HEAT EXHAUSTION DETECTION DEVICE

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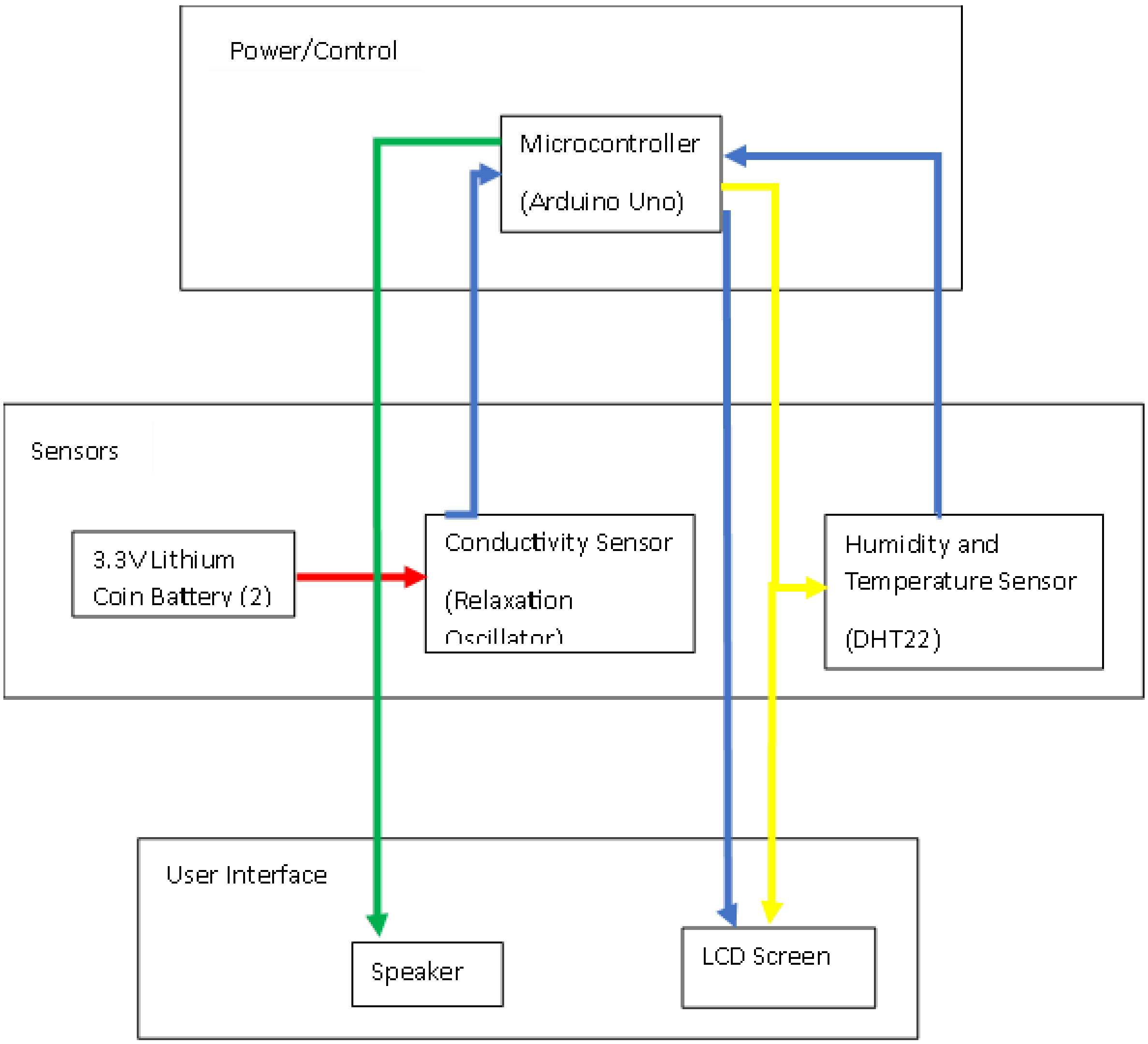
Abstract

In this project we designed and built a device capable of detecting heat related illness. The device utilizes chloride data from a study in the Journal of Taibah University Medical Sciences in combination with a relaxation oscillator to detect chloride concentration of the users sweat. The device also uses a temperature and humidity detector to provide heat index data to the user. Based on the sensor data the device will produce an alarm to indicate a heat related illness is possible. The report outlines the design specifications and testing results used for the development of the project.

