# Pain Alleviation Mechanism for CMC Arthritis Patients

Keshav Kohli, Puneet Kumar, Reith Sarkar

Client: Tiffany Harmon

# Outline

Overview of Need and Chosen Design

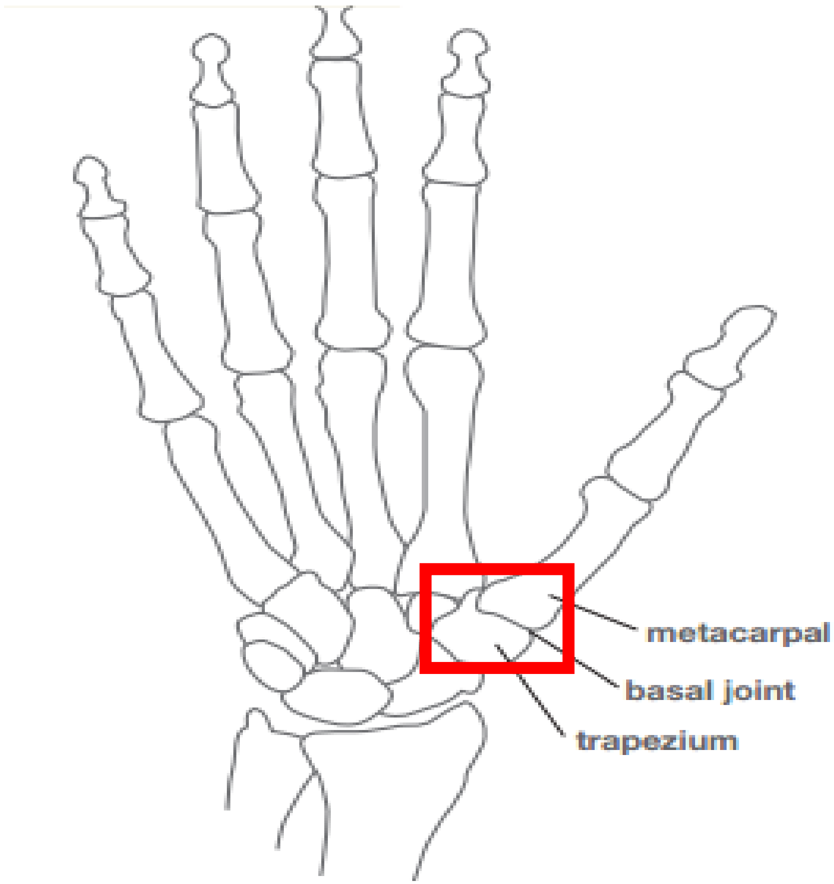
Details of Analysis Needed for Design

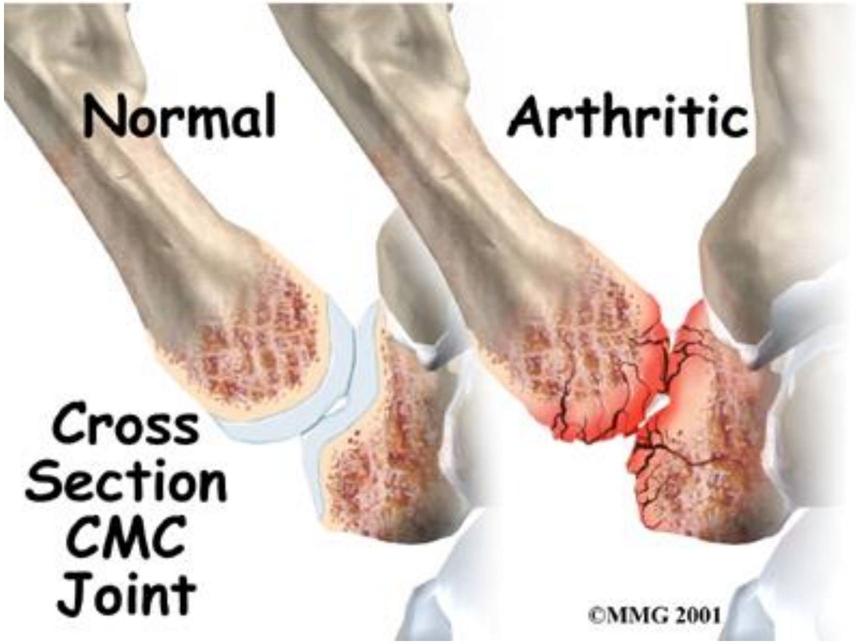
Details of Chosen Design

Material and Manufacturing Considerations

Conclusions and Future Directions

# CMC Arthritis



# Overview of Need

*"I have been working with patients for over 10 years that have expressed frustration with the lack of conservative options for the pain they experience with [CMC arthritis]."*

-Tiffany Harmon, OT

Standard for conservative therapy is splinting

# Overview of Need

Need for user-controlled pain alleviation system which can be used along with existing CMC arthritis splints.

# Specific Design Specifications

Temperature Therapy

- Heat between 95 – 110 °F
- Heating element should ramp to desired temp on order of min.
- Heat should be localized around CMC joint

Microcontroller

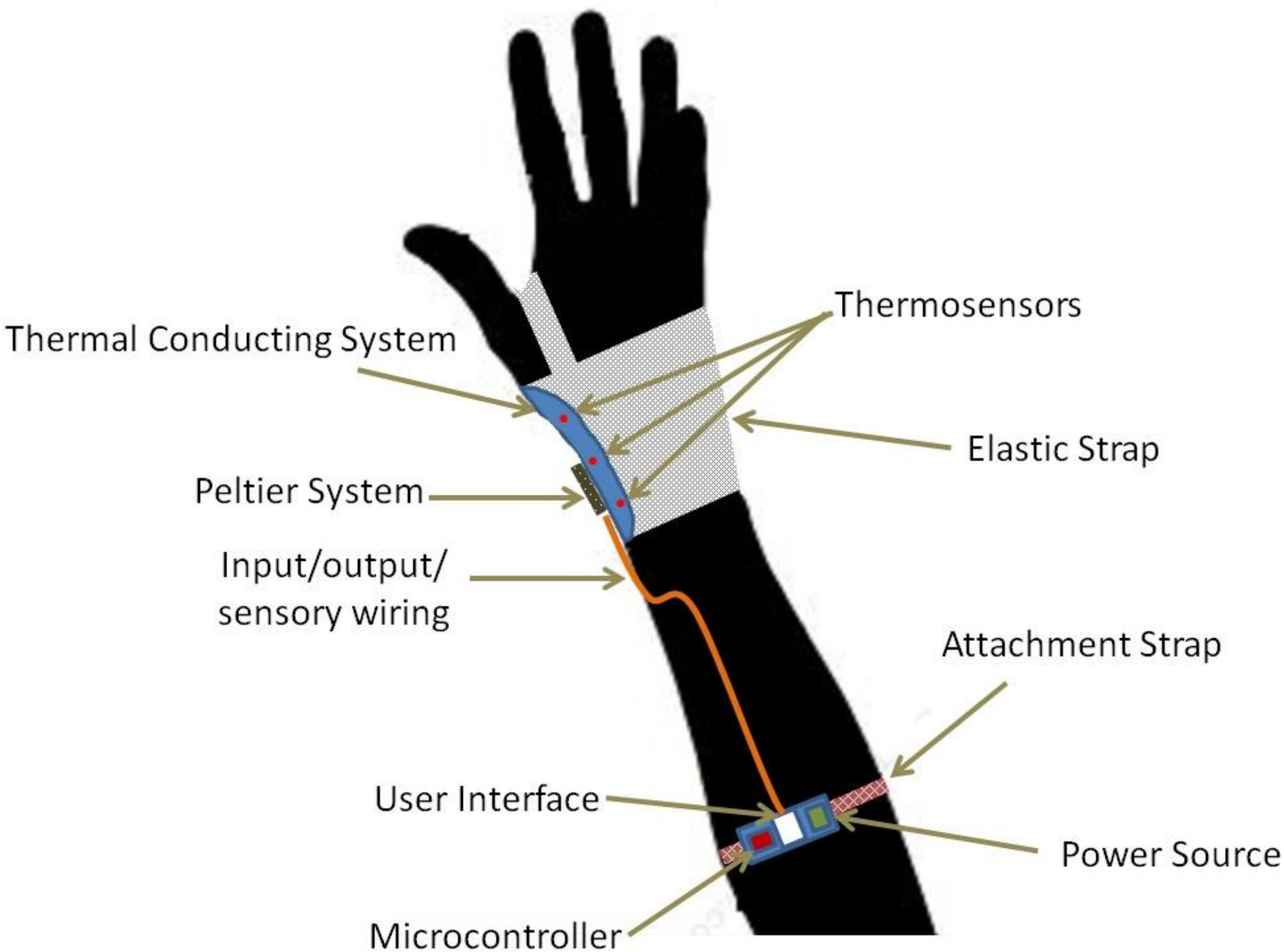
- Programmable
- User controlled (input variable set points)
- Pulse width modulation capabilities
- Sensor sampling at < 1 Hz

