HEAT EXHAUSTION DETECTOR

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Design Document

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Contents

1. Introduction

1.1 The Problem

Heat related illnesses such as heat stress, heat exhaustion and heat stroke are a serious problem for everyone but especially individuals who perform hard labor in harsh environments. 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 2012 and 2018 [1]. Workers such as construction workers, roofers and even factory line workers have an increased chance of experiencing one of these illnesses. Unfortunately for these people, there is no simple method or device that can provide them with an early warning to alert them that they are at risk of experiencing heat related illnesses. People in this situation should remove themselves from the environment and hydrate as soon as possible. Furthermore, many parts of the world are much more dangerous than others. Construction around the equator is very risky. In addition, these parts of the world tend to have much less resources.

1.2 The Solution

The solution to this problem is to design a wearable device that can measure several different factors and provide an alert to the user and those around them that they should be removed from the environment. The device is intended only as a warning to the wearer that they are at risk of a heat related illness. It is also important that the device is inexpensive, so people around the world can benefit from the safety it provides. To implement these safety measures the device will use a humidity and temperature sensor to provide data on the environment the individual is working in. This will provide the information necessary to determine the heat index and the danger level of the environment the person is working in. A gyroscope and accelerometer will be used to measure the individual's activity level. A conductivity measurement will be used to monitor the chloride concentration of the individual's sweat. According to a study in the Journal of Taiba University Medical Sciences patients experiencing one of these heat-related illnesses showed a marked decrease in the sweat chloride concentration as the illness got worse [2].

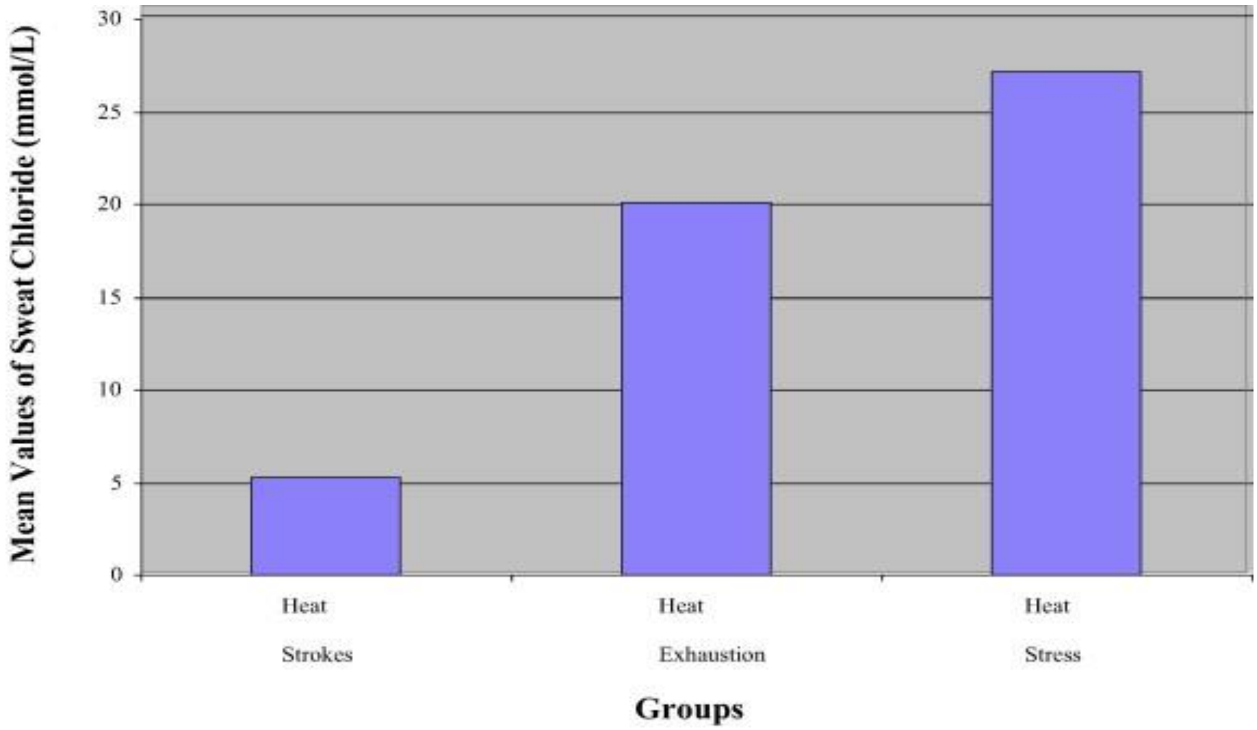


Figure 1.1 Sweat Chloride Concentration of Patients with Heat Illness [2].