Contents

1. Introduction

Heat related illnesses such as heat stress, heat exhaustion and heat stroke pose a great danger to people, especially those who work in harsh environments such as factory workers or construction workers. With global temperatures rising early estimates from the Center for Disease Control and Prevention have estimates that heat related deaths have increased by 56% between 2018 and 2012 [1]. The solution, and original design for this project, was to design a wearable device that could measure the chloride concentration of the wearers sweat, measure the outside conditions and measure the activity level of the individual. The device would then provide information to the wearer of the level of risk they are for a heat related illness and produce an alarm if the chloride concentration reached too low a value. Due to issues involving the compatibility and size of the initially ordered parts, the final block diagram of this design can be seen in Figure 1. The design consists of three major blocks: power and control, sensor and user interface. The power and control block consists of the Arduino uno which provides the necessary 3.3V and 5V power supplies as well as the microcontroller. The sensor block contains a relaxation oscillator which is used to measure the sweat conductivity and the DHT22 for temperature and humidity measurements. The user interface block consists of a CVS-1508 speaker for the alarm function and an LCD to display heat index information and alarm information. The original design included a voltage regulator to be used in conjunction with the batteries to power the device but given the use of the Arduino it was no longer necessary to use the voltage regulator as the Arduino has one built into the board. The original design also utilized an accelerometer to monitor activity levels but the ordered accelerometer was too small to be utilized in a breadboard so it was ultimately removed from the final design.



LEGEND	
Power (5.0V)	
Power (3.3V)	
Data	
Control	

Figure 1.1 Block diagram of design.

2. Design

2.1 Design Procedure

For the power and control block the Arduino Uno was decided upon. The Arduino uno offers both 3.3 V and 5.0 V regulated power supplies as well as multiple channels of analog to digital conversion. The Arduino is a very flexible development board with many functions and provides a method for simple debugging. For the sensory block, specifically the conductivity sensor, the LM741C op amp was chosen due to its breadboard compatible packaging as well as its wide range of supply voltages which allow the flexibility of battery sizes at the supply rails. The specific batteries used for this design were two 3.3 V Duracell industrial lithium coin batteries. These batteries provide the necessary power rail voltage to the op amp while also providing a large 245 mAh capacity which will provide the long battery life necessary for a device to be worn for at least an eight-hour shift of work. The DHT22 temperature and humidity sensor was chosen because of its breadboard compatible design, low power consumption and high accuracy measurements. For the user interface block the CVS-1508 speaker was chosen for its small size and low power consumption. A switch was also utilized to provide a method of silencing the alarm until the wearers condition has improved. The LCD was chosen as the 16x02 display was large enough to provide the necessary information but small enough that it could be incorporated into a wearable device. The display was also easily integrated into the Arduino development board.

2.2 Design Details

2.2.1 Power and Control

The power and control of the device is accomplished by the Arduino uno development board. The Arduino uno was an ideal choice as it offers a built-in voltage regulator with 5.5 V and 3.3 V power supplies which are ideal for powering the LCD as well as the temperature and humidity sensor. The Arduino is also capable of I2C communication which provides flexibility with the number of sensory devices that can be connected and is used for communication with the LCD and DHT22. The Arduino also features an analog to digital converter which is necessary for reading the conductivity sensor. The analog to digital converter provides a 10-bit digital equivalent reading of the electrode voltage which provides a voltage reading accuracy up to two decimal places. Another useful Arduino function that was used was the tone function which allowed the control of the speaker frequency which was used to generate different alarm tones for each of the alarming conditions. Because of the Arduinos ease of usage, compatibility with the breadboard and associated sensors and ease of debugging it was the best choice to provide power and control to the device.

