Jon Deaton, Diana Gong, Anna Jaffe
BIOE 141B
2/19/17

Milestone 3

3.0: Project Overview

Need statement: People uneducated about and at risk for non-exertional heat stroke in hot regions of India need a method to reduce the likelihood of experiencing heat stroke to decrease mortality.

To address our need statement, we are creating and testing a heat stroke risk prediction wearable device. The overall concept is a system of sensors that take environmental and the user's physiological parameters and connect to a mobile phone to estimate heat stroke risk. A complete project includes sub-projects of development of algorithms for risk assessment, wearable hardware, mobile-software, and experimental testing procedures; however, we have chosen to focus only on the first and last components (depicted in Figure 1) during BIOE 141A/B.

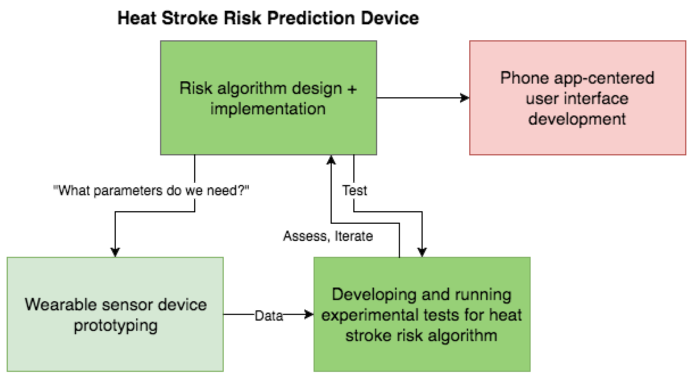


Figure 1: Complete concept subcomponent relationships and intended focus. Red indicates an area that we will not be addressing during BIOE 141A/B. Shades of green indicate areas that we will be addressing with our milestones, with dark green representing more focus and light green representing less focus.

We intend to implement a prototype that senses relevant parameters and need not necessarily be wearable, minimally intrusive, or connect wirelessly to a phone, as we aim to prove concept viability rather than produce a ready-to-use device. Our concept (Figure 2) involves sensors connected to a microprocessor that relays information to a computer, which predicts heat stroke risk using machine learning (ML) algorithms. By the end of BIOE 141B, we aim to have developed hardware and software that allow us to accurately sense and predict heat stroke, as well as a series of experimental tests verifying that our device functions as expected.

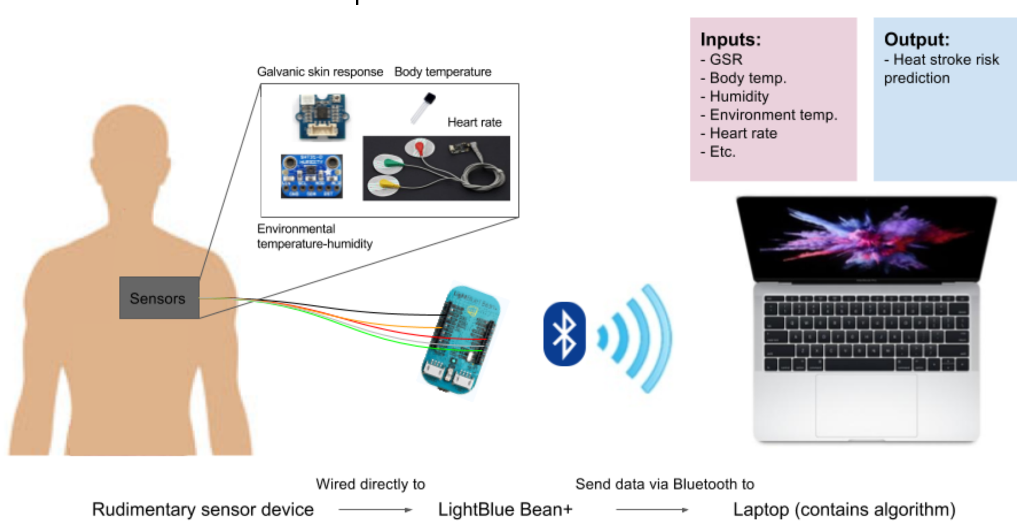


Figure 2: Graphic depicting our concept of a heat stroke risk prediction wearable device prototype.