Mechanical Considerations

- Electrically insulated
- Durable housing for microcontroller unit
- Wearable and comfortable on both hands

Retail Cost – ideally should be below $250

# Previous Chosen Design Concept

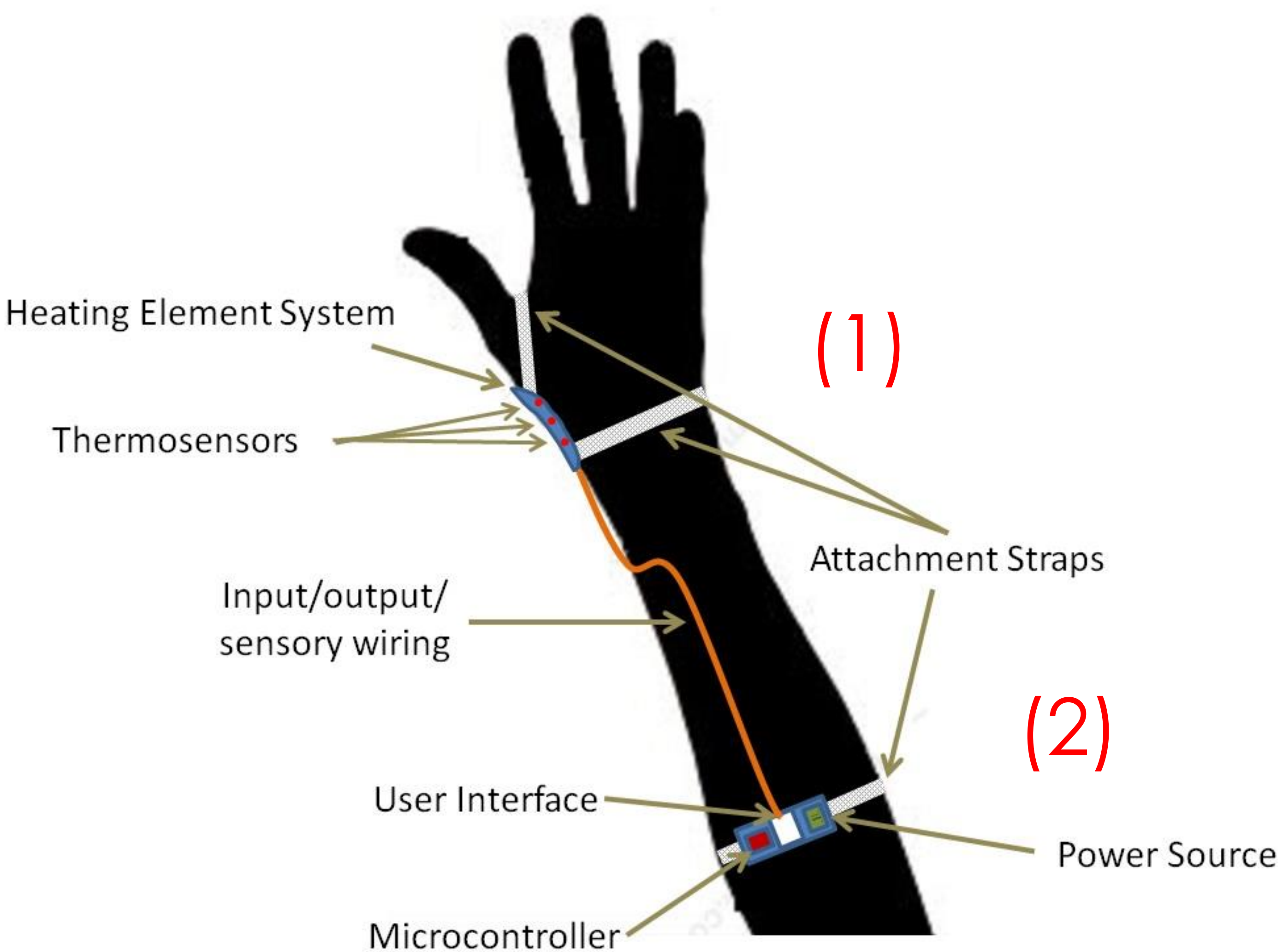


# Alternative Option

Resistive Heating

- Heat therapy (no cold capabilities)
- Applied current through conductor induces heat
  - Heat released is proportional to resistance
- **Lower power requirements, durable, inexpensive**

# Final Chosen Design Concept



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# Power Requirement Calculations

Device will be used for approx. 4 times a day for 15-30 minutes (2 hours total)

From spec sheet of resistive heating element:

Minimum voltage required is 5V (to operate efficiently)

Maximum amperage is 1A

$$\frac{x\ mAh}{1000\ mA} * 0.5 \geq 2\ hours$$

$$x \geq 4000\ mAh$$

Thus, battery should supply $\geq \mathbf{4000\ mAh}$

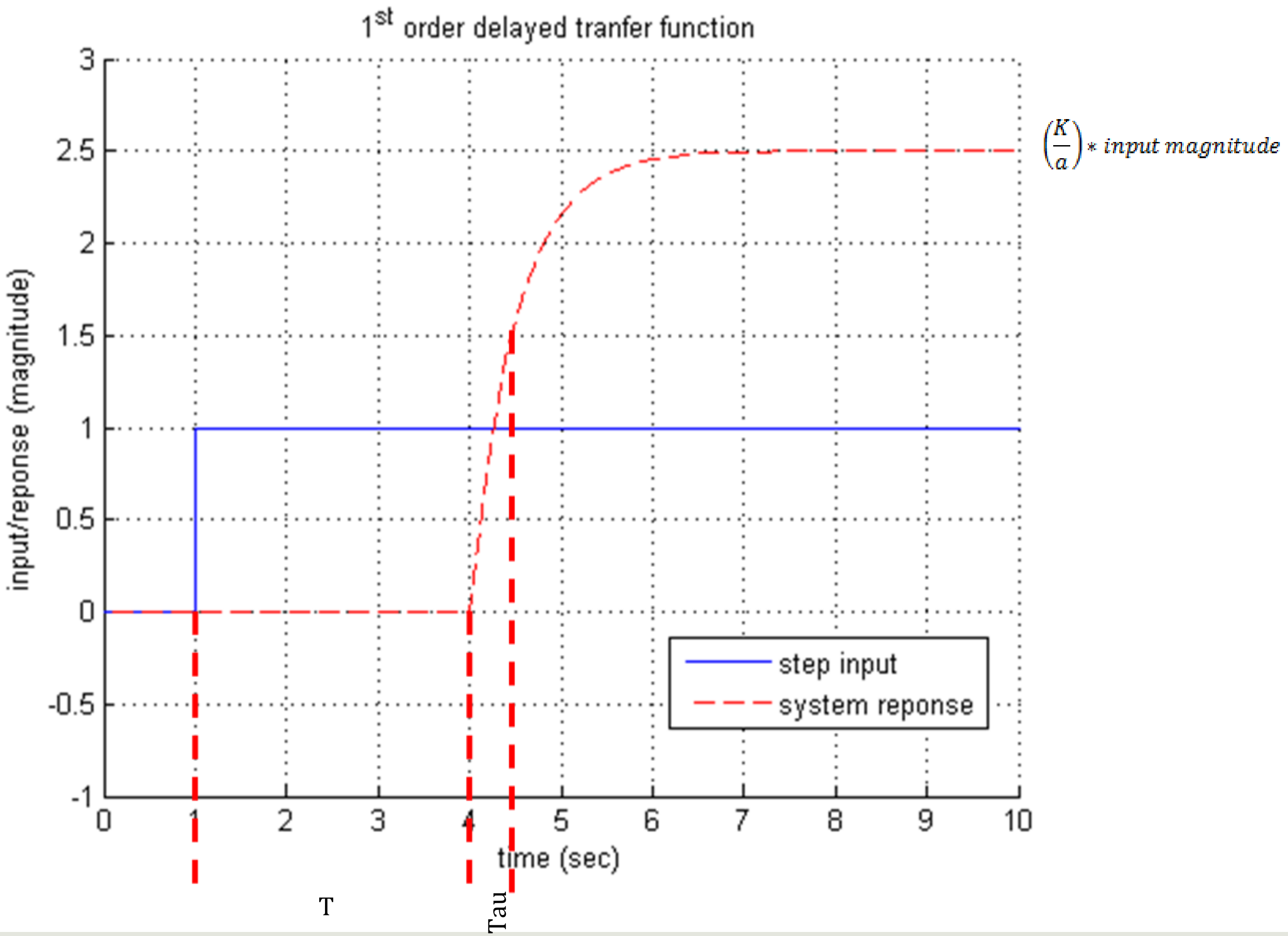
# Pulse Width Modulation (PWM)