2.2.2 Temperature and Humidity Sensor

The DHT22 temperature and humidity sensor was used to monitor the relative humidity and temperature of the environment in order to calculate the heat index. The main equation for calculating the heat index can be seen in Equation (2.1) where T is the temperature and RH is the relative humidity. The complete set of heat index calculations can be found in reference two [2].

$$
\begin{gathered}
HI = -42.379 + 2.04901523*T + \\
10.14333127*RH - .22475541*T*RH - \\
.00683783*T*T - .05481717*RH*RH + \\
.00122874*T*T*RH + .00085282*T*RH*RH \\
- .00000199*T*T*RH*RH
\end{gathered}
\tag{2.1}
$$

The functions found in the Adafruit GitHub library allowed for the conversion of the Celsius measurement to Fahrenheit as well as incorporate the full set of heat index calculations into a single function [3]. This was necessary for displaying the correct heat index warning to the wearer which corresponded to a set of safety precautions which can be seen in Figure 2.

Classification	Heat Index	Effect on the body
Caution	80°F - 90°F	Fatigue possible with prolonged exposure and/or physical activity
Extreme Caution	90°F - 103°F	Heat stroke, heat cramps, or heat exhaustion possible with prolonged exposure and/or physical activity
Danger	103°F - 124°F	Heat cramps or heat exhaustion likely, and heat stroke possible with prolonged exposure and/or physical activity
Extreme Danger	125°F or higher	Heat stroke highly likely

Figure 2.1 Heat index chart [4]

2.2.3 Conductivity Sensor

The conductivity sensor utilizes a relaxation oscillator in order to produce an AC square wave which is supplied to the electrodes. The AC voltage is necessary in order to prevent ionization of the salts in solution and to provide a more accurate conductivity reading. The schematic for the conductivity sensor can be seen in Figure 2.2 where R1 through R4 are 1 kohm and C1 is 0.4 μF. The positive and negative power rails of the op amp were supplied using the 3.3 V Duracell Lithium coin batteries. Using the inverting port of the op amp and the RC time constant the frequency of the oscillator can be determined. Equations (2.2) through (2.4) dictate the operation of the oscillator.

$$V_+ = \frac{V_{OUT}}{2} \tag{2.2}$$

$$V_- = V_{OUT} - V_{OUT}e^{\frac{-t}{RC}} \tag{2.3}$$

$$f = \frac{1}{2\ln(3)\,RC} \tag{2.4}$$

As the capacitor of inverting side of the op amp charges and discharges, the output of the op amp will oscillate between the positive and negative power rails at a frequency determined by equation (2.4). By using a resistance of 1 kohm and a capacitance of 0.4 μF a frequency of approximately 1138 Hz can be obtained. Due to the high sampling frequency of the

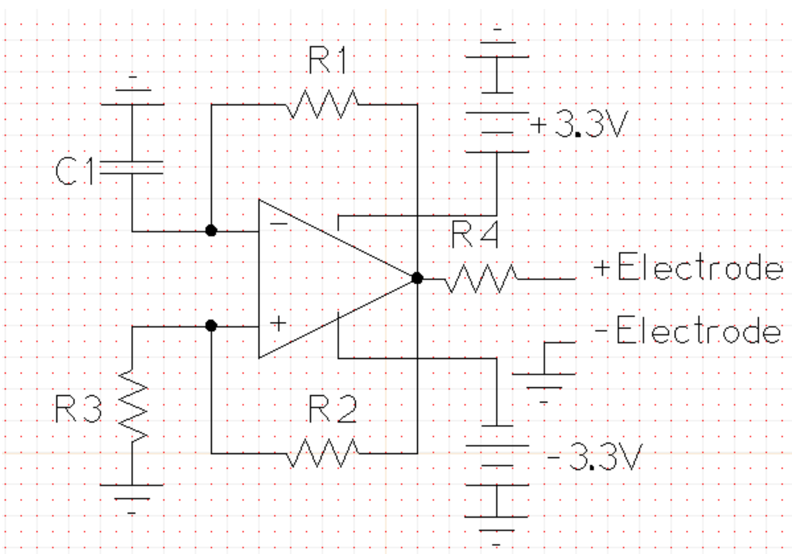


Figure 2.2 Schematic of relaxation oscillator.

microcontroller and the asymptotic nature of the voltage readings an average voltage value was used to determine the conductivity level. Solutions with higher salt content will conduct more current which will result in a lower voltage reading on the electrode. The results from testing on three premade solutions can be seen in Table 2.1.