Jon Deaton, Diana Gong, Anna Jaffe
BIOE 141B
2/19/17

3.1: Milestone Overview

<u>Milestone 3:</u> Build a system of sensors and measure accuracy of the components.

Milestone 3 involves assembling various sensors into an integrated system with a LightBlue Bean+ that transmits data via bluetooth to a computer for further processing. Here, rather than prioritize obtaining small, inexpensive, and extremely precise/accurate sensors for a prototype ready for distribution in India, our primary focus is proof-of-concept. In this milestone, our outputs will be **1)** a device that can measure environmental and physiological parameters for heat stroke risk assessment, and **2)** a bar graph +/- S.E.M. for percent error of each sensor (as measured against values assumed to be "ground truth," obtained from other devices). Success will be determined by being able to view a live stream of sensor data on a laptop, and percent error for sensors should be ≤ 30%, which we determined to be reasonable for an initial device prototype and leaves room for future improvement.

3.2: Milestone Methods

Obtaining and testing sensors: We used the following sensors that, based on literature review in Milestone 1 and algorithm design and data from Milestone 2, we thought would be useful moving forward:

- Environmental temperature/humidity (Adafruit SHT31)
- Galvanic skin response (GSR; BLUE)
- Oral thermometer, as a proxy for core temperature (Generation Guard)
- Pulse monitor (Pulse Sensor)

Gold standard devices:

- Hygrometer/digital thermometer (Pictek)
- Esophageal thermometer + heart rate monitor (Heller Lab)

Sensor code integration (Arduino): We have been using pre-existing open-source code for the GSR sensor, SHT31, and pulse monitor **(Appendix A)**. However, integration has been challenging; we believe this is due to Arduino Serial Monitor rates, but we are unsure because of the complexity of the code. For example, code for the pulse monitor has multiple tabs and uses timer interrupts, and the SHT31 code creates an instance of a non-Arduino IDE class. See **Appendix B** for our steps in setting up sensors and the LightBlue Bean+ with a laptop.

Testing sensors: Our first run-through was in the Heller Lab on 2/17/17 (**Appendix C and D**). Because our code was not yet fully integrated, we rotated taking measurements for each sensor. We obtained a measurement every 30 seconds for 2 minutes (5 measurements total) with a cycle of 6.5 min. The Heller Lab uses an esophageal temperature probe and a heart rate chest strap which served as gold standards against which to compare our oral thermometer and pulse monitor sensors, respectively.

To test the accuracy of the Adafruit SHT31 environmental temperature/humidity sensor against our gold standard Pictek device, we took measurements every 30 seconds for 5 minutes in the following environments:

- Inside dorm
- Inside shower stall immediately after hot water had been running
- Outside on overcast/drizzly day

3.3: Milestone Results

Our temperature, humidity, and pulse sensors are able to take measurements with percent error <30% in different environments (Figure 3; see Appendix E for raw data).

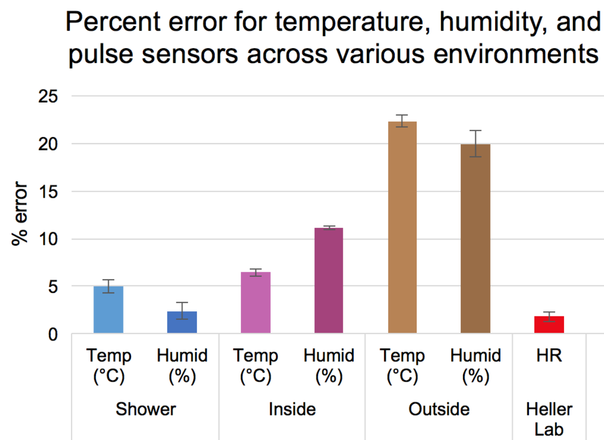


Figure 3: Percent error for sensors in various environments. Plot quantifying % error +/- s.e.m. in measuring parameters of wearable sensors (SHT31 and pulse sensor) compared to gold-standard measurement devices (Pictek and chest strap heart rate monitor).

