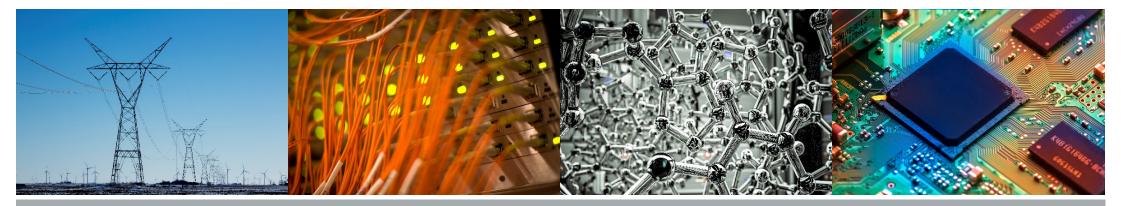
Low-Cost Thermal Cycler for LifeFoundry, Inc.

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

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Objectives

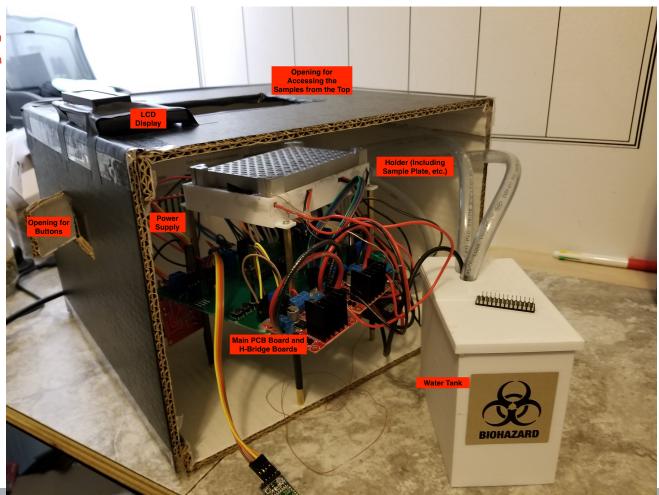
- Create a low-costthermal cycler under a budget of \$400
 -- Sponsored by LifeFoundry, Inc.
- Support 30 continuous cycles on 96 samples simultaneously
 -- Commercial grade
- Use water cooling for superior heat removal efficiency
 -- Scalable and end user ready





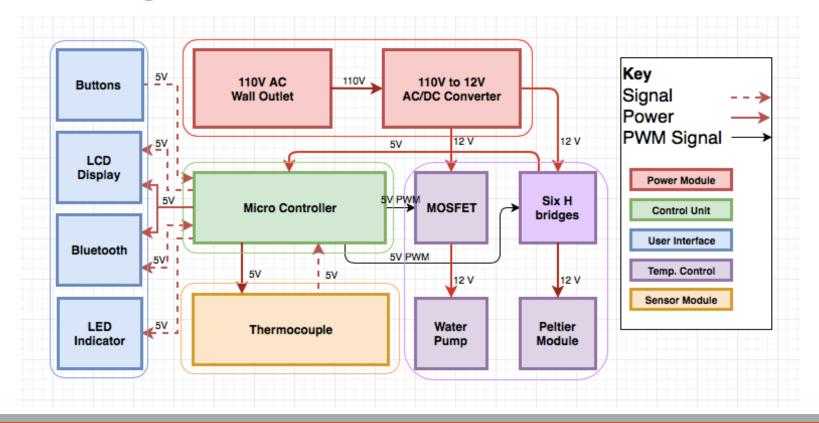
Finished Product

- Recycled cardboard casing
- Sample plateis put on the top
- LCD display is facing user
- Power supply is selfcontained