- To maximize power efficiency
- Battery provides DC pulses at a specific frequency instead of a constant pulse
- Must **experimentally determine** appropriate PWM frequency

$$T(s) = \frac{K}{s+a} e^{-sT}$$

- Assume first order delayed time system
- **K, a, and T** determined graphically

# Pulse Width Modulation (PWM)



# Pulse Width Modulation (PWM)

$$input\ magnitude = 1$$

$$\tau\ (time\ constant) = \frac{1}{a} = time\ to\ 63.2\%\ of\ steady\ state\ value$$

$$steady\ state = \left(\frac{K}{a}\right) * \ input\ magnitude = \left(\frac{K}{a}\right) * 1$$

$$T = delay\ time = 3\ seconds$$

$$\tau = 0.5\ seconds = \frac{1}{a}$$

$$\therefore a = natural\ frequency = 2$$

$$steady\ state = 2.5 = \left(\frac{K}{a}\right) = \left(\frac{K}{2}\right)$$

$$\therefore K = magnitude = 5$$

$$\therefore Tranfer\ Function \rightarrow T(s) = \frac{5}{s+2} e^{-3s}$$

# Pulse Width Modulation (PWM)

- From knowing natural frequency a, we can choose appropriate PWM frequency

$$Appropriate\ PWM\ frequency = 10 * a$$

- Can make **duty cycle calibration curve**, and implement it into script that microcontroller operates
  - Temperature differential vs. Duty cycle

# Weight

| | |
|---|---|
| **Housing Unit** | |
| Plastic Casing | 47.63 g |
| Battery | 190 g |
| **Heating Element** | |
| Wire | 0.2425 g |
| **Misc.** | |
| PCB | |
| Buttons, LCD, switch | |
| Polyester fabric | ~ 15 g |
| **Total** | **252.87 g** |

A bit more than the weight of an **orange**

# Sampling Speed

- What is a reasonable amount of samples we need to take?
- Temperature is relatively steady state
- Sampling speed of thermistors:

  Sampling speed $< 1$ Hz is ideal

  Chose **0.2 Hz** (take reading every 5 seconds)

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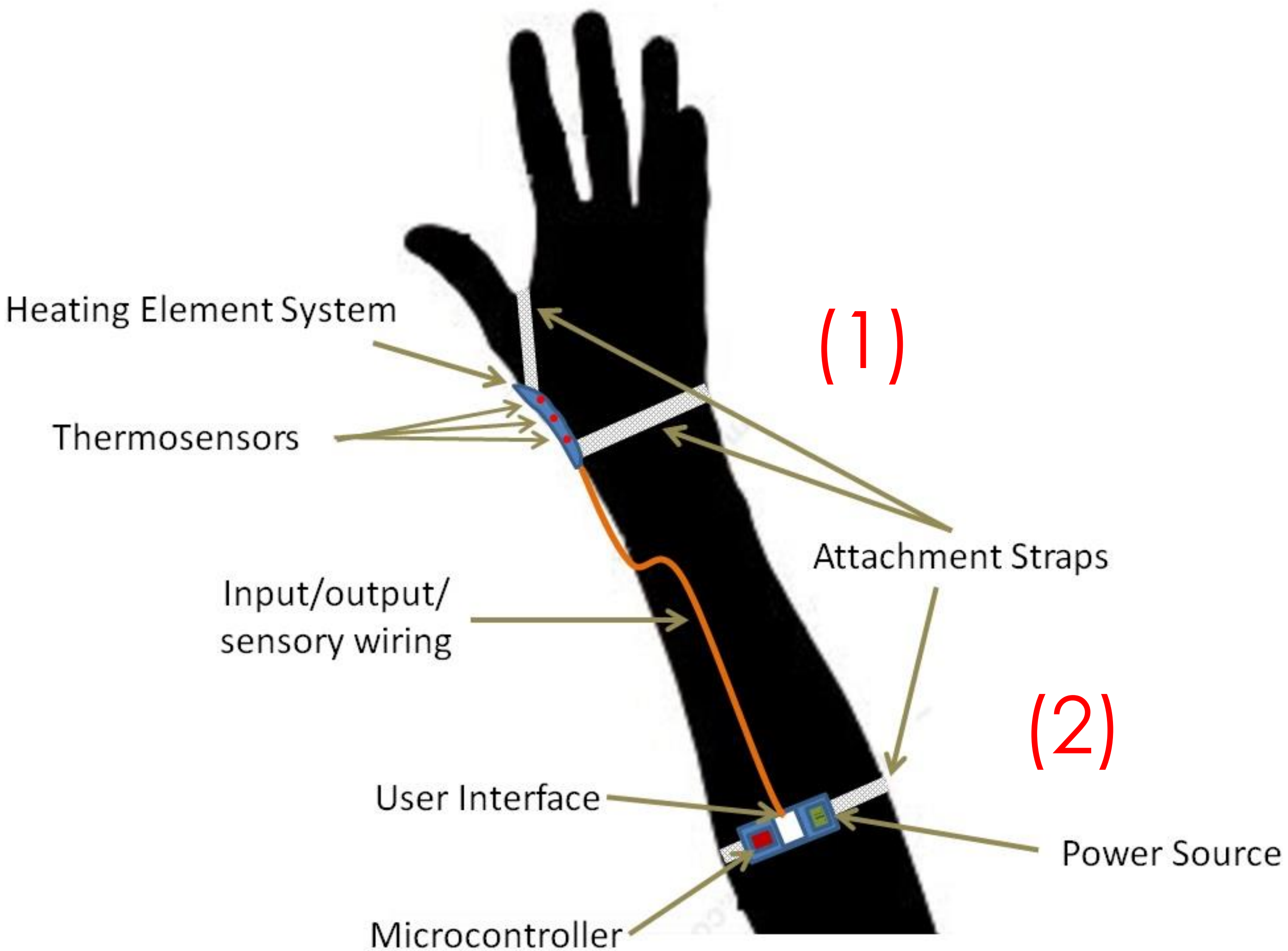
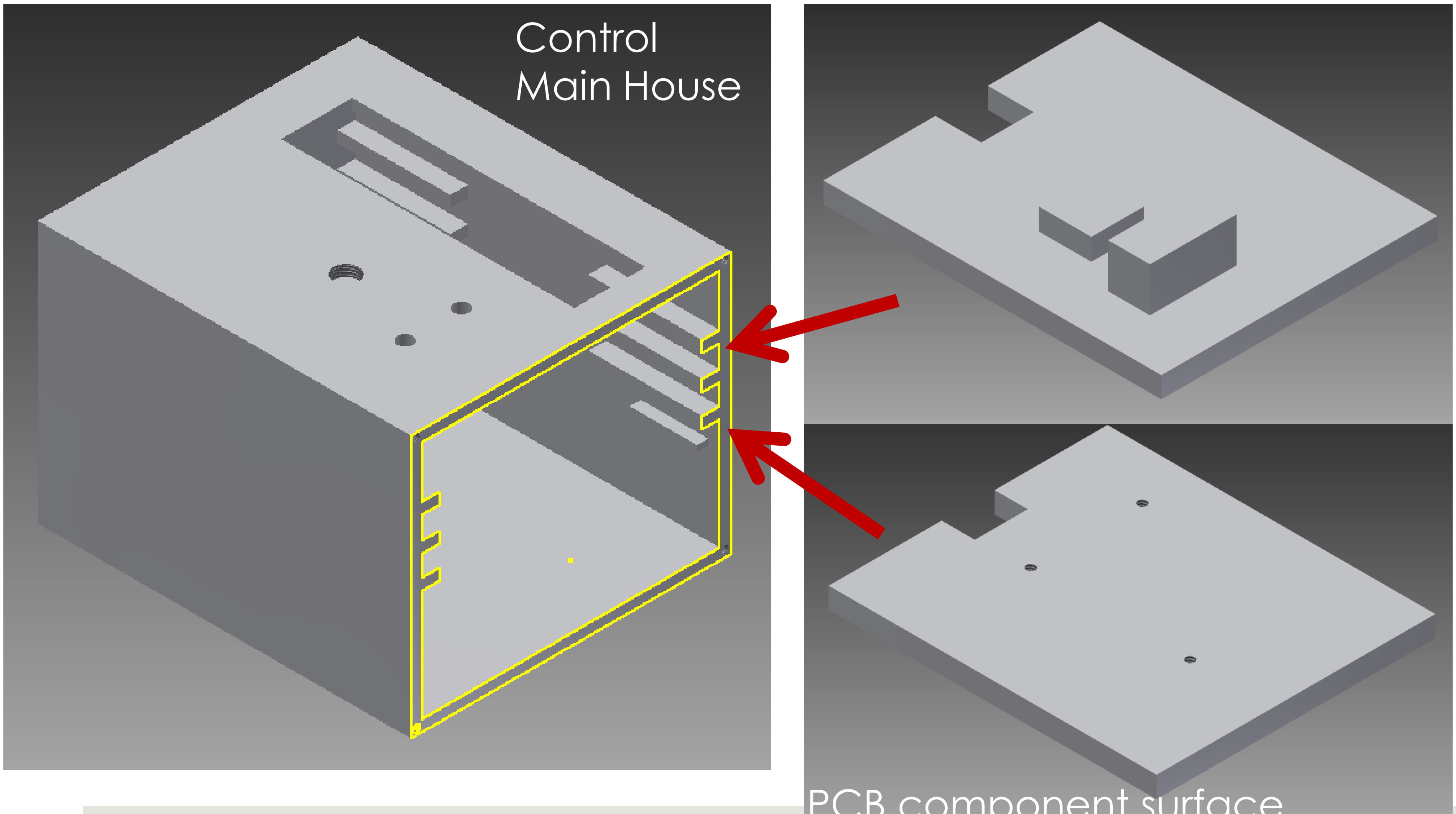