We were able to view a live stream of sensor data on a laptop in multiple conditions (indoors shown in Figure 4; outdoors and Heller Lab not pictured).

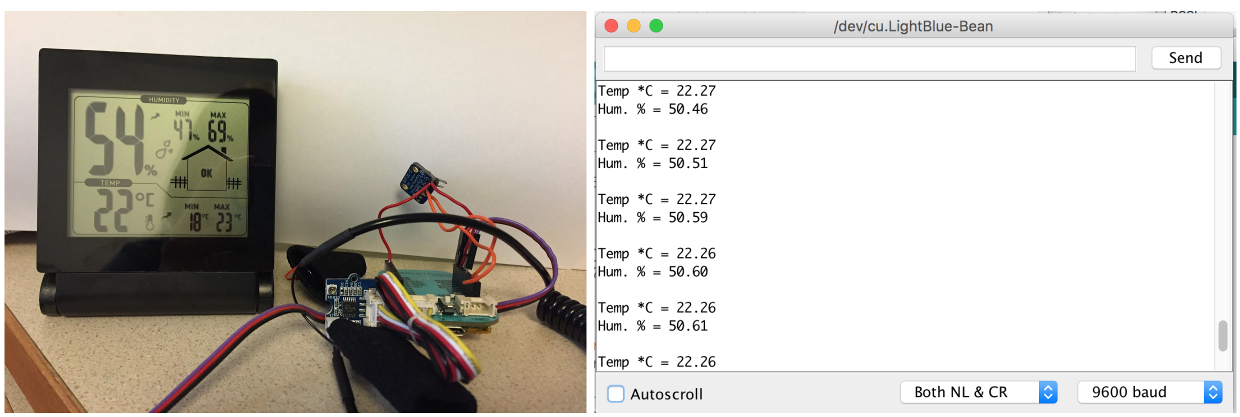


Figure 4: Gathering sensor data and comparing with gold standard. Successful collection of temperature and humidity readings from the SHT31 sensor and comparison with gold standard Pictek household hygrometer/digital thermometer.

3.4: Milestone Interpretation/Discussion

- We put together a device with multiple sensors that all output readings to the Arduino Serial Monitor.
    - The device did not break in the hot, wet (perspiration collected in the bottom of the garbage bags tied around the hands where the device was held) environment of the Heller Lab protocol, indicating that the system could be robust in environments where heat stroke is a risk.
    - The LightBlue Bean+ stopped connecting to the computer after ~33 minutes of the Heller Lab protocol, but we attribute this to the unreliability of the Bean Loader application. In the future, we could evade this problem by replacing the sensor system with a duplicate if the first one fails.
- Percent error is <30% for temperature/humidity and pulse sensors, meeting our success criteria.
    - Percent error was highest for the case where the sensors were outside. The Pictek device is described as an "indoor humidity monitor," so a less accurate gold standard reading could have skewed the results.
    - For the shower and indoor environments, percent error was <15%.

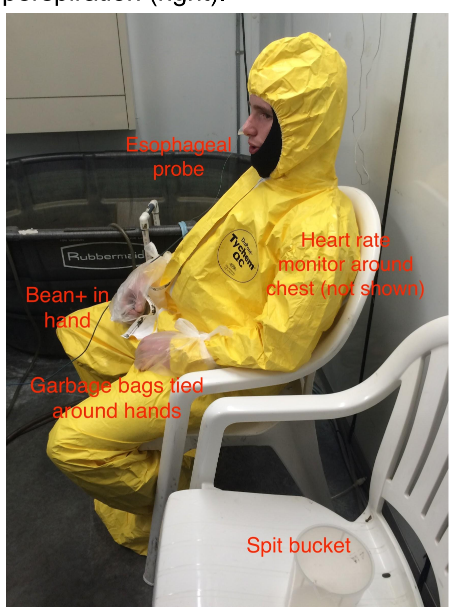
  - We are looking to continue testing sensors in additional extreme environments that will be more representative of those in which a heat stroke could occur (i.e., hot and humid) such as the Heller Lab, which we will be using in Milestone 4.
  - We do not yet have a gold standard for GSR and will accommodate for this by weighting GSR less heavily in the algorithm. The GSR sensor has little documentation and an output of unknown units, furthering the justification for a de-emphasis.
  - Sensors could be optimized in the future, but we will not be focusing our efforts on this area.
- We are turning in the milestone on the original due date (2/19/17).
  - We were not able to successfully integrate sensor code into one Arduino sketch but have reached out to Ross for help on this front and hope to have this figured out in the next week so that we can smoothly carry out Milestone 4.