As can be seen in Figure 1.1 the mean chloride level of a patient experiencing heat exhaustion is approximately 20.0 ± 1.5 mmol/L. This mean chloride level is what will be used for the conductivity alarming condition. The device will take these measurements and produce a visual and audible alert to the wearer and surrounding workers such that action should be taken to remove themselves from the environment to cool down, hydrate and replenish electrolytes.

1.3 Visual Aid

Figure 1.2 and Figure 1.3 show the front and back view of the proposed device. The front of the device will contain the LCD display screen in which the user can observe their risk level given current sensor data. The front of the device will also contain the speaker which will actuate during an alarming condition as well as the outside temperature and humidity sensor for more accurate measurements. The rear of the device will contain the electrodes used for conductivity measurement. The device will be able to be strapped to the forearm of the user.

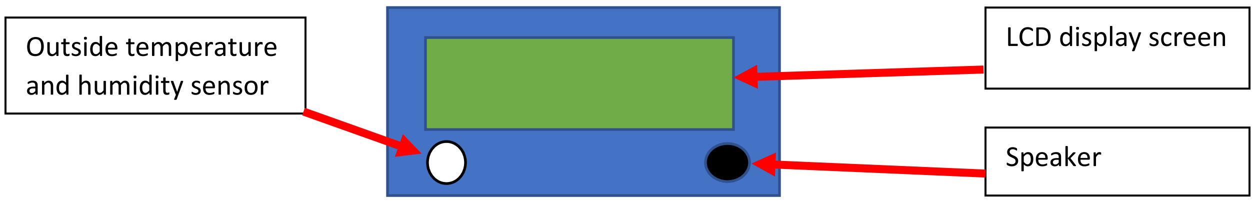


Figure 1.2 Front view of device

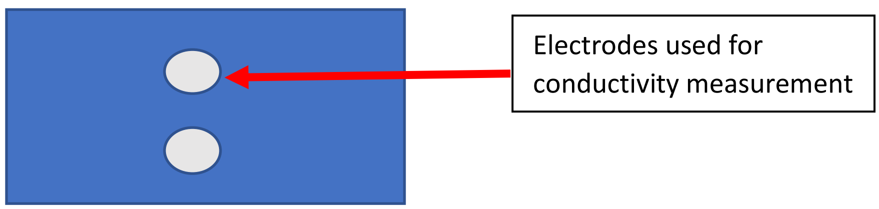


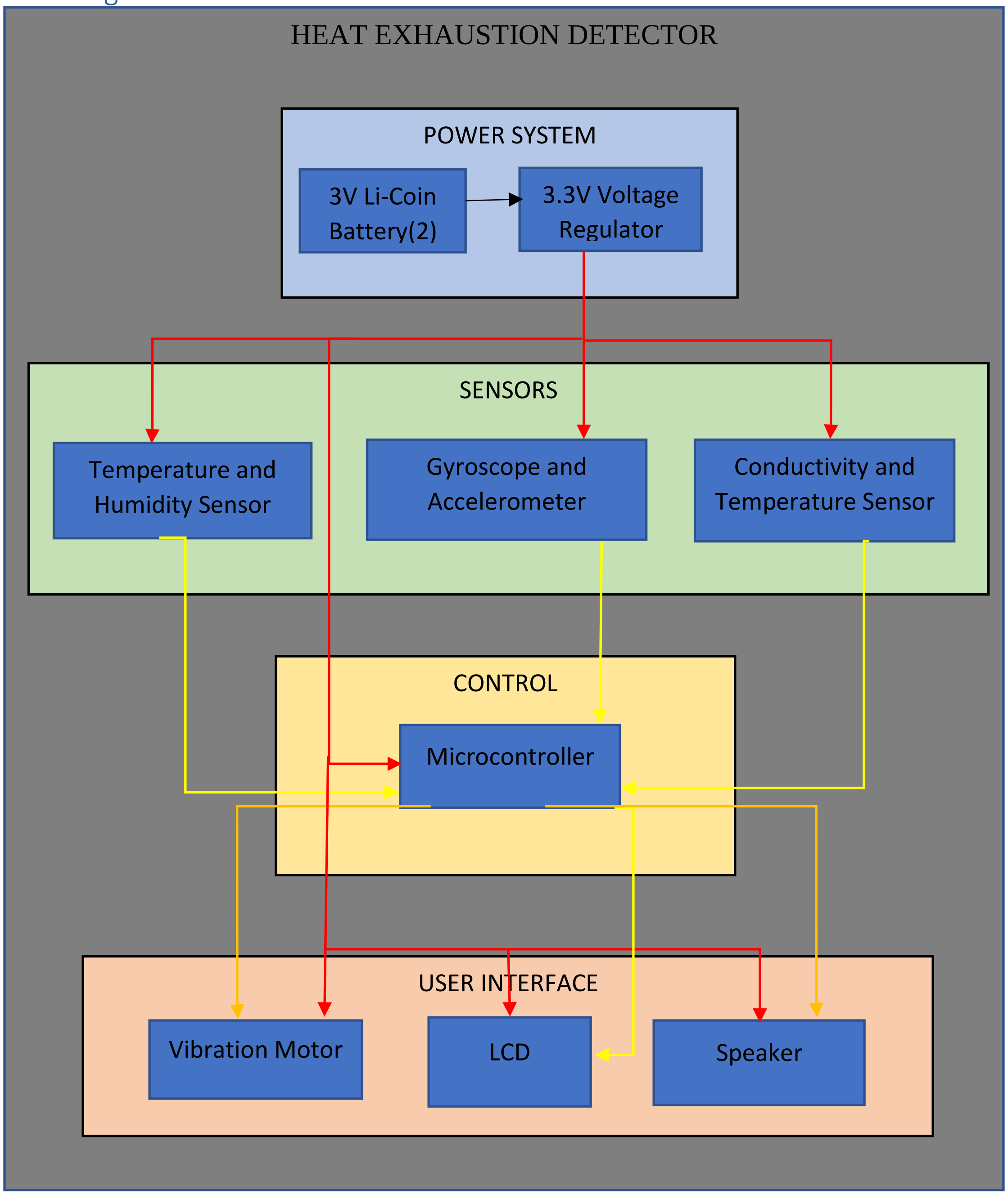
Figure 1.3 Reverse View of Device.

1.4 High Level Requirement

- The device will be able to accurately measure the chloride concentration of the wearers sweat through conductivity measurement within a threshold of ±1.5 mmol/L.
- The device will produce an alarming condition once the threshold of 20.0 mmol/L concentration is reached and will actuate the speaker, vibration motor and LCD screen to alert the wearer of this condition.
- The device will produce a risk level assessment based on the conductivity, accelerometer and outdoor sensors and display the risk level on the LCD screen.

2. Design

2.1 Block Diagram



	Power		Power System
	Data		Sensors
	Actuation Signal		Control
LEGEND			User Interface

The heat exhaustion detector can be broken up into four major blocks or functions. The power system, the sensors, the control and the user interface. The power system must be able to provide the necessary voltage and current to supply each sensor, microcontroller and the user interface components such as the LCD, speaker and vibration motor. The sensor block contains the sensors needed to assess the wearers heat exhaustion risk such as sweat conductivity, outdoor temperature and humidity and well as physical activity by using an accelerometer. The control block must perform the necessary calculations for determining sweat conductivity as well as taking in the sensory data and actuating the user interface components during an alarming condition. Lastly the user interface block provides the user with an LCD screen such that the current risk level can be seen as well as a speaker and vibration motor to alert the individual of potential heat exhaustion.