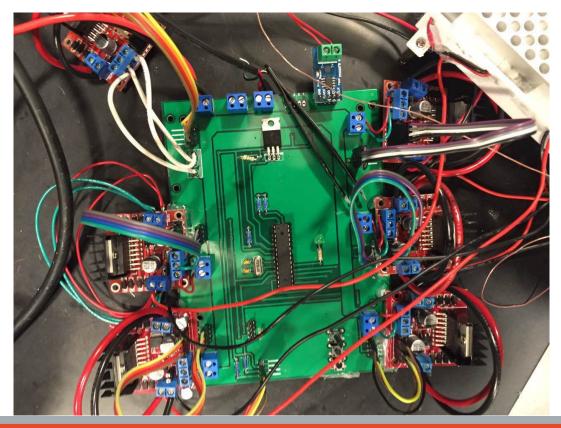
Block Diagram



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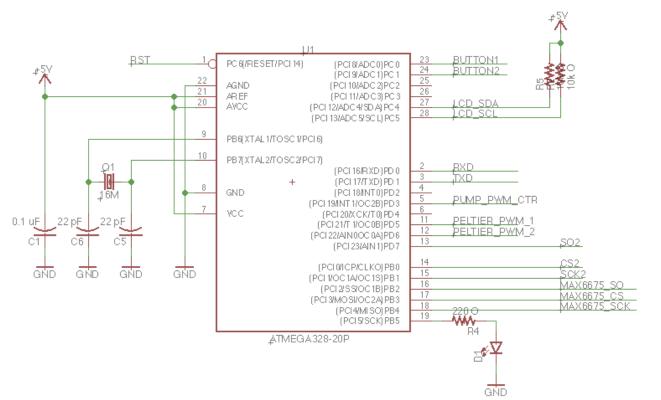
Hardware - Overview





Microcontroller ATmega328P

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



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Microcontroller - Challenge

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

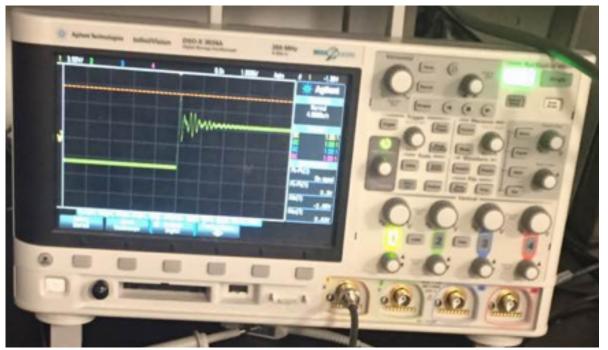




PWM Signal

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

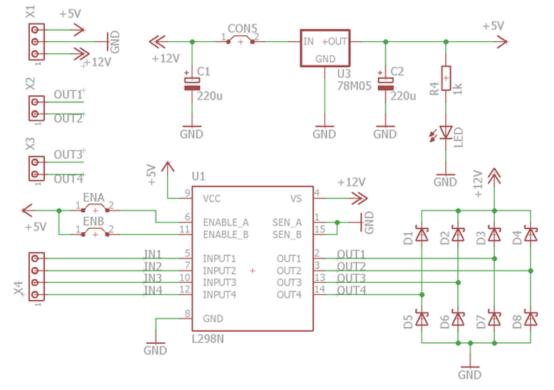
$$V_{\rm rms} = \sqrt{\frac{1}{T} \int_0^T (V(t))^2 dt}$$

