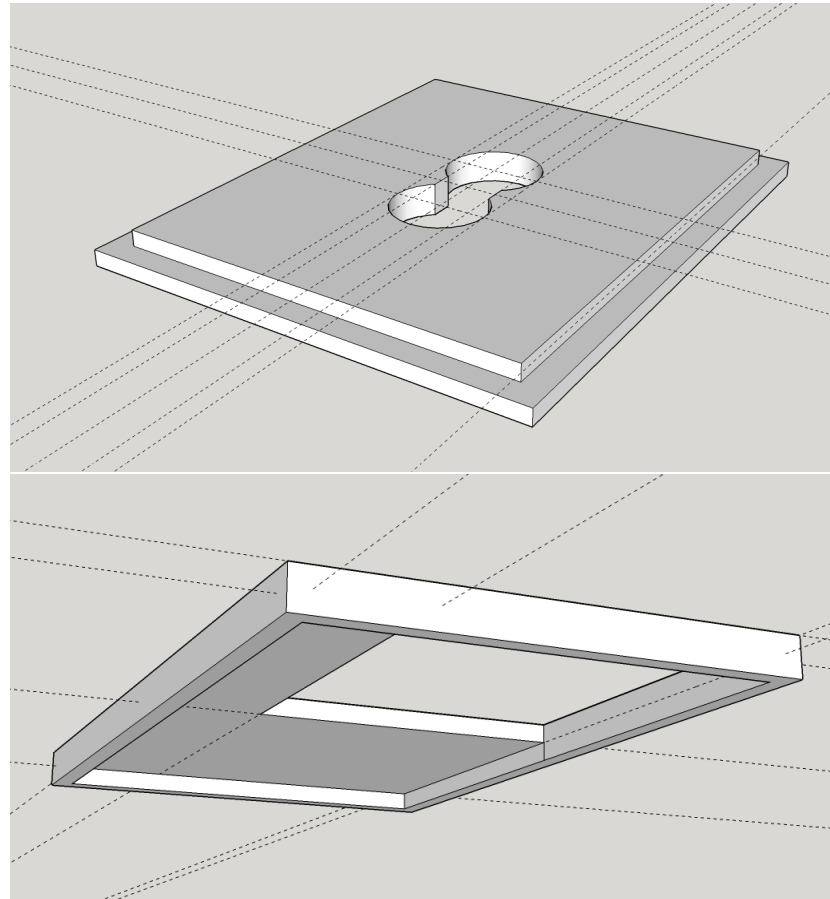
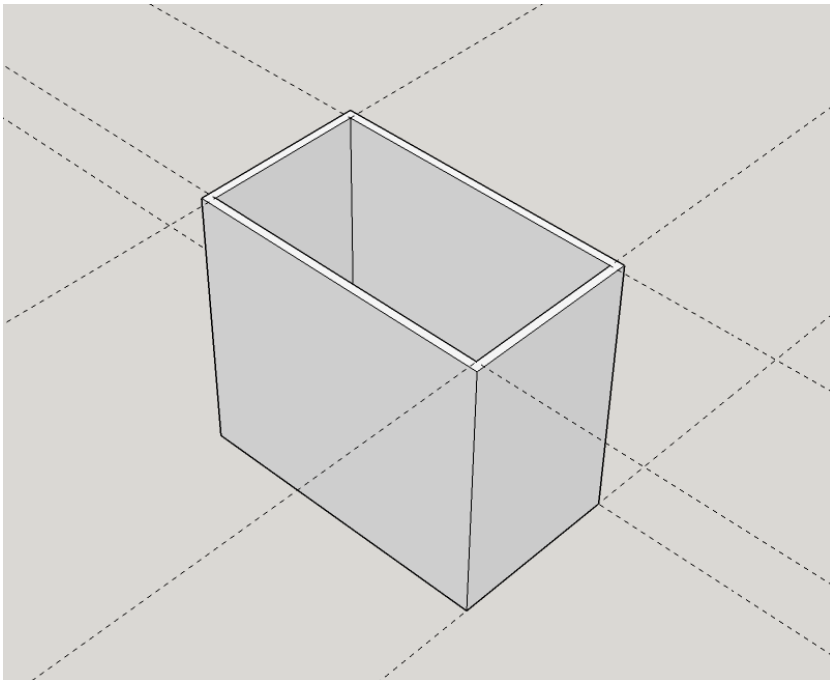