Table 2.1 Voltage reading from solution testing.

Solution	Average Voltage
None	1.10
Heat Stress (25 mmol/L)	0.65
Heat Exhaustion (20 mmol/L)	0.71
Heat Stroke (5 mmol/L)	0.77

The average voltage readings were recorded after ten consistent measurement loops to ensure accuracy of reading. Using the results obtained in Table 2.1 the alarm setpoint bands for the heat stress, heat exhaustion and heat stroke alarms were obtained.

2.2.4 LCD Screen and Speaker

The LCD screen and speaker provide the user interface components of the device. The LCD screen used was the LCD 1602 display. The display was chosen because of its small size, bright display and I2C compatibility. The LCD has a 16x2 character display which allowed for the display of the current heat index as well as the detected heat related illness alarming condition. The LCD was easily compatible with the Arduino uno. The speaker chosen was the CVS-1508. This was chosen due to its small size and easy compatibility with a bread board. During an alarming condition the speaker will produce a tone at approximate two second intervals. The speaker will also produce different tones for each alarming condition. The speaker will produce a 400 Hz tone for heat stress, a 600 Hz tone for heat exhaustion and an 800 Hz tone for heat stroke. A switch is also provided to silence an alarming condition until the condition is cleared.

3. Verification

In order to properly test and verify conductivity sensor a salt solution must be made as a representative of the users sweat. While there are several different electrolytes and minerals in a person's sweat the majority concentration can be attributed to sodium and chloride [9]. This can be accomplished by simply dissolving table salt in water. Because the referenced study only mentions the chloride concentration the chemical formula for salt can be used to work to the amount of salt needed to be dissolved to reach the cited threshold.

$$NaCl \rightleftarrows Na^{+} + Cl^{-} \tag{3.1}$$

Equation (3.1) shows the chemical formula for table salt. Using this equation in combination with the desired alarm threshold of 20.0 mmol/L and the molecular weight of salt being 58.44g/mol it can be found that 1.17 g/L of dissolved salt is needed to test the alarm setpoint. The setpoint of 20.0 mmol/L is the point of heat exhaustion and for heat stress and heat stroke the values of 27.0 mmol/L and 5.0 mmol/L will be used. This will equate to a 1.6 g/L salt solution for heat stress and a 0.3 g/L salt solution for heat stroke. The test solutions were developed by using a scale to make measurements of standard table salt and mixed using a 600 mL shaker bottle. In order to verify the operation of the temperature and humidity sensor, as readings were being observed on the serial monitor of the Arduino IDE a thumb and forefinger was placed over the sensor. This allows the body heat to raise the temperature and by covering the vents of the sensor the relative humidity also increased. This is used to verify the operation of the sensor as well as the heat index calculations by comparing the temperature and humidity readings to the corresponding heat index level seen in Figure A.2 of Appendix A. The remaining requirements and verifications can be found in tables A.1 through A.4 of Appendix A.

4. Cost

4.1 Parts Costs

Table 4.1 outlines the parts used for the final design and the total cost for parts used for the final design. Other parts such as resistors, capacitors, wiring and the breadboard were used from a personal supply.

Table 4.1 List of parts used in final design and costs.

Part/Part #	Description	Cost
Arduino UNO REV3	The development board used for demoing purposes	$28
Sunfounder serial LCD display	Display relevant information with I2C interface	$8
Duracell batteries 3.3V	Provide power to all the subsystems	$2.52
DHT22 Temperature and humidity sensor	Measure the temperature and humidity of the environment to provide heat index	$10.89
Battery Clip	Holds battery for breadboard placement	$3.00
Total:	$52.41	

4.2 Labor Costs

The average annual salary of an ECE graduate from the University of Illinois is approximately $93,000.00 per year [1]. Extrapolating at 52 weeks per year and working 40 hours per week roughly equates to a total of 2085 hours per year worked. Using this a rough estimate of hourly wage is $44.60 per hour. Through the duration of the project an estimate of 90 hours per person was worked with an overhead of 2.5.

$$\text{Labor Cost} = (\text{hourly rate}) * \text{actual hours spent} * 2.5 \tag{4.1}$$

Utilizing equation (4.1) with the estimated hours worked for each team member at the desired hourly rate the total labor costs can be calculated.

