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Development of Core Body Temperature (CBT) and Heart Rate Wearable Device

Brenna Carbone
Case Western Reserve University

Madison Castellanos
Case Western Reserve University

Jonathan Chen
Case Western Reserve University

Jenna Wagner
Case Western Reserve University

Core Body Temperature Wearable

EBME 370 Team 5:
Brenna Carbone, Madison Castellanos, Jonathan Chen, Jenna Wagner

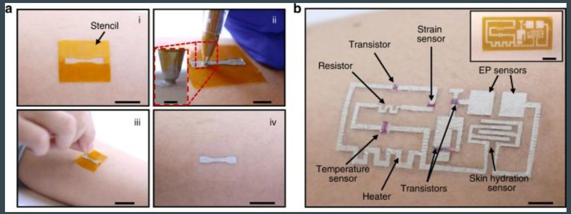
Background

Need Statement: There is a need for a wearable device that can accurately measure core body temperature through non-invasive means. The device will reliably relay information to users in order to prevent instances of hyperthermia during physical activities, which can have long lasting physical effects upon the body.

Current Standard of Care:

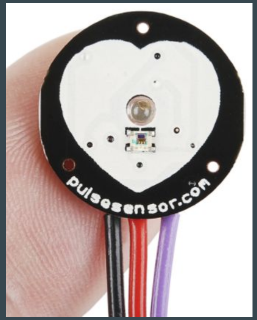
- Rectal Thermometer: medical standard, invasive, cannot take continuous temperature
- Measurement Types: skin temperature, heart rate, heat flux
  - Eliminate Artifacts: environment, movement, not continuous, sweat

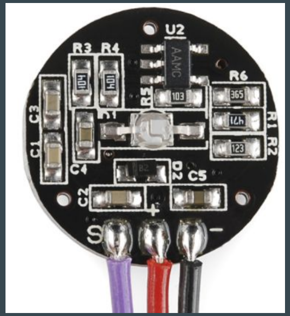
Current on the market devices and sensors: drawn on sensors and Oura Ring.



Concept Selection - Chest Belt

- Chest location determined to be most accurate
  - ± 0.21 °C accuracy
- Continuous active recording
- Similar to most chest belts on the market
  - Material
  - Adjustable sizes
  - Water resistant up to 30 m
- Improvements
  - Memory is one training session
  - 14°F to 122°F