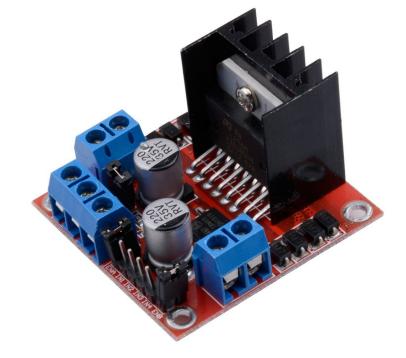










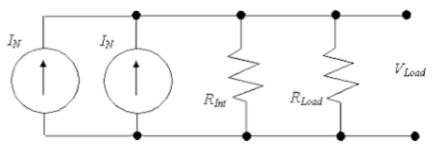


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H Bridge - Challenge

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

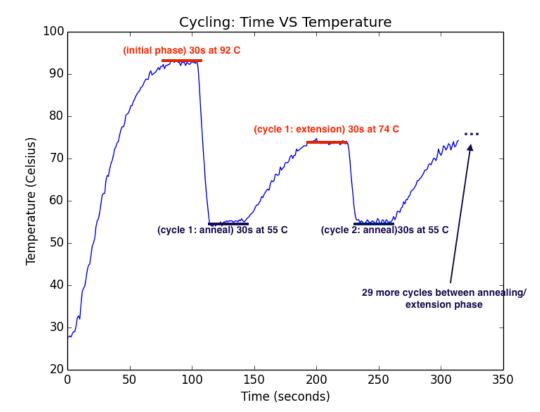






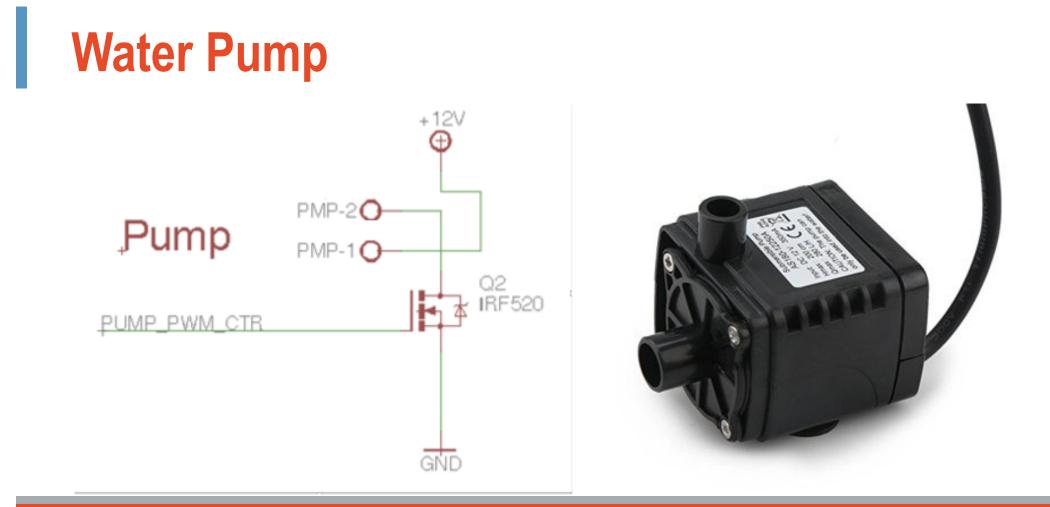
Peltier Target Temperature - Verification

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







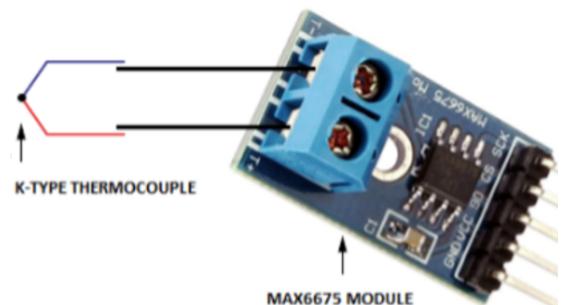




Thermocouple and MAX6675 ADC

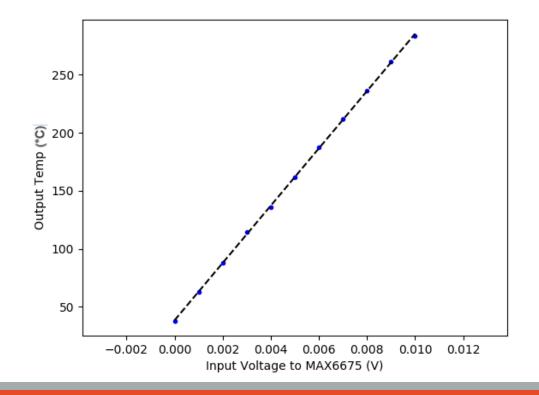
Goal:

- 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		

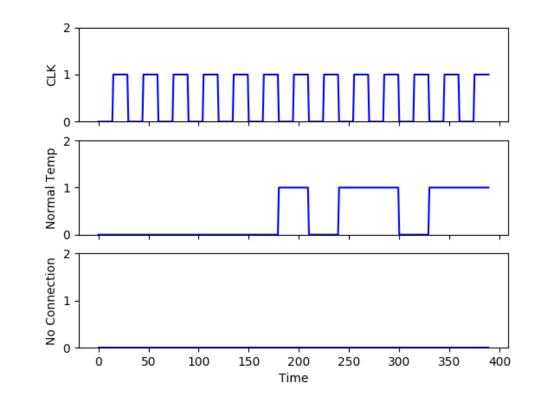




MAX6675 - Verification

Two digit precision

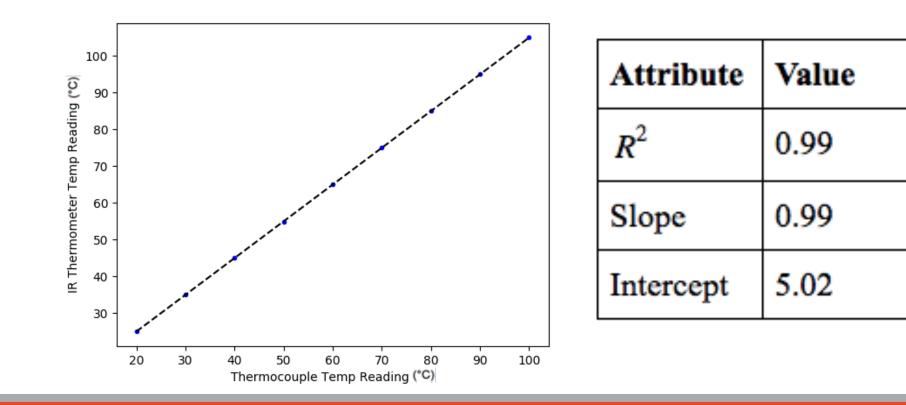
- 22.75 is 010110.11
 in binary form
- Not connected is flat zero