2.2 Power System

The power system contains two major components; the lithium batteries and the voltage regulator. The batteries chosen for this design are 3 V each with a capacity of 620 mAh. These batteries will be used in conjunction with the AP2127K-3.3TRG1 voltage regulator. The voltage regulator will be able to provide the steady 3.3 V necessary for the operation of the sensors, microcontroller and the user interface components. The voltage regulator is also capable of supplying 300 mA of current which is more than enough to supply the other subsystems of the device. In combination with the large capacity of the batteries the power system will be able to supply the necessary power to the device for over 9 hours of operation assuming maximum current draw from each component.

$$Time = \frac{Battery\ Capacity}{Current\ Draw} \tag{2.1}$$

$$Time \approx \frac{620\ mAh}{65\ mA} = 9.54\ h$$

Table 2.1 Requirements and Verification table for the Power System.

Requirements	Verification
• Provide a constant 3.3 V to the subsequent components of the system with a ± 0.2 V margin of error	• Connect the batteries to the voltage regulator and take a measurement of the output voltage utilizing a digital multimeter to verify.
• Provide a total current capable of powering the other sub modules which require approximately 65 mA.	• Verify the voltage regulator can supply the rated 300mA of current as dictated by the data sheet by placing an arbitrary resistance value to the regulator and measuring the current with a multimeter.

2.3 Sensors

The sensors block contains all the relevant sensory modules for assessing the wearers heat exhaustion risk. The main sensor in this block is the conductivity sensor which utilizes the AS321KTR-G1 operational amplifier to produce an alternating square wave meant to resemble an AC sine wave. This sinusoidal signal is necessary in order to prevent the collection of ionized

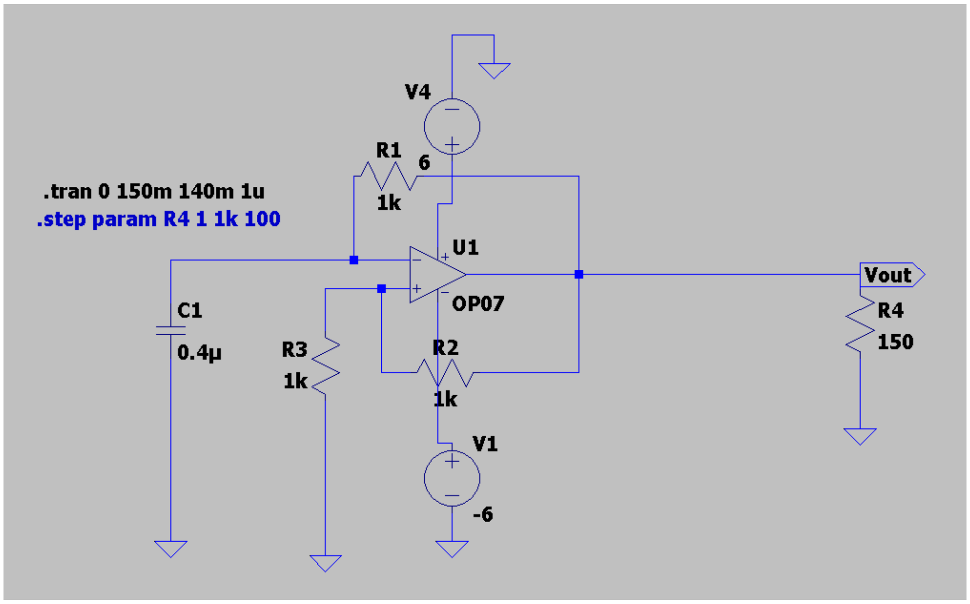


Figure 2.1 LTSpice Schematic of Proposed Conductivity Sensor.

particles on the electrodes and produce an inaccurate reading. Figure 2.1 illustrates the proposed schematic of the conductivity sensor using LTSpice. The positive and negative 6 V will be provided through the two lithium coin batteries. The Vout represents the point which will be fed to the microcontroller’s analog to digital converter for measurement and resistor R4 represents