Attribute	Value
R^2	0.99
Slope	0.99
Intercept	5.02

Stacked View



CAD – Water Tank

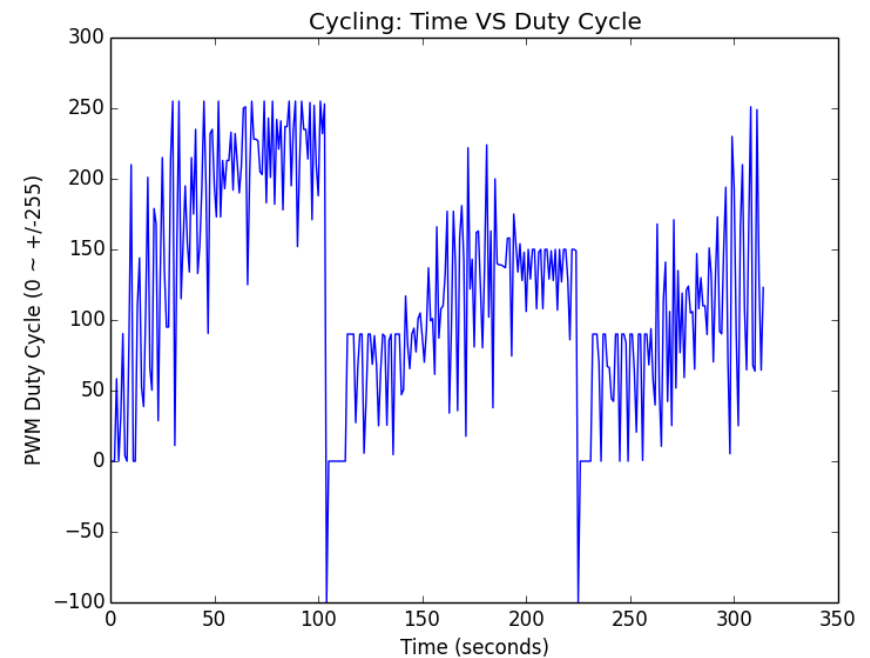


Software – PID Introduction

- Proportional, integral, derivative
- Determines output predictively based on past data
- Useful for controlling temperature precisely
- Minimizes overshoot and fluctuation

PID Implementation - Overview

- Used PID library by Brett Beauregard
- Input: thermocouple reading
- Output: PWM value for Peltier modules (0~255)
$$u(t) = K_p e(t) + K_i \int e(\tau) d\tau + K_d \frac{de(t)}{dt}$$
- K_p , K_i , K_d are tuning parameters that vary in different applications