Labor Costs = $30,105

Total Cost = $30,157.41

5 Ethical Considerations

This project is meant to address the safety risks that are involved with workers who must work in harsh environments. According to the CDC the symptoms of heat exhaustion can include dizziness, weakness and even fainting [12]. Experiencing one of these symptoms while operating a large piece of machinery, working around rotating equipment or working at a high elevation can be very dangerous not only for the individual but the other workers in the area. Following section I.1 of the IEEE code of ethics to hold paramount the safety, health, and welfare of the public, this project aims to provide workers an extra layer of safety by alerting them to the potential risk of experiencing a heat related illness [5]. The current design of the device hasn't been packaged and sealed, which means putting the current prototype directly in contact with body will pose some threats due to the wires, batteries, and PCBs. We will strive to minimize the size of the actual product to reduce the enclosure size and enable more realistic design in the future.

6. Conclusion

In this project, we created a heat exhaustion detection device that integrates different subsystems to comprehensively evaluate the risk of experiencing heat stress, heat stroke or heat exhaustion. We mainly used the temperature and humidity sensor to measure the environmental risk by means of displaying the current heat index, and an op amp to produce an AC square wave that enables the measurement of conductivity of sweat sample. We then implemented logic to integrate the data to alert the user of current status and condition. This provides the user a real time measurement of the heat index of the environment they are in as well alarm the user of a potential heat related illness.

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Appendix A Additional Charts and Tables

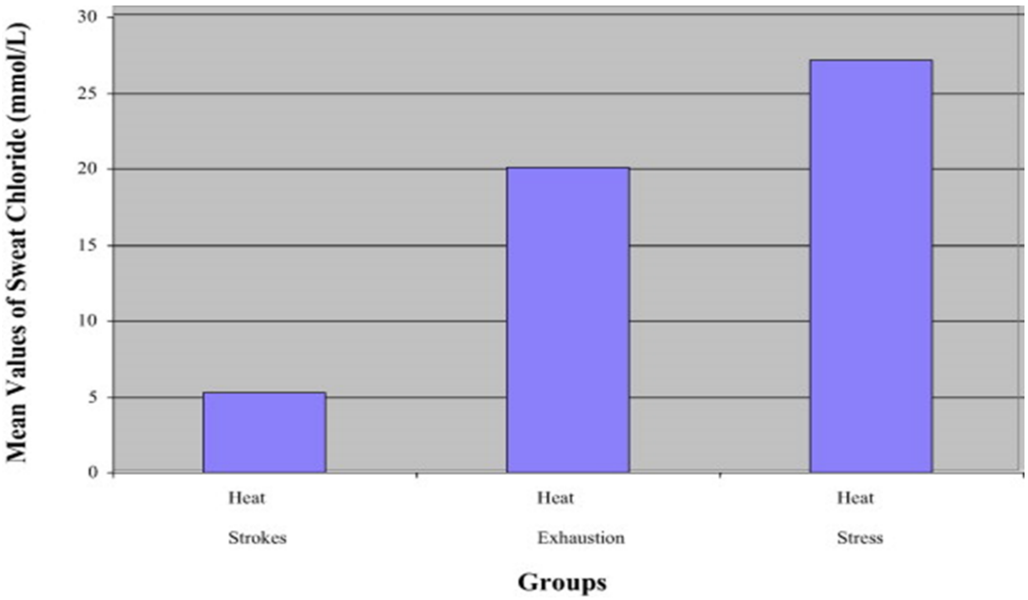
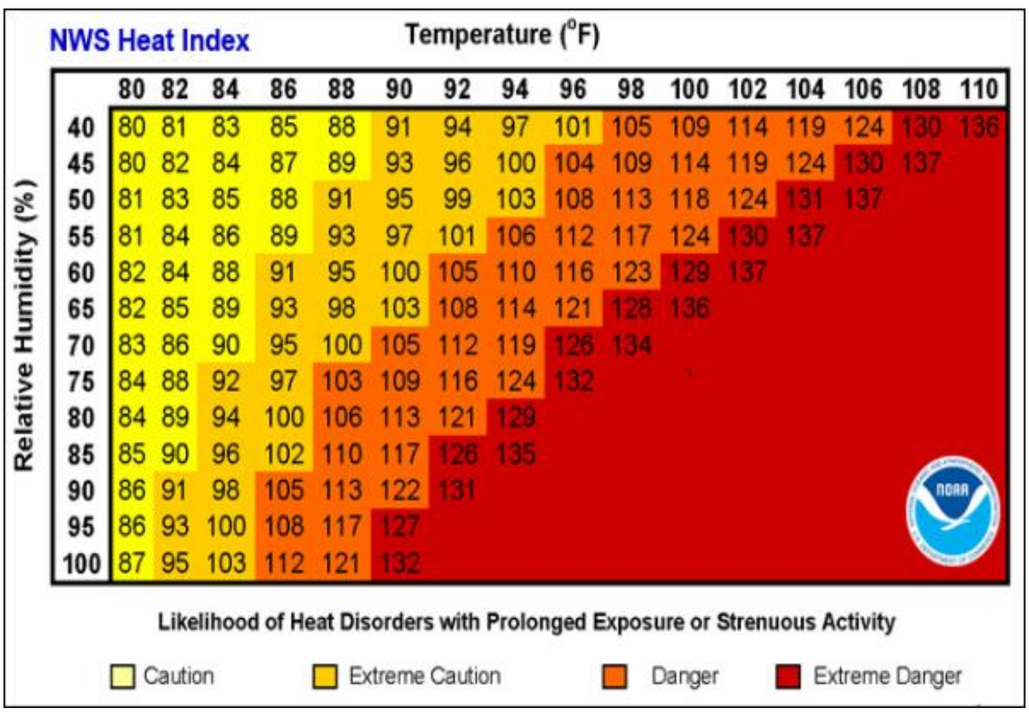