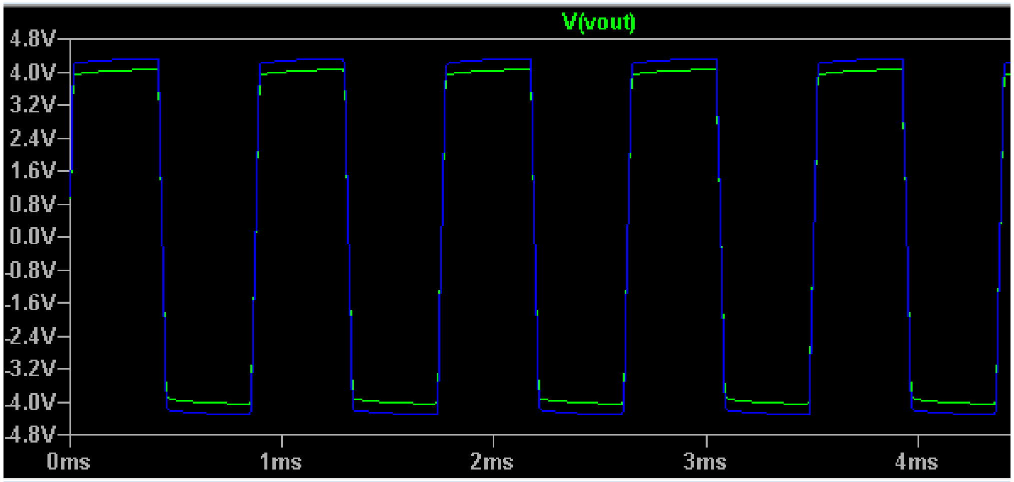


Figure 2.2 Conductivity Sensor Output Waveform.

the resistance of the measured solution or the wearers sweat. Figure 2.2 shows the resulting waveform at Vout and as can be seen the resulting output waveform represents sinewave to be used for conductivity measurement.

For determining the outside temperature and humidity the SHTC3-TR-10KS sensor was chosen. This sensor is capable of measuring temperature within ± 0.2 °C and capable of measuring relative humidity with ± 2% accuracy. The sensor provides accurate enough measurements to calculate the heat index of the environment the wearer is in. The sensor block also contains a gyroscope and accelerometer sensor. This sensor is used to monitor the level of physical activity the wearer is engaged in. The sensor chosen for this function is the LSM6DSMTR due to its low power consumption as well as providing an accelerometer accuracy of ±2 g. The combination of the accelerometer, humidity and temperature sensors will be able to provide a general risk assessment when the conductivity sensor is unable to produce a reading such as before the wearer has begun producing sweat.

Table 2.2 Table of Requirements and Verification for the Sensor Block

Requirements	Verification
• Provide a conductivity measurement such that the chloride concentration can be measured to within ± 1.5mmol/L.	• By measuring the conductivity of a known concentration of a sodium chloride solution and calibrating the output current to the chloride concentration level
• Provide a temperature and humidity measurement to within the devices specified tolerance ranges such that the heat index can be calculated	• By performing sensory measurements in a controlled indoor environment where the temperature and humidity levels are known and comparing those values to the measured values
• Provide an accelerometer reading within the devices specified tolerances such that a general physical activity level can be calculated.	• Move the sensor in such a fashion to simulate generic working motions in order to determine the number of g's produced in order assign a low, medium and high marker to the generated value

2.4 Control

The control block utilizes an ATMEGA808-XUR microcontroller in order to perform the necessary calculations for conductivity measurement, risk assessment and actuate the user interface devices during an alarming condition. In order to achieve a correct conductivity measurement the reading at the sensor must be fed into the analog digital converter of the microcontroller and the microcontroller must perform the calculations necessary for temperature correction. Equations (2.2) through (2.4) dictate the factors involved in the conductivity measurement.

$$K = \frac{D}{A} \tag{2.2}$$

$$\sigma = C_{measured} * K \tag{2.3}$$

$$G = \frac{\sigma}{1 + \alpha(t - t_r)} \tag{2.4}$$

Equation (2.2) calculates the cell constant where K is the cell constant, D is the distance between the electrodes and A is the area of the electrode. Equation (2.3) and (2.4) are used to standardize the conductivity measurement where $C_{measured}$ is the measured conductivity value and σ is the adjusted conductivity value taking into account the cell constant. The next equation dictates the