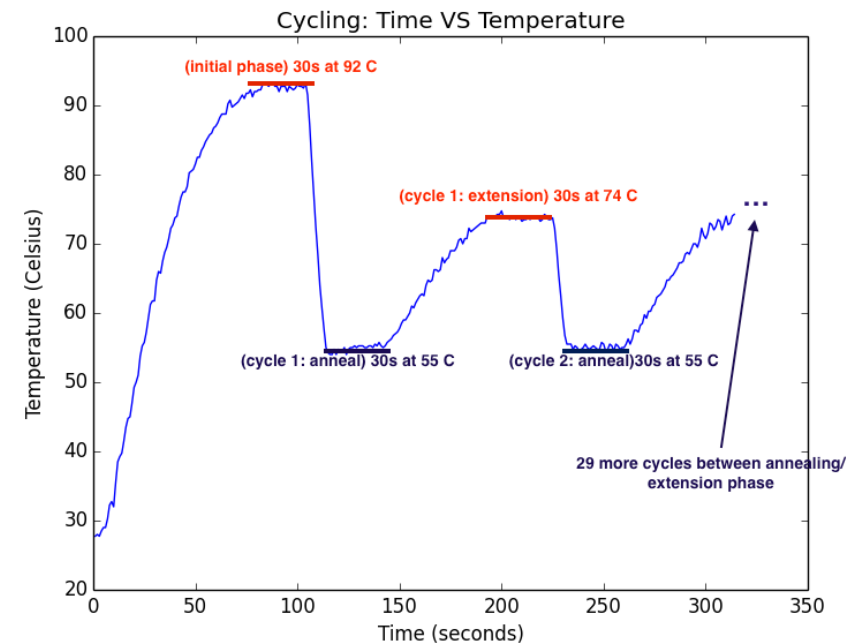


PID Implementation - Tuning Parameters

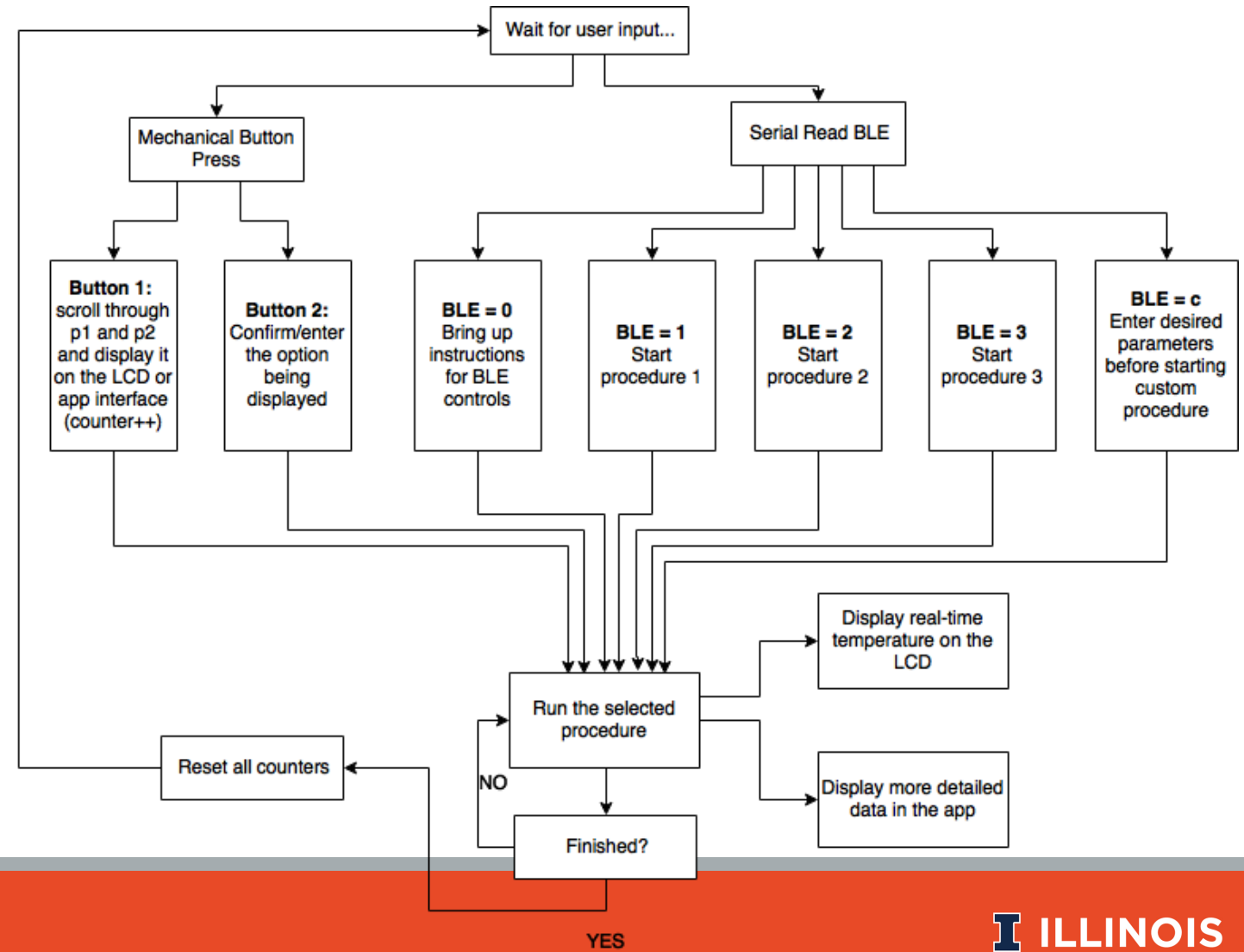
- The aluminum attached to Peltier modules has a significant heat capacity
- This heat capacity results in thermal inertia
- Thermal inertia → delay → overshoot
- Repeated experiments of tuning the K_p , K_i , K_d parameters to minimize this effect
- Smaller K_p larger K_d