3.5: Supporting Material/Appendices

Appendix A: Github containing Arduino codes for each sensor.
Pulse monitor: AllSensors_2-17-17
Galvanic skin response sensor: Arduino_GSR
Environmental temperature/humidity sensor: SHT31_anotherattempt

Appendix B: Milestone 3 Tutorial (for Bean Loader and sensors)

Appendix C: Photos of Jon undergoing and after the Heller Lab non-exertional hyperthermia-inducing protocol (room held at ~46°C; left). Vasodilation was noticed in the face and hands, as well as excessive perspiration (right).



Appendix D: Data entries for 2/17/17 Heller Lab sensor (HR, GSR, temp, humidity) test.
Appendix D.1: 2/17/17 Heller Lab sensor test graphs (below).

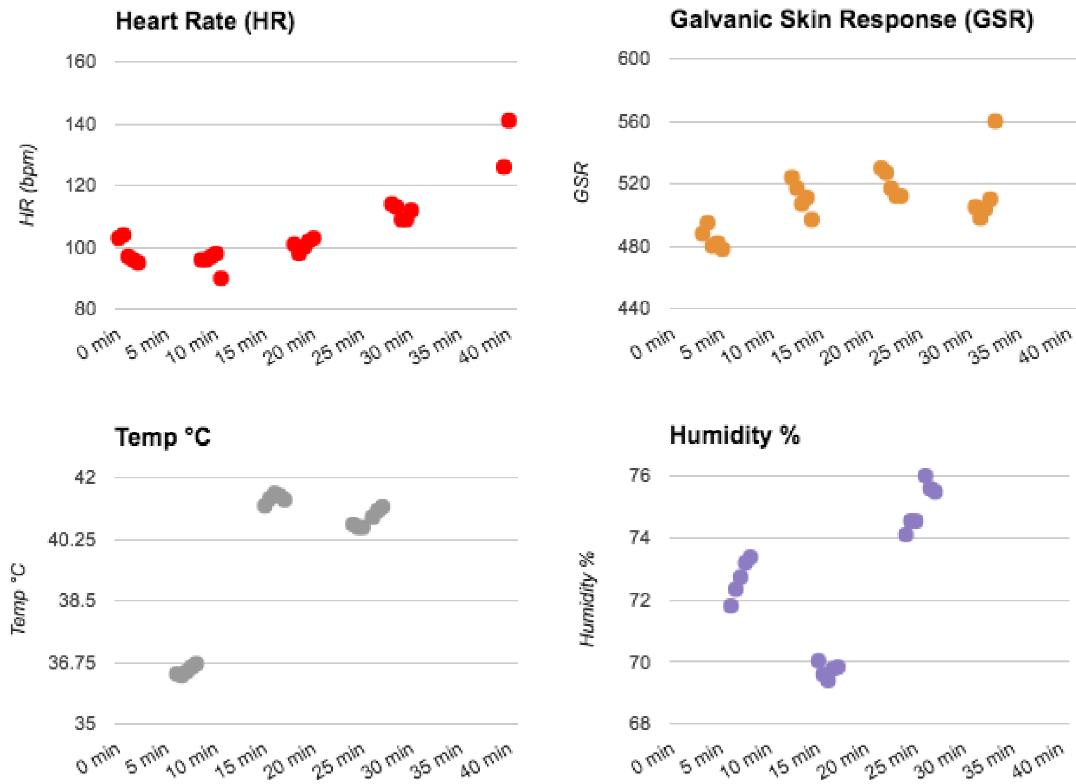


Figure D.1: Results from sensor system, Heller Lab test 2/17/17. Due to code that was not fully integrated, measurements for each sensor were viewed on Arduino Serial Monitor manually recorded for 2 minutes over ~6.5 minute intervals. Heart rate trends appear to be consistent with gold standard data (see Figure 3, Figure D.2). Temperature and humidity were measured inside of the garbage bags covering the hands, which become very hot and moist due to collected perspiration over time and may have skewed sensor readings.

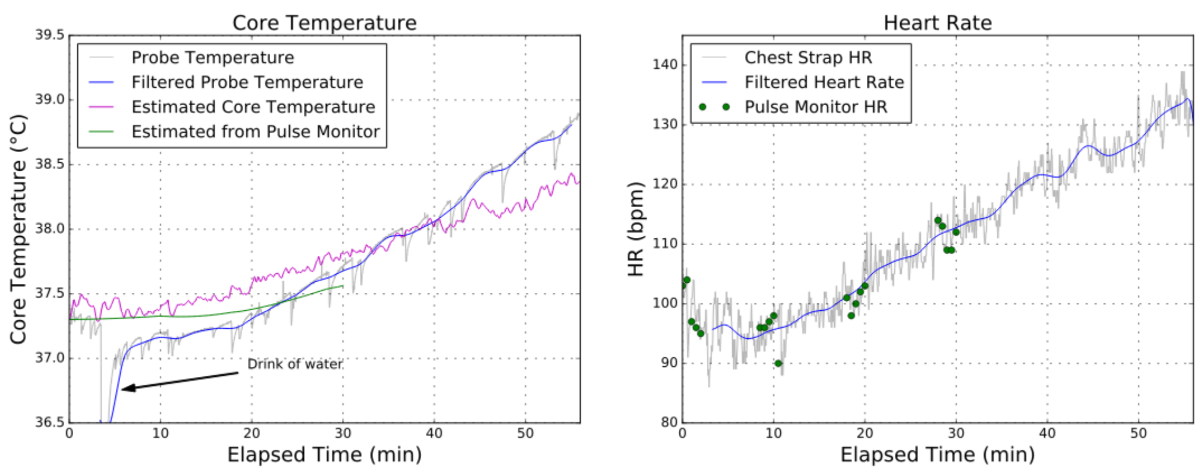