NOAA's National Weather Service

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	126	130					
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 Streuous Activity

Caution · Extreme Caution · Danger · Extreme Danger

Figure 2.3 NOAA National Weather Service Heat Index Determination [3].

temperature compensation where G is the standardized conductivity reading, t is the temperature of the sample, t_r is the reference temperature which is 25 degrees Celsius and α is the temperature compensation factor. The microcontroller will also take in the temperature and humidity data and calculate the heat index level utilizing the NOAA's national weather service heat index. Figure 2.3 shows the heat index table which will be used to determine the danger level of the outside conditions. The heat index will be taken in combination with the data from the accelerometer to determine the risk level of the wearer. The microcontroller will also have to take the results from these calculations and provide the information through the LCD screen for the wearer see. If an alarming condition is to occur the microcontroller will have to actuate the vibration motor and the speaker to alert the wearer that chloride concentration has gotten too low.

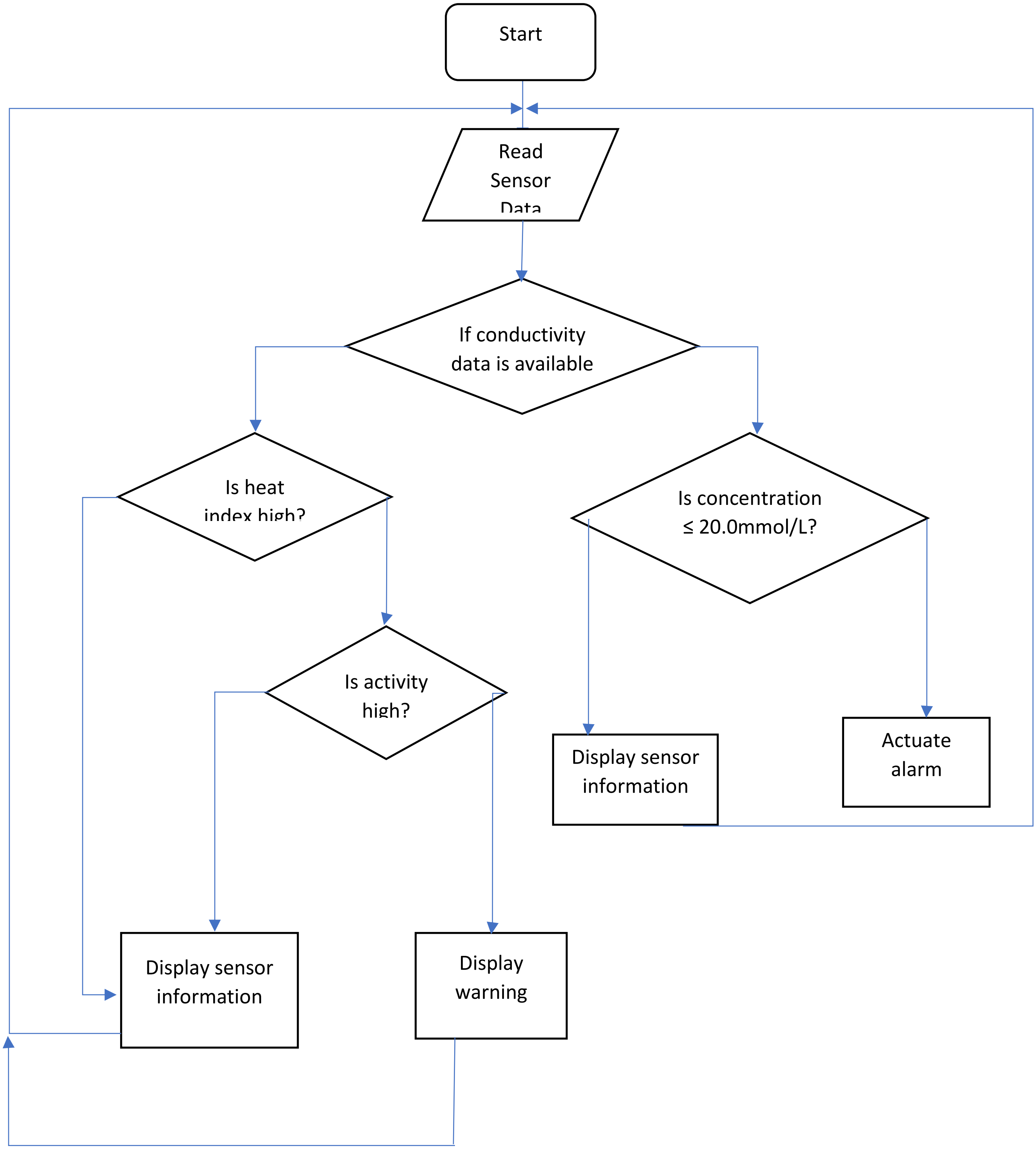


Figure 2.4 Simplified Flowchart of Microcontroller Operation.

Table 2.3 Requirements and Verification Table for the Control Block.

Requirements	Verification
• Perform the temperature correction calculations in order to provide accurate conductivity measurement data within the ±1.5mmol/L concentration threshold.	• Measure the conductivity of a solution with known chloride concentration at a high temperature and continue measuring as it cools to determine the temperature correction coefficient.
• Correctly interpret the temperature and humidity data to the assigned risk level from the heat index table	• Artificially heat up the temperature and humidity sensor and verify danger level is displayed correctly
• Generate signals to actuate the speaker and vibration motor during an alarming condition where chloride concentration reaches below 20.0 mmol/L	• Simulate an alarming condition to the microcontroller and verify the speaker and vibration motor activate.
