ENSC 305W/440W Grading Rubric for Design Specification

Criteria	Details	Marks
Introduction/Background	Introduces basic purpose of the project.	**/05%**
Content	Document explains the design specifications with proper justification for the design approach chosen. Includes descriptions of the physics (or chemistry, biology, geology, meteorology, etc.) underlying the choices.	**/20%**
Technical Correctness	Ideas presented represent valid design specifications that will be met. Specifications are presented using tables, graphs, and figures where possible (rather than over-reliance upon text). Equations and graphs are used to back up/illustrate the science.	**/20%**
Process Details	Specification distinguishes between design details for present project version and later stages of project (i.e., proof-of-concept, prototype, and production versions). Numbering of design specs matches up with numbering for functional specs.	**/15%**
Test Plan	Provides a functional test plan for the present project version. (Note that project success will be measured against this test plan.)	**/10%**
Conclusion/References	Summarizes functionality. Includes references for information from other sources.	**/05%**
Presentation/Organization	Document looks like a professional specification. Ideas follow in a logical manner.	**/05%**
Format Issues	Includes letter of transmittal, title page, abstract, table of contents, list of figures and tables, glossary, and references. Pages are numbered, figures and tables are introduced, headings are numbered, etc. References and citations are properly formatted.	**/10%**
Correctness/Style	Correct spelling, grammar, and punctuation. Style is clear concise, and coherent. Uses passive voice judiciously.	**/10%**
Comments		

November 14, 2013

Mr. Lakshman One
School of Engineering Science
Simon Fraser University
Burnaby, BC V5A 1S6

Re: Ensc 440 Design Specification For the Vital Band: A wristband to measure heart rate and skin temperature

Dear Mr. One,

The enclosed document is the design specification for our product, Vital Band, which outlines our Engineering Science 440 Capstone project. We plan to build a wristband, which allow the user to measure his heart rate and skin temperature. This device will eliminate the need for manual pulse palpation and thermometer.

The design specification describes in detail how we plan to build our overall device and each individual part. This document will later be used as a guide for the design and development of our device.

Snail Tech consists of four skilled and hard working fourth year engineering science students: Ardavan Kalhori, Amir Kassaian, Sepehr Sheikholeslami, and Ghazal Saray-sorour. If you have any questions or concerns about our proposal, please feel free to contact us by phone at 604-374-8116 or by email at aka66@sfu.ca.

Sincerely,

Ardavan Kalhori,
CEO
Snail Tech

Enclosure: Design Specification for Vital Band

Design Specification:

Vital Band

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Submitted to

Mr. Lakshman One – Ensc 440

Mr. Mike Sjoerdsma – Ensc 305

School of Engineering Science

Simon Fraser University

Issue Date

November 14, 2013

Abstract

An aging population, increasing stress levels, and decrease in physical activity in modern days have caused people to become more health-conscious. Since the two most prominent determinants of health are cardiac function and body temperature, we are seeking to introduce a product that would make heart rate and body temperature measurement convenient not only for the elderly, but also for young athletes.

Therefore, we propose a wearable wristband capable of both heart rate and body temperature monitoring. While the market is filled with similar products, we seek to differentiate Vital Band in its capability of being individualized, accurate and competitively priced.

In order to appeal to the masses, the product needs to be very easy to use and relatively inexpensive. Therefore, we propose a wearable wristband capable of both heart rate and skin temperature monitoring. Heart rate is to be measured via a pulse sensor and skin temperature is measured with a thermistor.

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Glossary

BPM	Beats per Minute
CMAJ	Canadian Medical Association Journal
GE	General Electric
LCD	Liquid-Crystal Display
LED	Light Emitting Diode
MHR	Maximum Heart Rate
MM	Millimeter
MPB	Mode Push Button
PCB	Printed Circuit Board

1. Introduction

A way of measuring heart rate is taking pulse manually, which can be inaccurate if it is measured not carefully. To take pulse accurately, athletes have to concentrate on counting their pulse that makes them slow down or even stop their workout. Vital Band is a device made for athletes to measure their heart rate and skin temperature while training instantly. Another way to evaluate exercise intensity is to measure the skin temperature. Vital Band is a wristband that contains several parts: a thermistor, a pulse sensor, a microcontroller, a LCD, a rechargeable battery, a switch and a push buttons. Pulse sensor measures the heart rate when user puts his fingertip on top of the sensor, while the thermistor takes measurements continuously from the surface of the skin on the wrist. Microcontroller communicates with two sensors and LCD to display the data and a rechargeable battery powers the wristband.