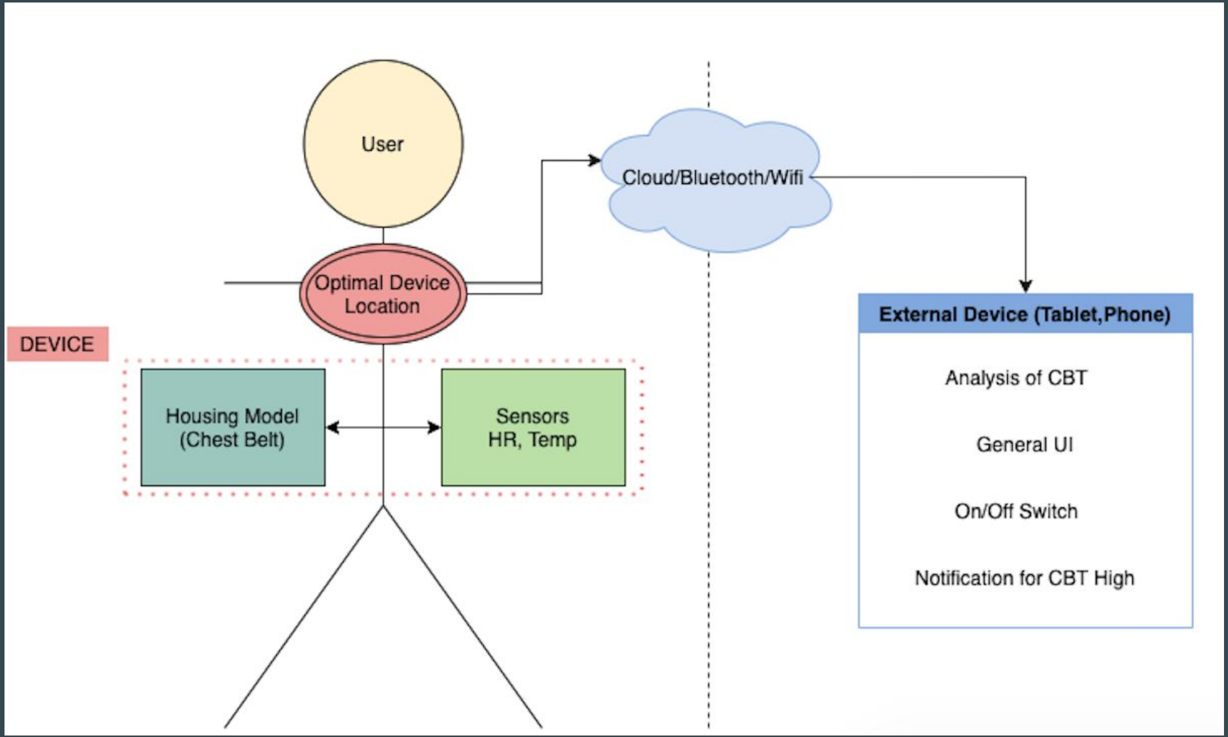




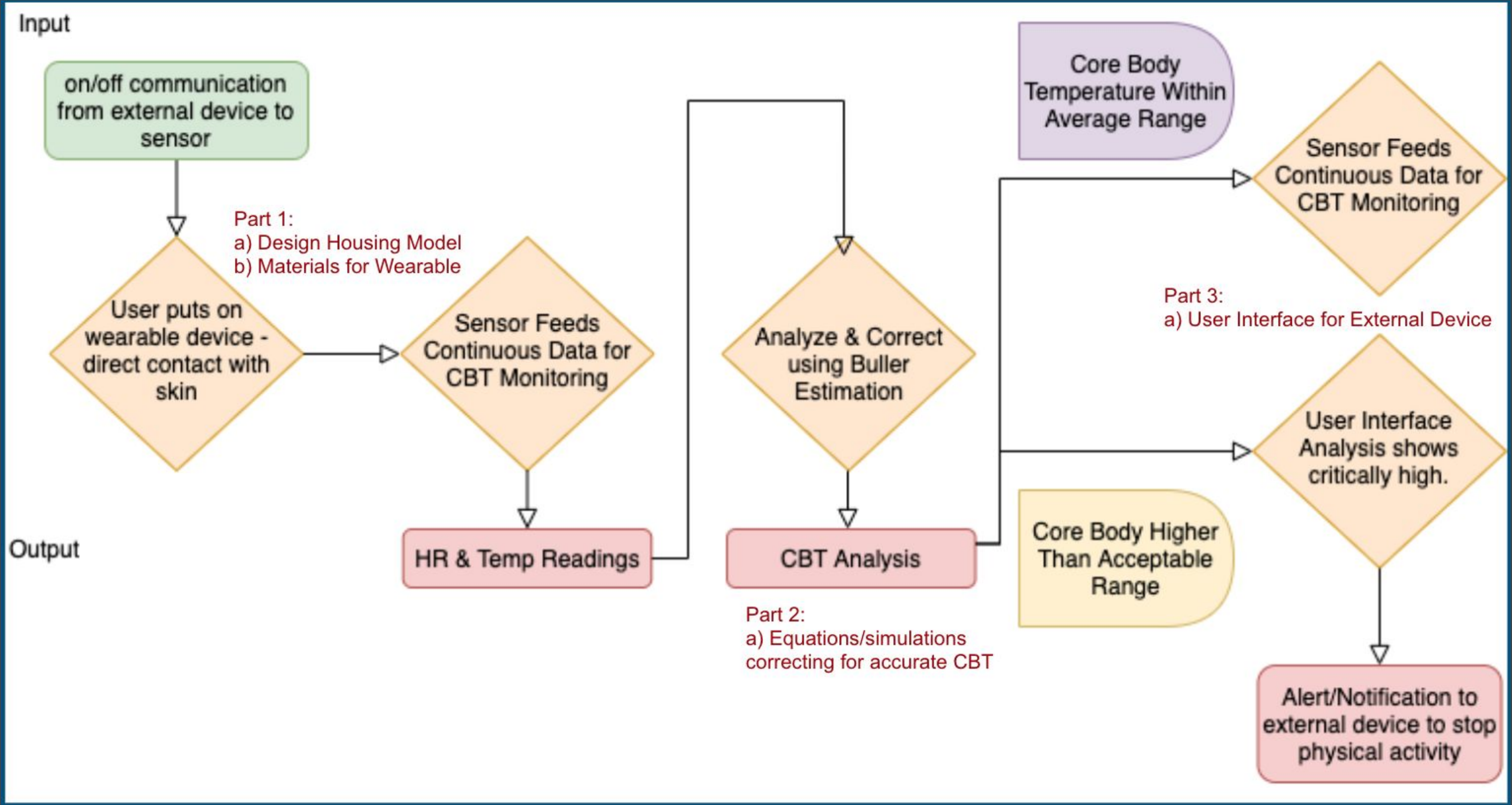
Key Problems

- Continuous monitoring
- Waterproofing
- Maintaining contact
- Impact
- Flexibility

System Architecture



System Architecture



```
for i = 1: length(HR) %Looping through all HR readings - HR array defined
    eqn = HR(i) == 41+(152/(1+0.06*exp((-0.89*(T-37.84))))^(1/0.07)); % EQ(8)
    S = solve(eqn,T); % solving for T represents CBT
    Sval = vpa(S); %manipulates symbol to value symbols
    Snum = double(Sval); %manipulate symbols to value
    Sreal = Snum(real(Snum)>0 & imag(Snum) == 0); %identifying real soln
    BullerCBT(i) = Sreal; %set value for HR to CBT array which will be graphed
end
```

$$HR_t = 41 + \frac{152}{\left(1 + 0.06e^{-0.89(\widehat{CT}_t - 37.84)}\right)^{1/0.07}}$$

```
figure
plot(time,BullerCBT)
title('Core Body Temperature (Buller) vs. Time')
xlabel('Time Point')
ylabel ('CBT in ° Celsius')

figure
plot(time,HR)
title('Heart Rate vs. Time')
xlabel('Time Point')
ylabel ('CBT in ° Celsius')
```

Input

```
HR = 59
```

```
Snum =

  33.9394 - 2.9566i
  33.9394 + 2.9566i