• Print a warning to the LCD screen if the heat index and activity levels are both high.	• Simulate a high heat index signal and verify the correct warning is displayed

2.5 User Interface

The user interface block consists of components to relay information to the wearer such as an LCD screen, speaker and vibration motor. The LCD chosen for this design is the NHD-C12832A1Z-FS(RGB)-FBW-3V due to its low operating voltage and small size. The LCD will display the heat index and current chloride levels of the wearer. In a case where the chloride concentration is too law the LCD will display "ALARM" and in a case where the heat index and activity levels are at a dangerous level but the conductivity can not be measured the LCD will display "WARNING". The user interface block also contains the PRT-20660 speaker and the VCLP0820B004L vibration motor. During a condition where the chloride concentration is ≤ 20.0 mmol/L the microcontroller will actuate the motor and speaker to provide a physical and audible alarm indication.

Table 2.4 Requirements and Verification Table for the User Interface Block.

Requirements	Verification
• The LCD correctly displays the heat index level and chloride concentration.	• Connect the LCD to the microcontroller and verify the correct information is displayed.
• During an alarming condition the speaker and vibration motor actuate and continue to operate until reset	• Simulate alarming condition to verify the activation of the vibration motor and speaker

3. Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor Costs

The average annual salary of an ECE graduate from the University of Illinois is approximately $93,000.00 per year [8]. 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. Assuming each person in the group works 12 hours per week for 10 weeks at this hourly wage the labor costs can be calculated.

$$Labor\ Costs = \frac{\$}{hour} * \frac{hour}{week} * \#\ of\ weeks$$

$$Labor\ Costs = \frac{\$44.60}{hour} * \frac{12\ hour}{week} * 10\ weeks = \$5{,}352.00$$

$$Total\ Labor\ Costs = \$\mathbf{16,056.00}$$

3.1.2 Parts Costs

Table 3.1 outlines the parts used for this design including the quantity required, link to the purchase website as well as all applicable data sheets. The total cost for parts can be seen at the bottom of the table which is $37.80.