# Housing Unit – CAD Drawings

User-interface component surface



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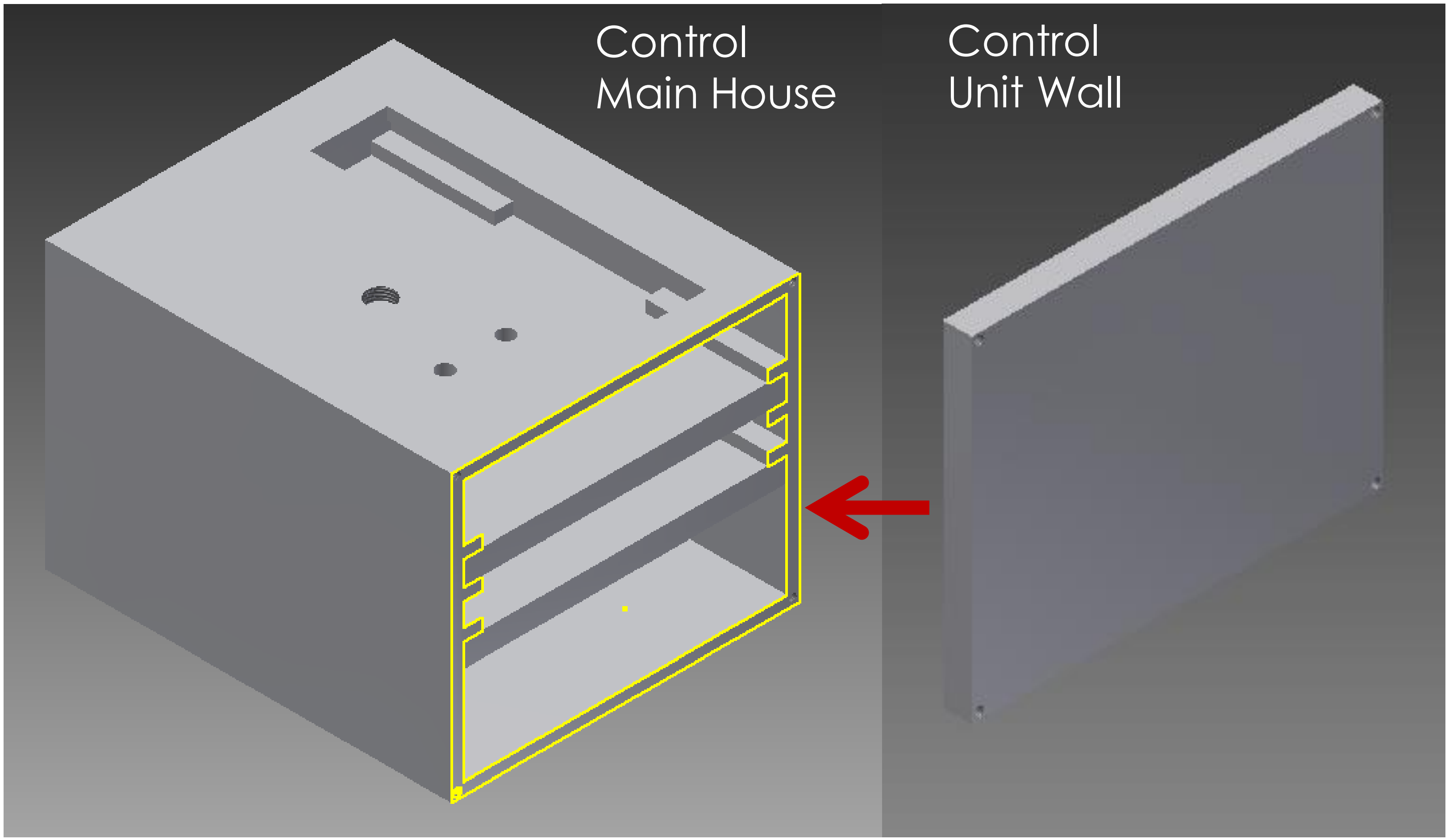
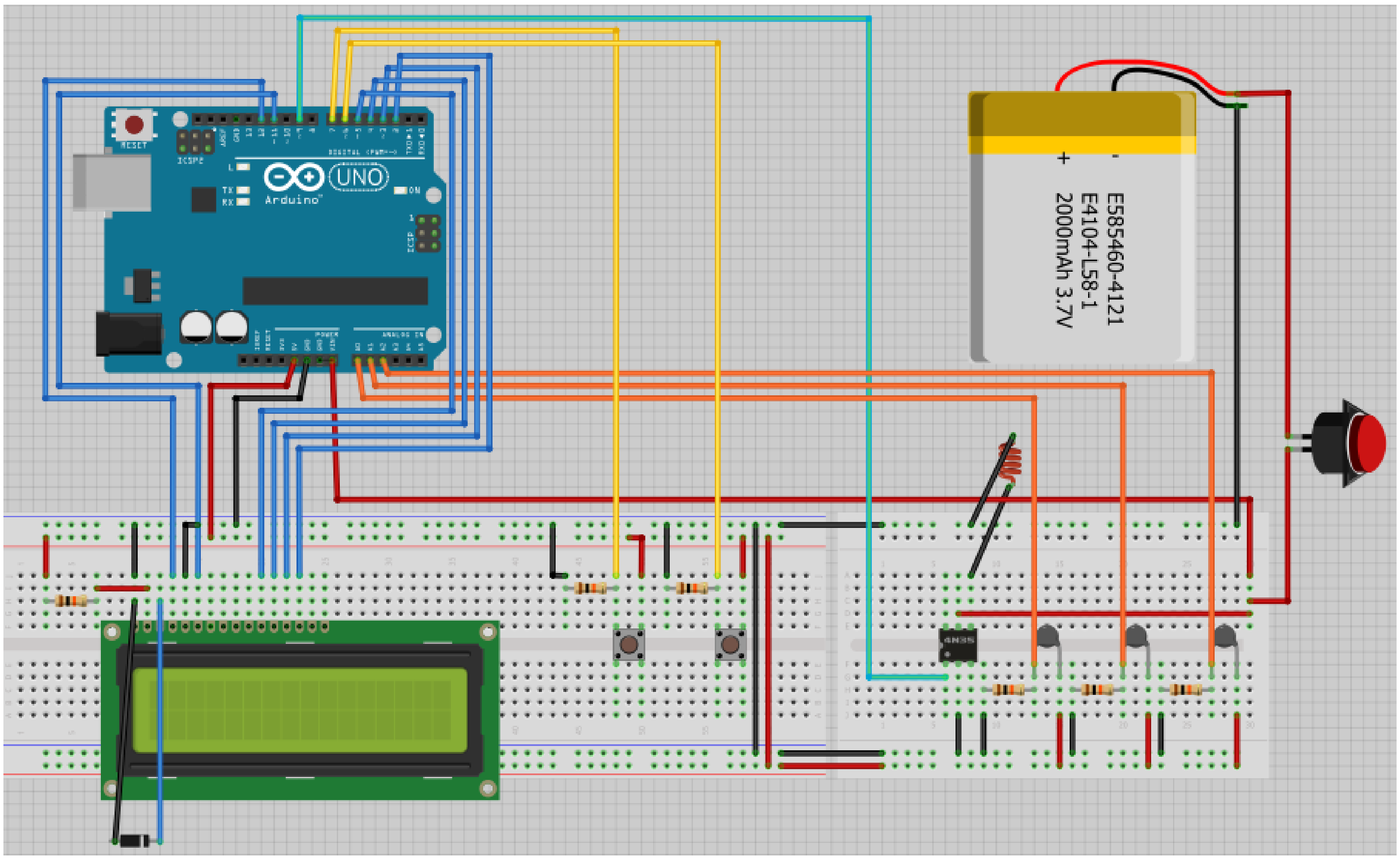
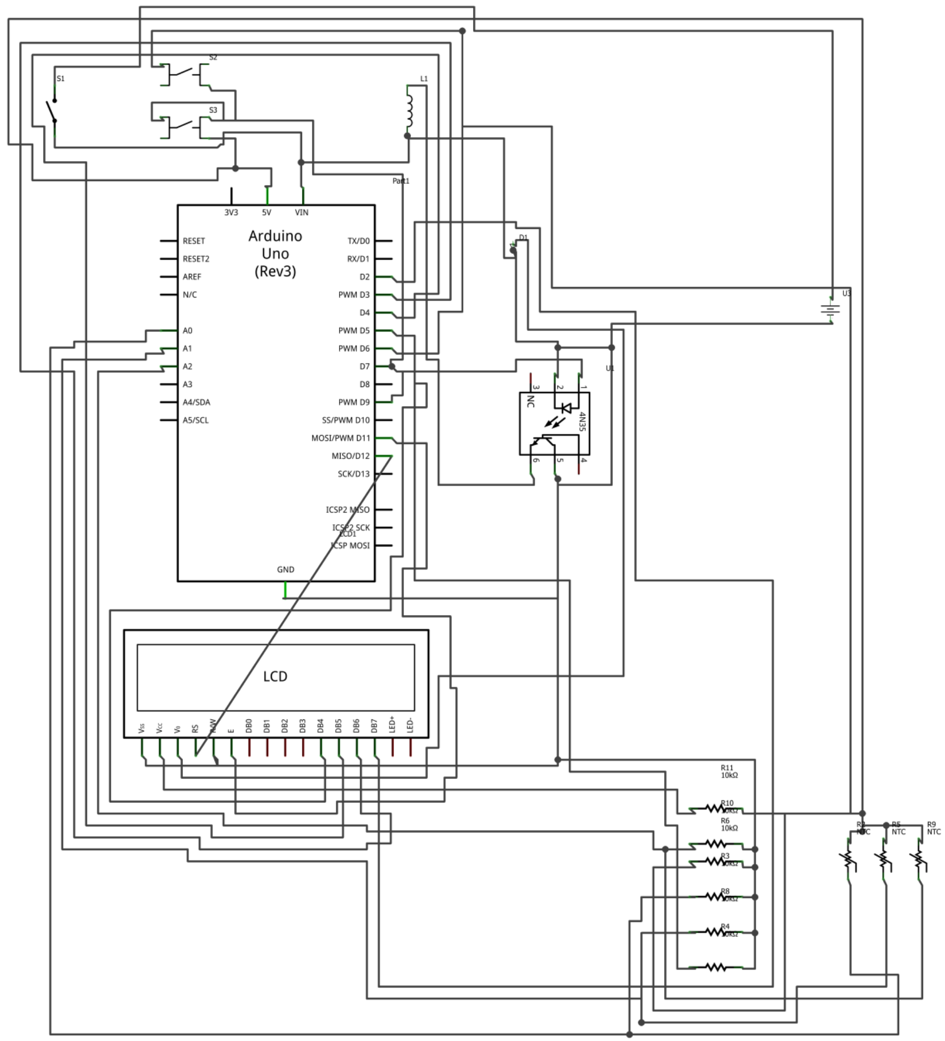