1.1 Scope

This document outlines the design specification for our proof-of-concept Model for the Vital Band and explains how some of the design features will satisfy the functional requirements as described in Functional Specification for the Vital Band [1]. This document will focus on the requirement for our proof-of concept Model and further optimization for the final product will be included for reference.

1.2 Intended Audience

This design specification is to be used by the members of Snail Tech during the design, development and testing stages of the Vital Band. This document will be used as general design guidelines during the prototype design and implementation. Engineers will refer to this document to verify the similarities of functional aspects of final proof-of-concept with the design specification.

2. Physiological Considerations

Since the Vital Band is considered as a biomedical device and it directly interacts with humans, it is important to note the relevant physiological factors.

2.1 Heart rate

Heart rate is not only one of the most important indicators of general health, but also of exercise intensity. As the intensity increases, the Oxygen requirements of the skeletal muscles involved increases. Furthermore, the metabolic waste such as carbon dioxide increases [2], and therefore blood needs to circulate faster and with higher efficiency, which results in a higher heart rate.

However, according to a study published in 2002 in the CMAJ, strenuous exercise resulting in heart rates beyond the predicted MHR (equation.1) for longer than 30 minute period causes poor heart rate recovery and episodes of nonsustained ventricular tachycardia [3].

$$MHR = 220 - age \qquad \text{(Eq.1)}$$

To ensure the health of the Vital Band's users, Equation 1 is used to calculate the "safe zone" for their exercise intensity, and once this threshold is passed, they will be notified via a message on the LCD. This is implemented in the prototype and the final product (discussed later in detail). Table 1 shows different age group and their respective MHR's that is used in the Vital Band.

Age Group	MHR (BPM)
20-30	~195
31-40	~185
41-50	~175
51-60	~165

Table 1: Age Group and MHR

2.2 Skin Temperature

As a by-product of skeletal muscle contraction, the core temperature (measured at rectum) is increased up to 3 degrees Celsius during exercise [4], and thus is an indicator of exercise intensity. Figure 1 illustrates the rise of core temperature with respect to rising Percent Maximal Oxygen Uptake (%VO2 max), which is a suitable indicator of exercise intensity. [4]

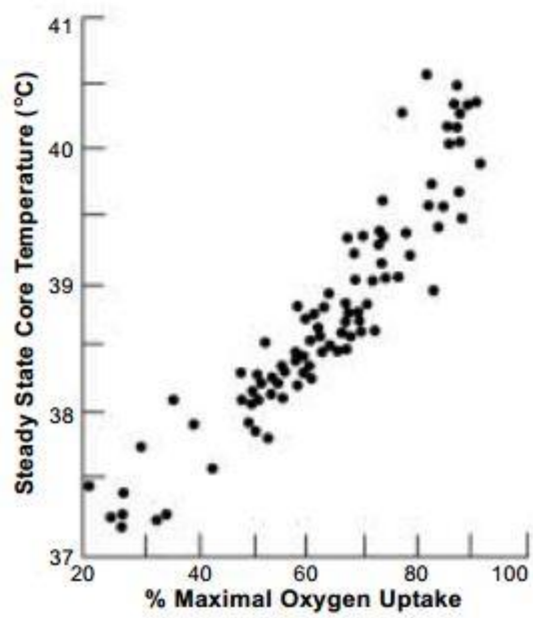


Figure 1: VO2 max vs. Core Temperature [4]

The skin temperature, under normal conditions (25 degrees Celsius, no humidity) is around 33 degrees Celsius. This value however is dependent on a variety of physiological and physical factors such as the sweating rate, skin blood flow, ambient temperature, humidity and other factors [5]. Moreover, the locality of skeletal muscles being used during exercise also affects the skin temperature. For example, when leg exercise is being performed, the forearm skin temperature falls due to decrease in forearm subcutaneous blood flow, caused by a proportionate increase in lower body blood flow [5]. Therefore, the absolute value of skin temperature, more specifically, forearm skin temperature could not be used as an indicator of exercise intensity.