Table 3.1 Parts Description and Price

Part Number	Description	Purchase Link	Datasheet	QNTY	Price/Unit [$]
AP2127K-3.3TRG1	Voltage regulator	Digikey	Datasheet	1	0.43
LSM6DSMTR	Gyroscope and accelerometer	Digikey	Datasheet	1	4.67
SHTC3-TR-10KS	Temperature and humidity sensor	Digikey	Datasheet	1	3.04
AS321KTR-G1	Operational Amplifier	Digikey	Datasheet	1	0.49
ATMEGA808-XUR	Microcontroller	Digikey	Datasheet	1	1.09
NHD-C12832A1Z-FS(RGB)-FBW-3V	LCD display	Digikey	Datasheet	1	13.34
PRT-20660	Speaker	Digikey	Datasheet	1	3.12
VCLP0820B004L	Vibration Motor	Digikey	Datasheet	1	3.10
3046-2450-ND	Lithium Coin	Digikey	Datasheet	2	1.40
2057-BH-32C-1-ND	Battery Holder	Digikey	Datasheet	2	1.66
RC0402JR-0710KL	Resistor (10k)	Digikey	Datasheet	4	0.10
RNCP1206FTD1K00	Resistor(1k)	Digikey	Datasheet	3	0.10
CL05A104KA5NNNC	Capacitor(0.1uF)	Digikey	Datasheet	7	0.10
CL10A105KO8NNNC	Capacitor(1uF)	Digikey	Datasheet	10	0.10
Case					
Strap					
				TOTAL:	**$37.80**

3.1.3 Total Costs

The total costs for the design combining the total cost for parts and the total costs for labor comes to **$16.093.80.**

3.2 Schedule

Table 3.2 Table for Important Deadlines and Task Assignments

WEEK	DEADLINES	ZACK	TONGLI	DANNY
2/20	• 2/23- Design Document • 2/24- Team Contract	- Finish Design Document	- Work on team contract	- Work on team contract
2/27	• 2/27-2/29 Design Review • 2/28- PCB Board Review	- Work on Finalizing PCB design - Pick up parts	- Work on Finalizing PCB Design - Pick up parts	- Working on Finalizing PCB Desing - Pick up parts
3/6	• 3/8- Teamwork Evaluation	- Test and calibrate conductivity sensor	- Test and calibrate temperature and humidity sensor	- Test and calibrate accelerometer
3/13	• Spring Break	- Program microcontroller	- Program microcontroller	- Program microcontroller
3/20		- Test conductivity reading	- Test temperature and humidity reading	- Test accelerometer reading
3/27	• 3/29 Individual Progress Report	- Test alarming condition	- Test warning condition	- Test alarming condition
4/3		- Verify device functionality	- Verify device functionality	- Get case dimensions to machine shop
4/10	• 4/14 Team Contract Fulfillment	- Assemble device and perform mock demo	- Assemble device and perform mock demo	- Assemble device and perform mock demo
4/17	• Mock Demo	- Perform mock demo and work on presentation	- Perform mock demo and work on presentation	- Perform mock demo and work on presentation
4/24	• 4/24-4/26 Final Demo • 4/27-4/28 Mock Presentation	- Work on final paper	- Work on final paper	- Work on final paper
5/1	• 5/1-5/2 Final Presentation • 5/3 Final Paper	- Turn in final paper and perform lab checkout	- Turn in final paper and perform lab checkout	Turn in final paper and perform lab checkout

4. Ethics and Safety

This project is meant to address the safety risks that are involved with workers who must work in harsh environments. As stated in section 1.1 there has been an increase in heat related illnesses which can not only result in death but can also result in workplace accidents. According to the CDC the symptoms of heat exhaustion can include dizziness, weakness and even fainting [7]. 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 device itself does not pose any safety risk to the wearer as many of the electronics will be sealed in the casing and not exposed to the wearer. Although the device itself poses no risk to the user there is a potential that by wearing the device around rotating equipment could present a potential risk to the wearer. The device should be worn around the forearm which will mitigate those risks but for an added measure the casing supporting the straps should be strong enough to support the device but not so strong that it presents a hazard while at work. The potential for risk is due to the device being an extension of the body. If the device is in a vulnerable location, it could be clipped, but, or crushed, exposing the body to danger. Debree from the device could inflict harm to the wearer. The device is intended to be worn around the wrist, but that position may not be safe for a particular job. One should examine their surroundings and check to make sure the device is in a suitable location. If the wrist is an unsafe location for the device, consider it to another. The user must be aware that certain parts of the body sweat less than others so they should avoid moving the device into those locations. The lower back, for example, is typically another good location as it avoids getting crushed here.

5. References

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