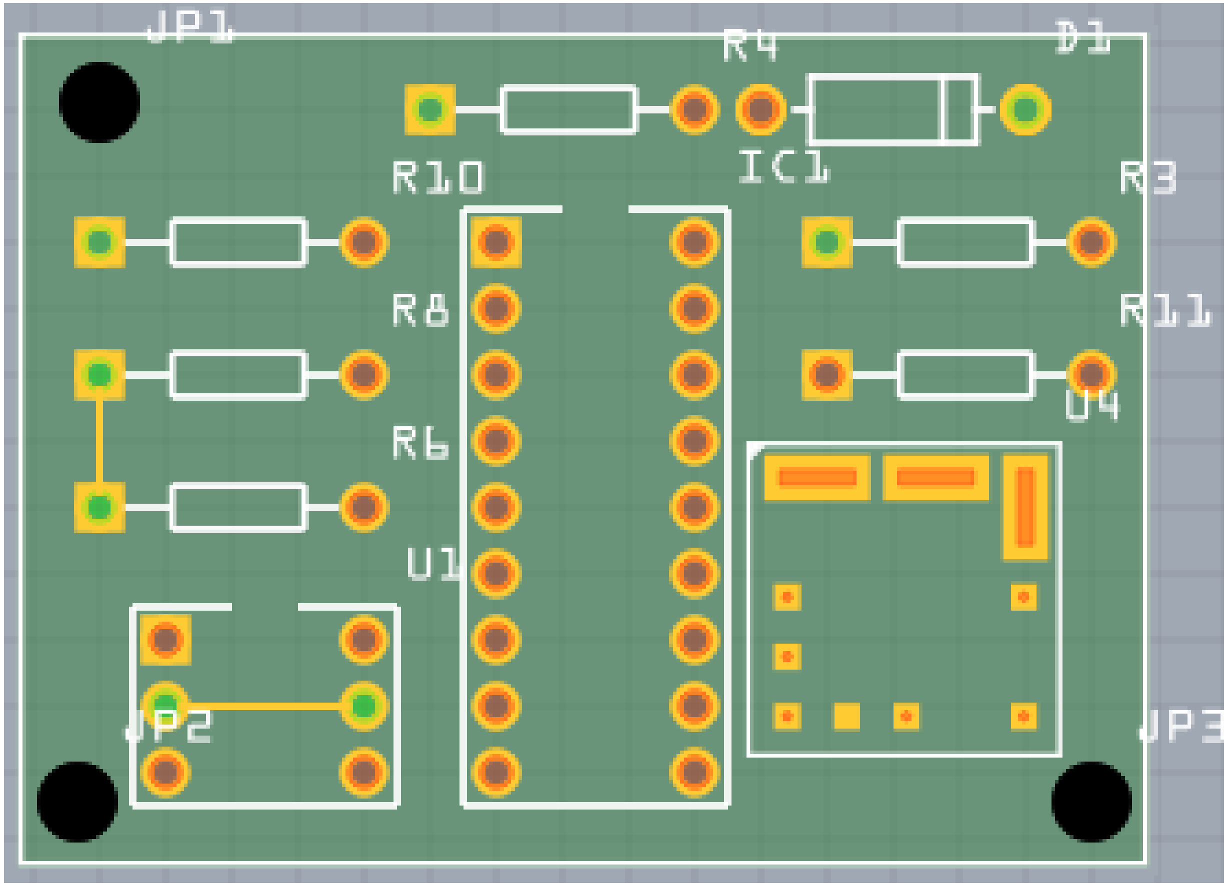
# Circuit Design



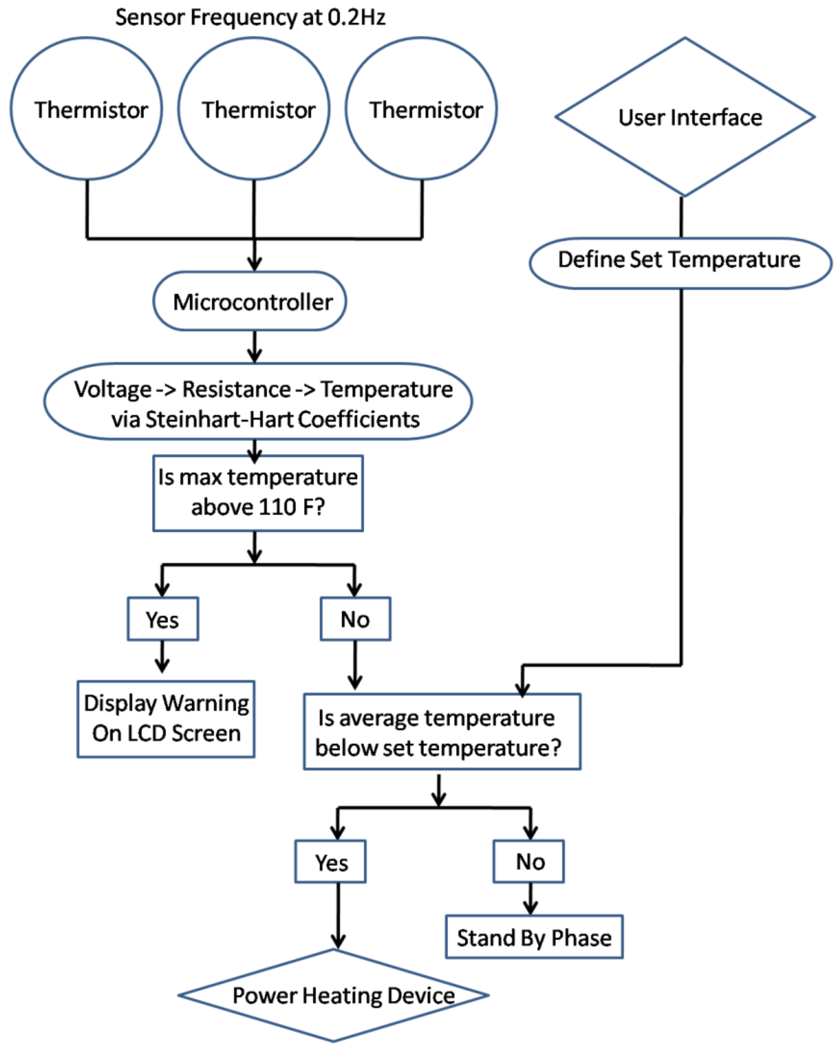
# Circuit Design



# PCB Board Design



# Software Overview



# Power Supply

## Lithium-ion vs. Nickel-cadmium battery

| | Li-ion | NiCad |
|---|---|---|
| **Nominal cell voltage:** | 3.6 / 3.7 V | 1.2 V |
| **Cycle durability:** | 400-1200 cycles | 2,000 cycles |
| **Specific power:** | ~250-~340 W/kg | 150 W/kg |
| **Charge / discharge efficiency:** | 80-90% | 70–90% |
| **Self-discharge rate:** | 8% at 21 °C, 15% at 40 °C, 31% at 60 °C (per month) | 10% per month |
| **Energy density:** | 250-620 W•h/L | 50–150 W•h/L |
| **Specific energy:** | 100-250 W•h/kg | 40–60 W•h/kg |
| **Disposal:** | Non-hazardous waste | Hazardous waste |
| **Maintenance:** | Does not need periodic discharge | Requires full discharge before recharge |
| **Weight:** | 20%-35% less than Nicad | Heavier than Li-ion |
| **Memory effect:** | Do not suffer from memory effect | Suffer from memory effect |

# Power Supply

Lithium-ion safety concern:

- If a Li-ion battery is overcharged, it can overheat and in certain cases ignite.
- This safety concern can be mitigated with the implementation of a specific built-in IC chip to the battery.
- This IC-chip prevents over charge and over discharge.