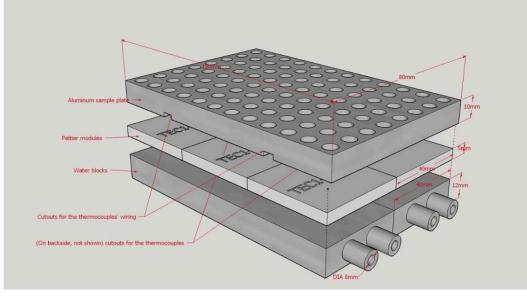
MCU Offset - Adjustment

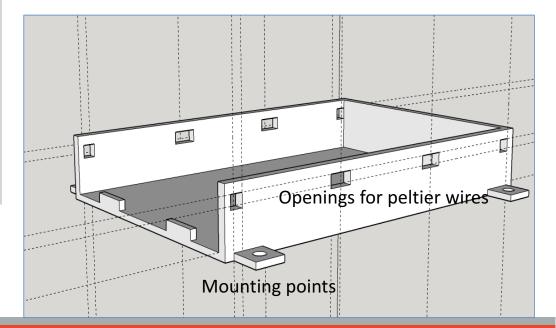


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Stacked View

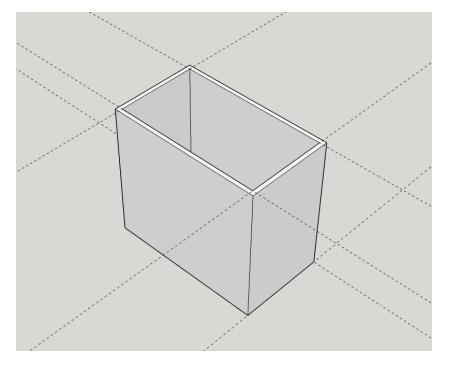


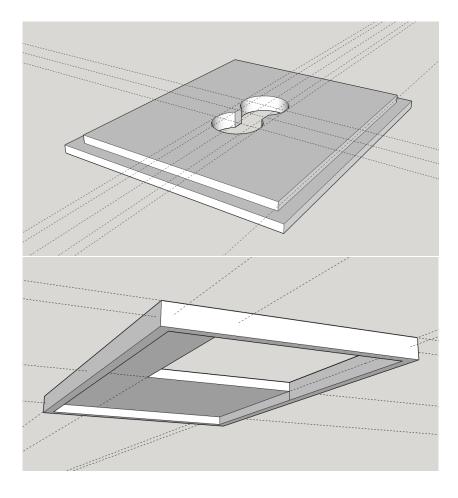


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CAD – Water Tank







Software – PID Introduction

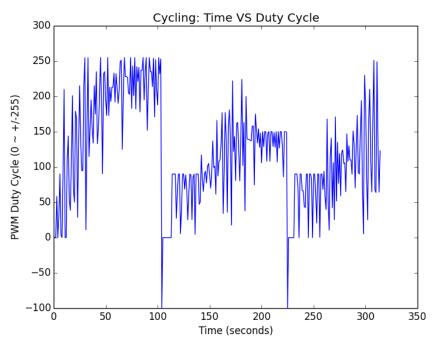
- Proportional, integral, derivative
- Determines output predictively based on past data
- Useful for controlling temperature precisely
- Minimizes overshoot and fluctuation





PID Implementation - Overview

- Used PID library by Brett Beauregard
- Input: thermocouple reading
- Output: PWM value for Peltier modules (0~255) u(t) = K_pe(t)+K_i∫e(τ)dτ+K_ddt
- *Kp*, *Ki*, *Kd* are tuning parameters that vary in different applications





PID Implementation - Tuning Parameters

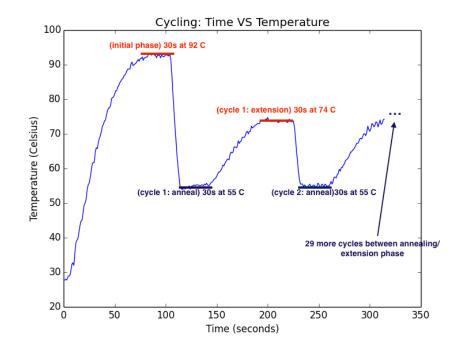
- The aluminum attached to Peltier modules has a significant heat capacity
- This heat capacity results in thermal inertia
- Thermal inertia
 delay
 overshoot
- Repeated experiments of tuning the Kp, Ki, Kd parameters to minimize this effect
- Smaller Kp larger Kd





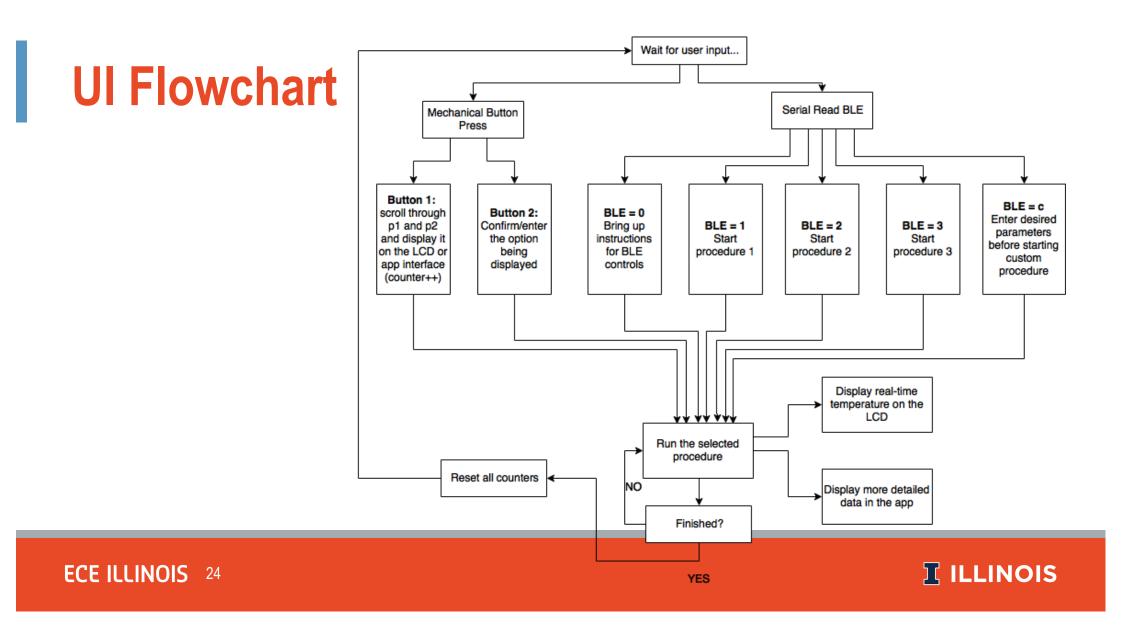
PID - Requirement / Verification

- Goal: overshoot magnitude less than 5°C at all times
- Verification: overshoot was limited to ±2°C as the graph for cycling between 55°C and 92°C shows