Figure A.1 Chloride concentration as it relates to heat related illnesses [5]



NWS Heat Index

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution · Extreme Caution · Danger · Extreme Danger

Figure A.2 National Weather Association heat index chart [4]

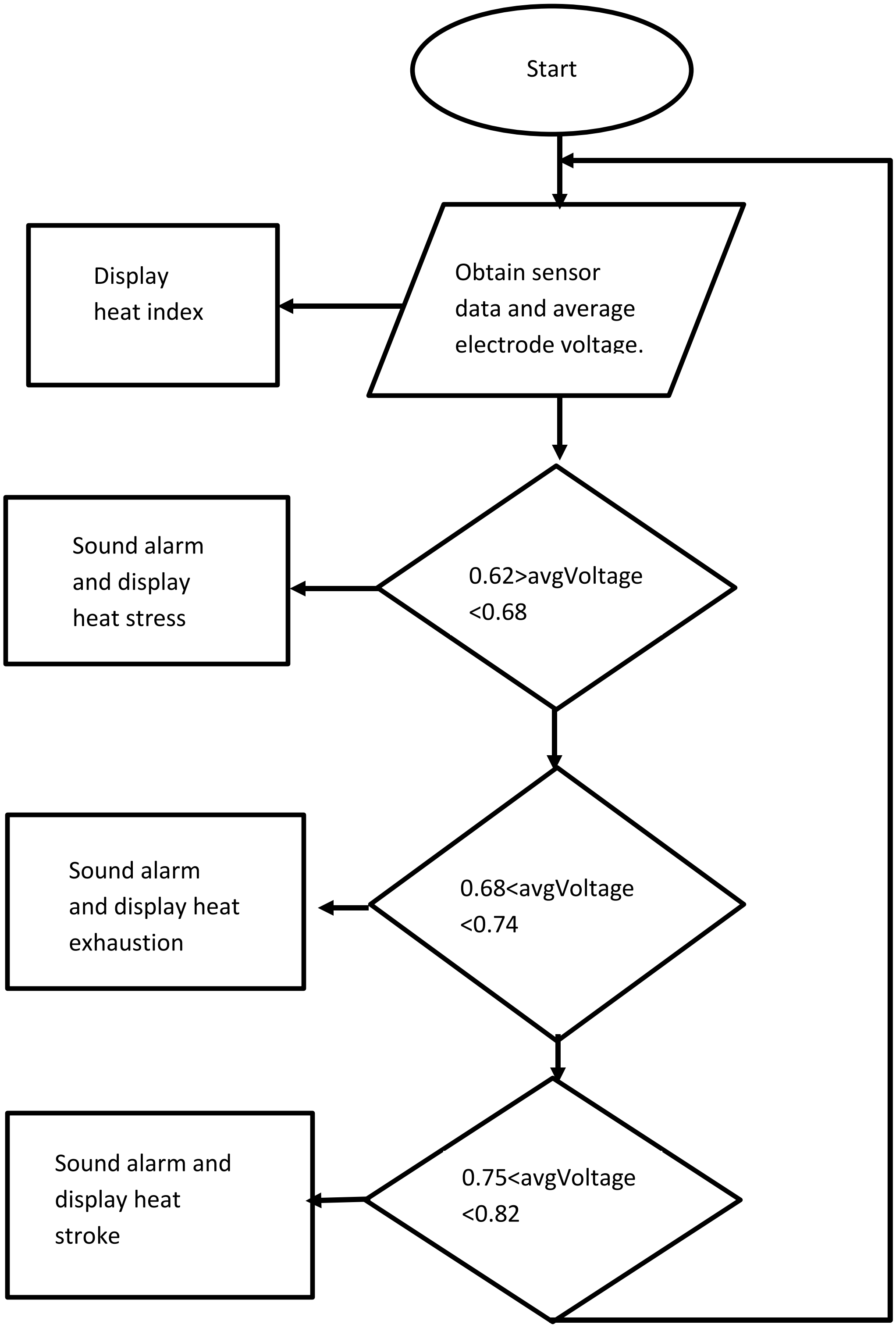


Figure A.3 Program flow chart.

Table A.1 Power Requirements

Requirements	Verification
• Provide the necessary 5V to the LCD display as well as the DHT22 temperature and humidity sensor	• The Arduino Uno has a built-in voltage regulator that produces both 5.0V and 3.3V power supplies verified through digital multimeter measurements.
• Provide the positive and negative voltage necessary to the op amp in order to produce an AC voltage	• Two 3.3V Duracell batteries are used for the op amp. Even at end of life the battery will provide +/- 2.0V to the op amp. Voltage verified through digital multimeter measurements.

Table A.2 Sensor Requirements

Requirements	Verification
• Provide a conductivity measurement that can be used to determine the chloride concentration of a sample within +/- 1.5mmol/L	• The conductivity was measured among four different premade samples containing 25 mmol/L, 20 mmol/L, 5 mmol/L and regular water respectively. Verified by taking periodic average voltage measurements.
• Provide air temperature and relative humidity measurements with enough accuracy to calculate the heat index.	• The accuracy of the DHT22 is +/- 2% RH and +/- 0.5 degrees Celsius. Verified by covering sensor and observing increase in temperature and humidity readings.

Table A.3 User Interface Requirements.

Requirements	Verification
• Produce different tonal alarms for each of the three alarming conditions; heat stress, heat exhaustion and heat stroke	• Verify alarm tone sounds when testing conductivity of each concentration sample.
• Vibrate the casing during each of the alarming conditions	• Verify the vibration motor actuates during each sample measurement.
• Display the current heat index level as well as the current chloride concentration level (displayed as normal, heat stress, heat exhaustion and heat stroke).	• Verify the LCD displays the current heat index level based on current temperature and humidity measurements. • Verify LCD displays the current chloride concentration level (heat stress, heat exhaustion, heat stroke and normal).

Table A.4 Control Requirements.

Requirements	Verification
• Actuate speaker alarm for each alarming condition	• Set alarm setpoints and verify speaker actuates desired tone for each sample. Setpoints verified by consistent sample measurements and noting average voltage reading.
• Take in temperature and humidity data and calculate heat index.	• Verify heat index function calculation based on NOAA equation given current conditions.