  36.6984 + 0.0000i
  33.8462 + 3.2254i
  34.7553 - 2.0780i
  34.1013 + 2.6823i
  34.1013 - 2.6823i
  34.7553 + 2.0780i
  33.8462 - 3.2254i
  33.8111 + 3.4919i
  35.4591 - 1.6414i
  34.3552 - 2.3957i
  34.3552 + 2.3957i
  35.4591 + 1.6414i
  33.8111 - 3.4919i
```

Output

```
Sreal =

   36.6984
```

(4) Compute the Kalman gain (k_t) weighting factor based on the preliminary estimate of variance and using the extended Kalman filter mapping function variance coefficient (m_t).

$$k_t = \frac{\widehat{v}_t m_t}{m_t^2 \widehat{v}_t + 356.4544} \quad (4)$$

(5) Compute the final CT estimate (CT_t) using the preliminary time-update estimate, the error between the HR_t observation and the expected HR given the preliminary estimate of CT.

$$CT_t = \widehat{CT}_t + k_t(HR_t - (-4.5714\widehat{CT}_t^2 + 384.4286\widehat{CT}_t - 7887.1)) \quad (5)$$

(6) Compute the variance of the final CT estimate (v_t).

$$v_t = (1 - k_t m_t)\widehat{v}_t \quad (6)$$

The new sigmoid equation was fit using a generalized logistic function (Richards, 1959). The generalized logistic function used can be written as:

$$HR_t = A + \frac{K - A}{\left(1 + Qe^{-B(\widehat{CT}_t - M)}\right)^{1/v}} \quad (7)$$

```
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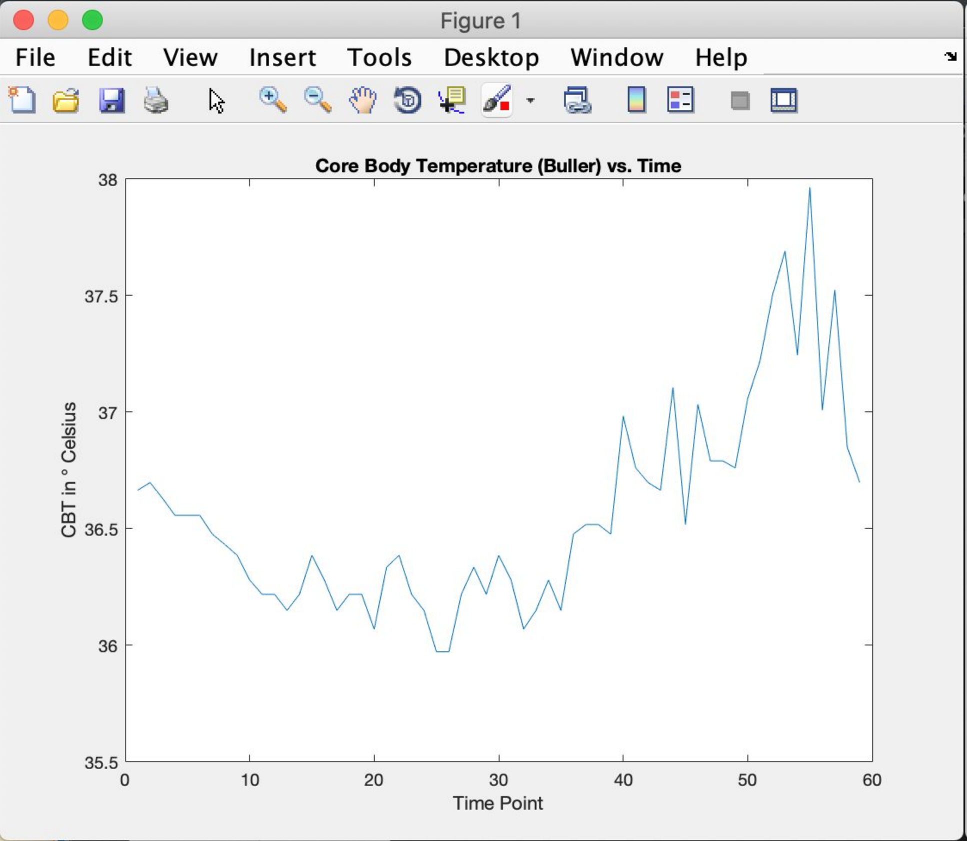
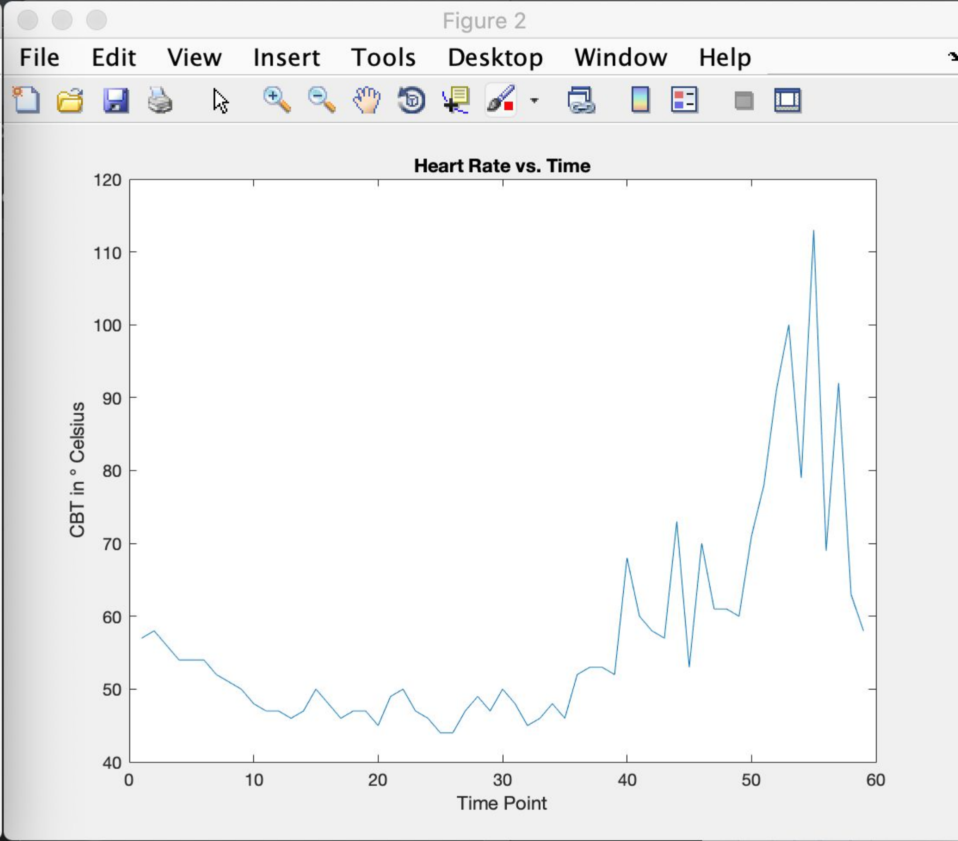
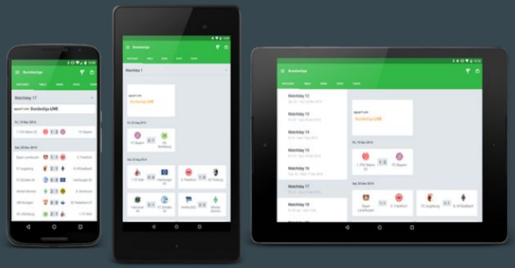
$$HR_t = 41 + \frac{152}{\left(1 + 0.06e^{-0.89(\widehat{CT}_t - 37.84)}\right)^{1/0.07}}$$





Sample of Interface



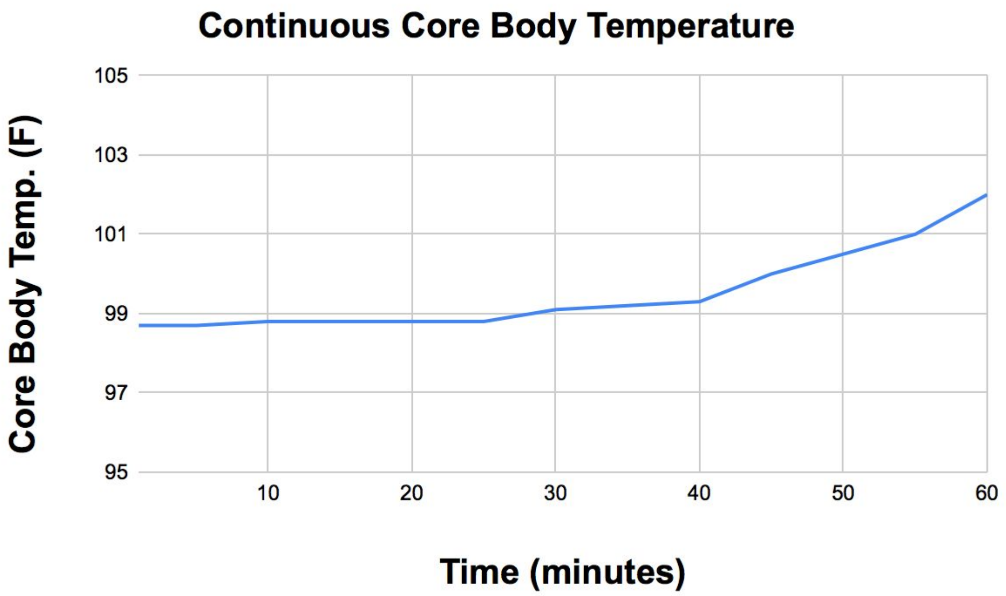
Back to Team Status

High Core Body Temp Detected:
Seek Medical Attention

Player's Medical History

Player's Emergency Contacts

PLAYER: JOHN SMITH



DEVICE STATUS:
ACTIVE

Power ON

Device Battery

Settings

Saved History

Verification & Validation Testing Planned

- Prototype Polar sensor with algorithm and GUI, then with purchased heart rate sensor
- Testing before introduction to User and with User
  - Does device meet design and technical specifications
  - Is device intuitive and works as expected
- Device specs testing
  - Waterproofing, impact, continuous measurement, longevity
- **Testing Method Example:** Our core body temperature device must measure the user's temperature while the rectal thermometer takes the user's temperature then the temperatures are compared. The technical specification is verified if our device is accurate within 0.01°F of the rectal thermometer, the industry standard.

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