Bluetooth HC-08

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

	11:25 AM	🕑 🕈 70% 🔳 🕨	$+ \Rightarrow$	11:27 AM	🕒 🕈 🖇 65% 🗖	
Connect	Bluetooth Serial	Settings	Connect	Bluetooth Serial	Settings	
Bluetooth Command Menu type in '1' to enter procedure 1 type in '2' to enter procedure 2 type in '3' to heat to 55 degrees and maintain it type in c(ustom) to program your own procedure waiting for bluetooth input procedure 1? procedure 1? procedure 1? procedure 1? procedure 1? procedure 1? procedure 1?			Custom PCR Options Enter desired annealing temperature (lower bound) Confirmed!Enter desired extension temperature (upper bound)			
			Confirmed!Enter desired number of cycles Confirmed!Starting custom procedureheating to designated temperature heating output: 0.00 Deg C = 32.50 heating output: 42.90 Deg C = 32.00 heating output: 0.00 Deg C = 32.75 heating output: 0.00 Deg C = 33.50 heating output: 0.00 Deg C = 34.00			
Custom PC Enter desired a bound)	CR Options annealing temperature	e (lower	heating output: 42.45 Deg C = 33.50 heating output: 0.00 Deg C = 34.25 heating output: 0.00 Deg C = 34.50 heating output: 0.15 Deg C = 34.50			

Enter your message and hit 'Send'		Enter your message and hit 'Send'			
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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 sthe middle of a procedure





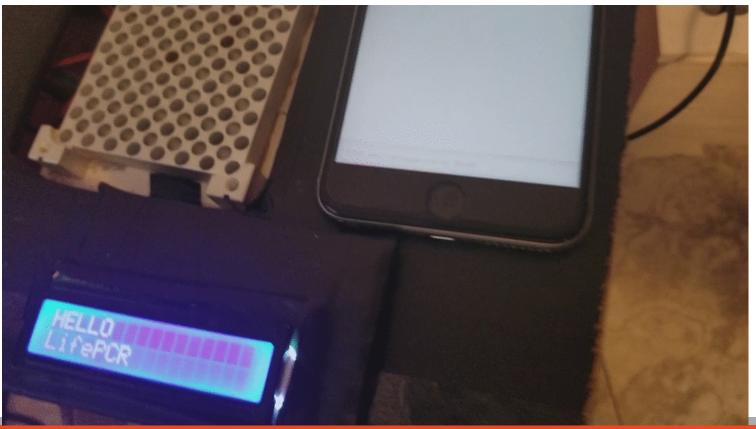
Accomplishments

- 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



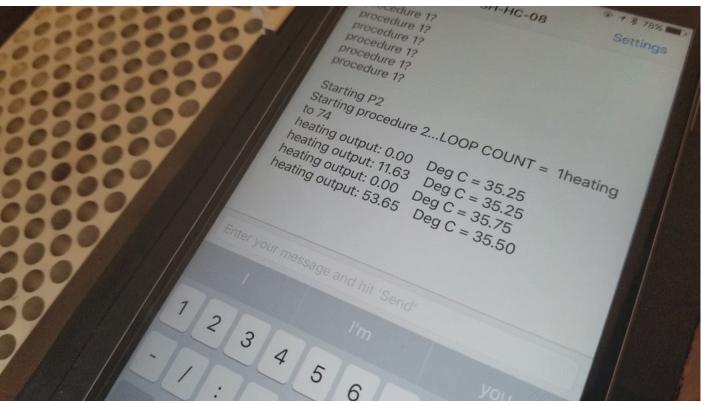


Demo





Auto Shut Down





Future Works

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