# Power Supply

Power Supply Requirements

- $\geq 4000\ mAh$
- Minimum voltage of 5V

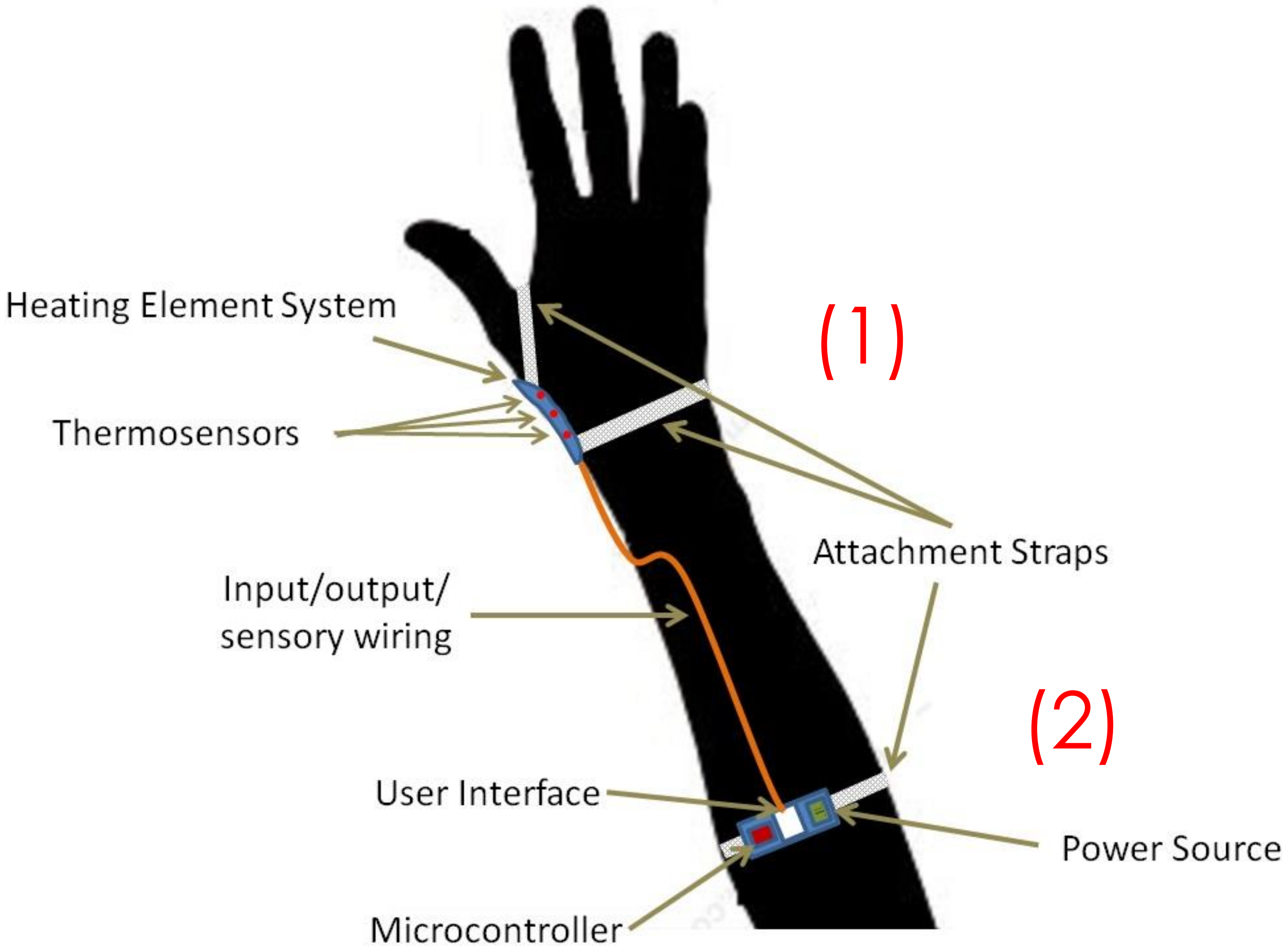
Lithium-ion Battery

- 5200 mA-hour
- 7.4 V
- Built-in IC chip for safety
  - Prevents over charge and over discharge
- Rechargeable battery

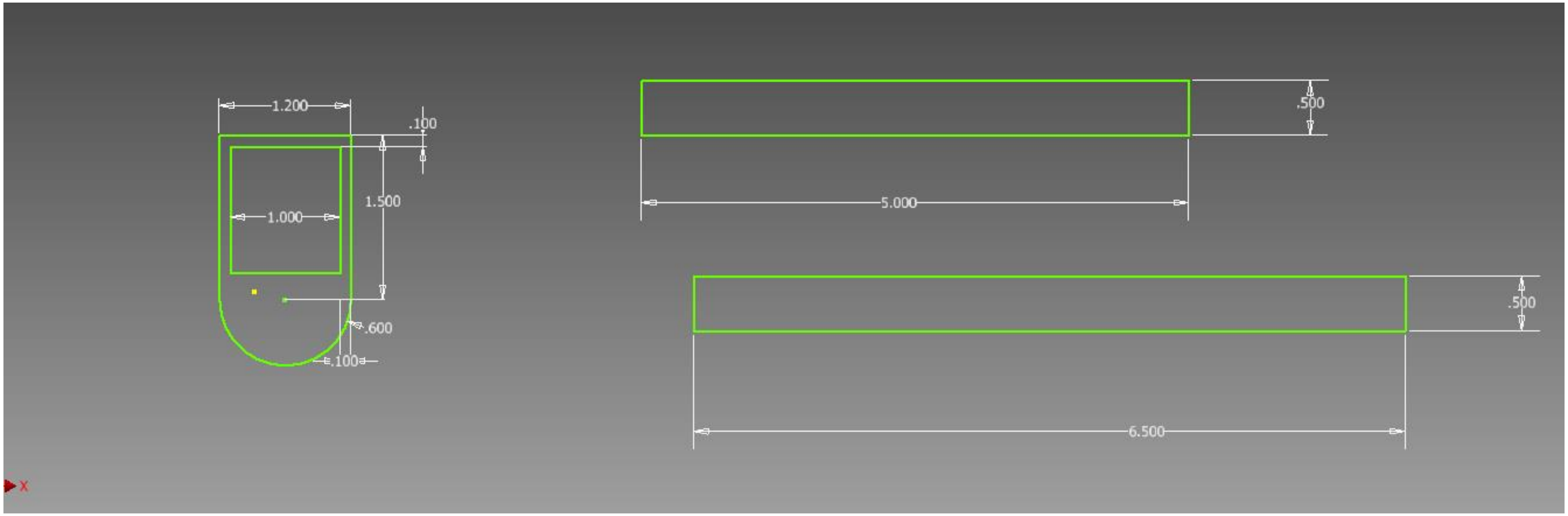
# Velcro Straps for Arm

"3 inch Velcro cinch strap"

# Final Chosen Design Concept



# Heating Element Drawings

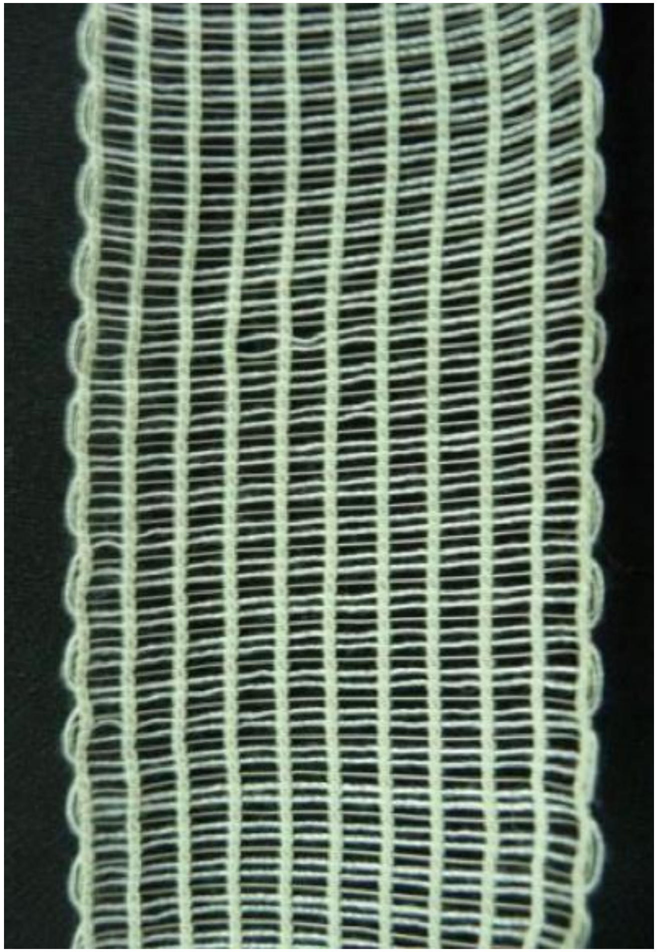


# Resistive Heating Wire

Insulated Steel Mesh

"Ultra Heating Fabric"