Figure D.2: Results from Heller Lab esophageal probe and heart rate monitor (used on Jon). Core temperature (left, grey) and heart rate (right, grey) were measured continuously throughout the non-exertional hyperthermia experiment using an esophageal probe and chest strap-mounted heart rate monitor. Core temperature initially decreased due to hypothalamic regulation. Heart rate increased throughout the experiment in an attempt to dissipate heat through the glabrous areas. Convolutional filtering was performed on both datasets to show general data trends and remove the presence of dips in core temperature measurement due to swallowing saliva. Several heart rate measurements were also made using our device's pulse sensor on the finger at intervals of ~10 minutes (green, right). Estimations of core temperature from heart rate measurements were made using the Kalman Filter Model adapted from Buller et al. (2013)[1] on the raw heart rate data from the chest strap (left, magenta), and the pulse monitor data after interpolation (left, green). The general upward trend of core temperature prediction from our pulse monitor readings and Heller Lab equipment matches those of the actual values, but the slopes are less steep.

Appendix E: Raw + processed data and plots for testing SHT31 temperature/humidity sensor in 3 different environments: shower, indoor, and outdoor.

[1] Buller MJ et al. "Estimation of human core temperature from sequential heart rate observations." Physiol Meas. 2013 Jul;34(7):781-98. doi: 10.1088/0967-3334/34/7/781. Epub 2013 Jun 19.