PID - Requirement / Verification

- Goal: overshoot magnitude less than 5°C at all times
- Verification: overshoot was limited to $\pm 2^{\circ}\text{C}$ as the graph for cycling between 55°C and 92°C shows

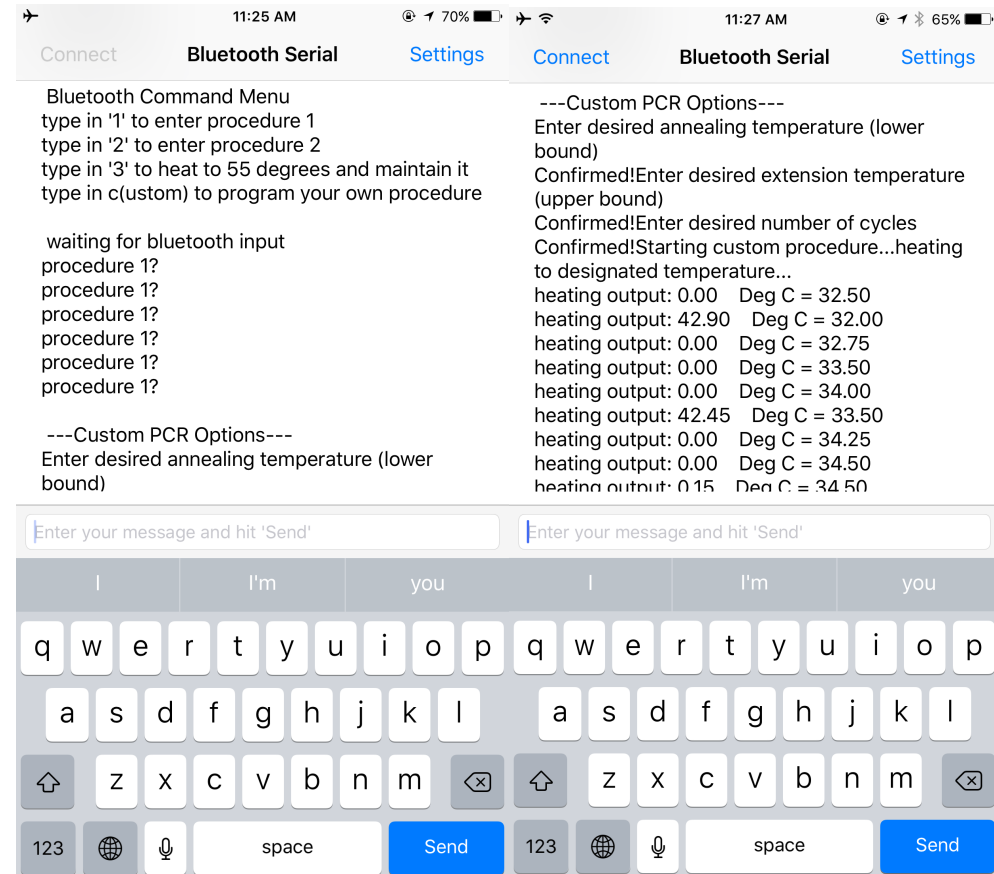


UI Flowchart



Bluetooth HC-08

- Customizable PCR procedures directly from mobile app
- Real-time duty cycle and temperature display



Safety

- Operators of this device face two main threats: malfunctioning thermocouple and malfunctioning Peltier modules
- Check 1: thermocouple self-check, device locks if thermocouple is not connected or is dead
- Check 2: if the thermocouple gets a unreasonably high reading, device locks