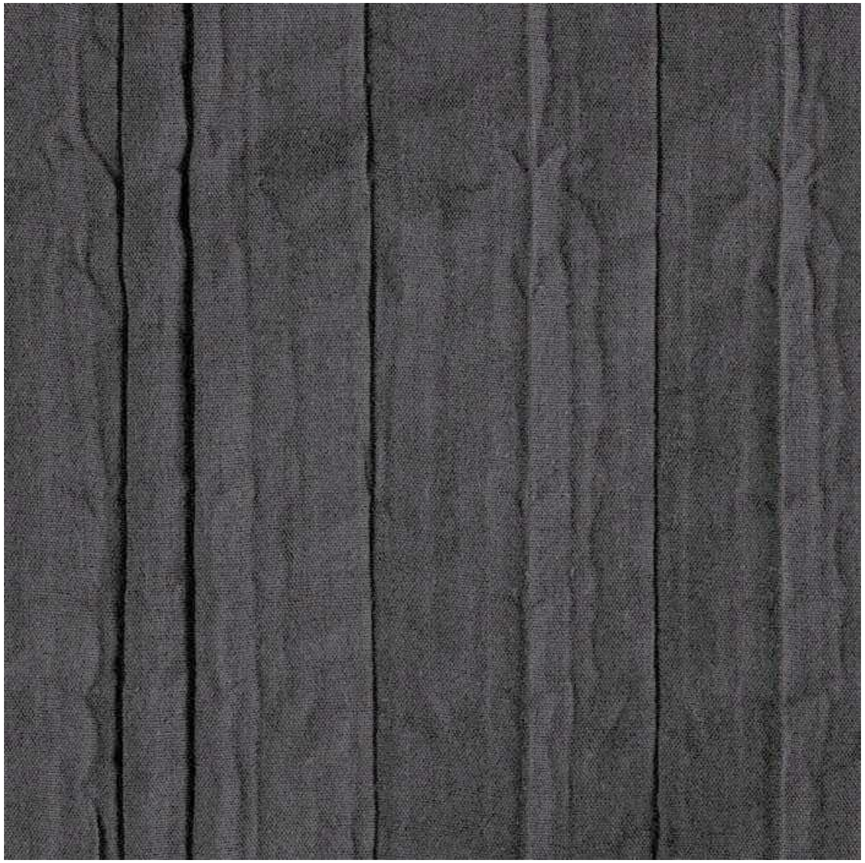
- Patented steel-polymer fiber composite conductive yarn
- Light, thin, durable
- Electrically Insulated



# Polyester Fabric

"Accordion Shirting Black"

- 100% polyester
- Lightweight
- Low thermal conductivity
- Will cover heating element to provide comfort and some thermal insulation



# Velcro Straps for Hand

"Nylon Velcro Cinch Strap"

# Designsafe Analysis

| | Initial Assessment | | | Final Assessment | | Status / |
|---|---|---|---|---|---|---|
| Hazard / | Severity | | | Severity | | Responsible |
| Failure Mode | Probability | Risk Level | Risk Reduction Methods | /Comments | Probability | Risk Level |
| Physician's Assistant | biological / health : unsanitary conditions | Moderate | Low | | Minor | Negligible |
| diagnose patient condition(s) | Lack of sanitization before use | Unlikely | | | Unlikely | |
| Physician's Assistant | electrical / electronic : energized equipment / live parts | Moderate | Low | | Minor | Negligible |
| monitor patients | Electrical components | Unlikely | | | Unlikely | |
| Physician's Assistant | electrical / electronic : water / wet locations | Moderate | Low | | Minor | Negligible |
| monitor patients | If components not kept dry | Unlikely | | | Unlikely | |
| Physician's Assistant | electrical / electronic : overvoltage /overcurrent | Moderate | Low | | Minor | Negligible |
| monitor patients | If too much current drawn | Unlikely | | | Unlikely | |
| Patient | mechanical : pinch point | Minor | Negligible | | Minor | Negligible |
| All Activities | If Velcro clasp is pinched against skin | Unlikely | | | Unlikely | |
| Patient | electrical / electronic : energized equipment / live parts | Serious | Medium | Isolate electrical components from user | Serious | Low |
| All Activities | Electrical Components | Unlikely | | | Remote | |
| **Patient** | **electrical / electronic : water / wet locations** | **Serious** | **High** | **Warn patient well of danger of water** | **Serious** | **Medium** |
| **All Activities** | **If components not kept dry** | **Likely** | | | **Unlikely** | |
| Patient | electrical / electronic : overvoltage /overcurrent | Serious | Medium | Internal mechanism to shut off device | Serious | Low |
| All Activities | If too much current drawn | Unlikely | | | Remote | |

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# Part Prices - Prototyping

| Part | Price/one | Quantity | Total cost ($) |
|---|---|---|---|
| LCD | 8 | 1 | 8 |
| temp up/down buttons | 0.35 | 2 | 0.7 |
| battery | 32.49 | 1 | 32.49 |
| charger | 19.99 | 1 | 19.99 |
| optocoupler | 3.21 | 1 | 3.21 |
| 3 toggle switch | 4.6 | 1 | 4.6 |
| resistors | 0.09 | 6 | 0.54 |
| thermistors | 1.38 | 3 | 4.14 |
| diode | 0.13 | 1 | 0.13 |
| jumper wires (kit) | 2.5 | 1 | 2.5 |
| Arduino Uno | 27.09 | 1 | 27.09 |
| Large Velcro Strap (Wrist) | 2.598 | 1 | 2.598 |
| Small Velcro Straps (Hand) | 0.1 | 2 | 0.2 |
| Fabric (Polyester) | 0.005029 | 3 | 0.015087 |
| Heating Fabric | 3.95 | 1 | 3.95 |
| **Total Prototype Cost** | | | **$107.56** |

Estimated **lead time** for all shipped products ~ **2 weeks**

# Part Prices – Commercialization

| Part | Price/one | Quantity | Total cost ($) |
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| optocoupler | 3.21 | 1 | 3.21 |
| 3 toggle switch | 4.6 | 1 | 4.6 |
| resistors | 0.09 | 6 | 0.54 |
| thermistors | 1.38 | 3 | 4.14 |
| diode | 0.13 | 1 | 0.13 |
| jumper wires (kit) | 2.5 | 1 | 2.5 |
| PCB board | 13.14 | 1 | 13.14 |
| ABS Plastic Housing | 4.24 | 1 | 4.24 |
| Undercut Flathead, S.S. 4-40 thread, length 3/16" | 0.1462 | 3 | 0.4386 |
| Flathead, S.S. 2-56 thread, length 5/16" | 0.0772 | 4 | 0.3088 |
| ABS Plastic Wall | 2.5 | 1 | 2.5 |
| Large Velcro Strap (Wrist) | 2.598 | 1 | 2.598 |
| Small Velcro Straps (Hand) | 0.1 | 2 | 0.2 |
| Fabric (Polyester) | 0.005029 | 3 | 0.015087 |
| Heating Fabric | 3.95 | 1 | 3.95 |
| Voltage Converter Chip | 17.32 | 1 | 17.32 |
| PIC Chip | 1.84 | 1 | 1.84 |
| **Total Manufacturing Cost** | | | **$122.85** |

Estimated **lead time** for all shipped products ~ **2 weeks**

# Manufacturing Processes

- **Fritzing Fab** – PCB board
  - Would have to solder individual components onto PCB board
- **Protomold** – Housing
  - Injection molding with ABS plastic
- **WireKinetics** – Resistive heating element
  - Cut specific area and assemble

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# Problem Solved?

Need for **user-controlled** **pain alleviation system** which can be used **along with existing CMC arthritis splints**

Delivered:

- Heat therapy system
  - Allows for user input of variable set points
  - Temperature regulation by microcontroller
- Heating element is thin, light, durable
  - Compatible with CMC splints

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**Yes, but room for future improvements!**

# IP Considerations

- Most of the intellectual property used in this design is already patented
- We are using design components that we will have to license from other companies (i.e. battery, Velcro straps, resistive heating wire, etc.)
- At this phase, we are not concerned with IP protection because nothing in our design is novel technology; rather, it is an application of several technologies

# Lessons Learned

- We were too eager to pursue the Peltier option
  - Lack in consideration for power requirements
  - Too committed to the idea of integrating both heating and cooling modalities
- Learned that when designing a product, we must be truly open to considering all design options
- **Eliminate client bias** in choosing a design option

# Future Directions

We have:

- CAD drawings for all design components
- Required part pricing and lead times
- Assembly method

Opportunity for:

- Second design team to continue to prototyping phase
- Revision of design to better fit prototyping requirements
- Eventual large scale production via startup company

# References


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# Questions?