Safety - Verification

- Point a heat gun with temperature set to 100 degree Celsius
- Disconnect the thermocouple in the middle of a procedure



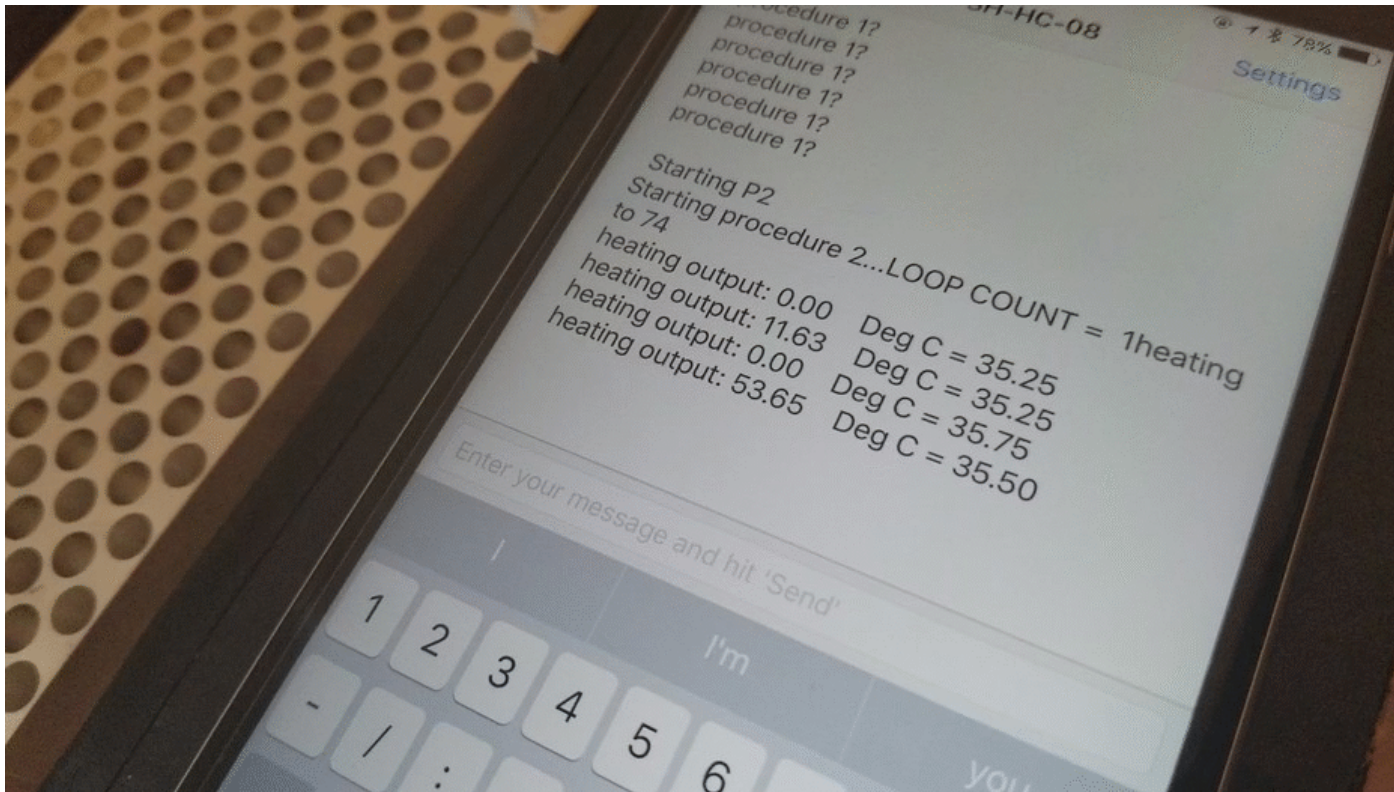
Accomplishments

- Very capable, reliable PCR machine at fraction of the cost of current commercial machines.
- Extensive functionalities, including the ability to customize procedures
- User-friendly interface

Demo



Auto Shut Down



Future Works

- Add Wi-Fi capabilities for remote control
- Increase device reliability and accuracy
- Cluster multiple thermal cyclers that share a single water cooling system to maximize cost efficiency
- Questions...?