However, studies have shown that the absolute value of the change in skin temperature is directly proportional to the change in core temperature and thus to exercise intensity [6]. Therefore, although a lower body exercise causes the core body temperature to rise and the forearm skin temperature to fall, the absolute value of their change is equal.
Therefore – making the safe assumption that during an exercise session the change in humidity and ambient temperature is negligible – the exercise intensity could be monitored by studying the change in skin temperature (3 Degrees = 90% VO2 max). This is to be implemented in the final product (discussed in detail later).

3. System Specification

Vital Band will allow athletes to measure their heart rate and skin temperature while training instantaneously. Vital Band is a wristband that is worn around the wrist and displays the temperature or heart rate. The thermistor that is in contact with the user's skin measures the skin temperature. The pulse sensor measures the heart rate when the user places the fingertip on top of the sensor. The microcontroller collects the measurements and displays it on the LCD. The battery powers the system and the switch connects/disconnects the battery, which turns On/Off the whole system.

4. System Overview

This section provides a high level overview of the Vital Band system, which is shown in Figure 2.

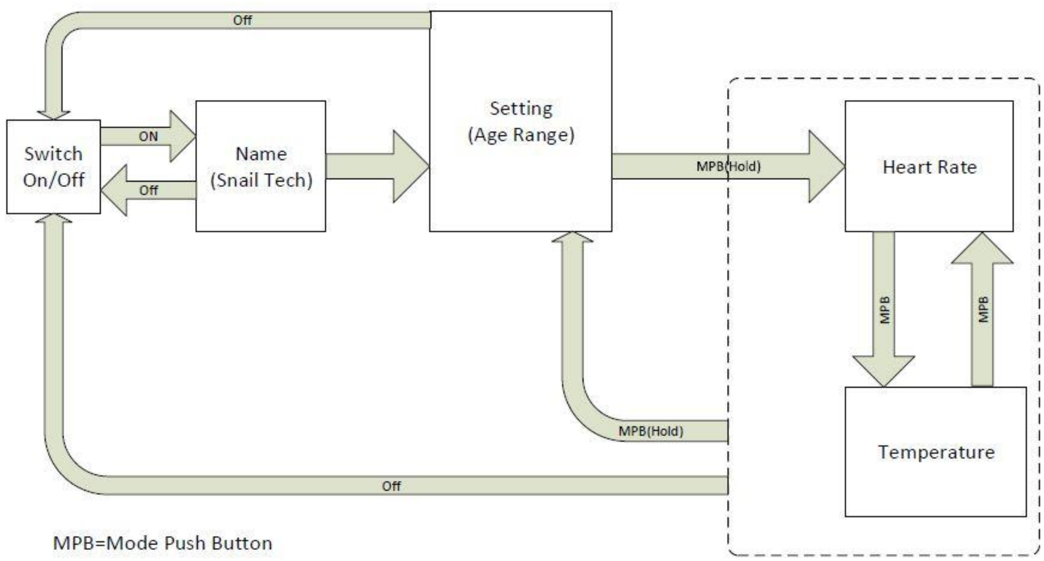


Figure 2: High Level Overview of the Vital Band

Vital Band can be divided into six different components: The On/Off switch, MPB, pulse sensor, temperature sensor, microcontroller and LCD. When the user turns on the system, the settings page is displayed after the name of the company and he/she is asked to select the age group that includes his/her age. The settings information is saved until the user holds the MPB to go back and another group. After the group is chosen, he/she is directed to heart rate mode. He/she can change the mode by pressing the MPB once. The pulse sensor collects the data from the user's fingertip and the temperature sensor collects the data by being in contact with the user's skin. Each sensor sends the collected data to microcontroller to process and to be displayed on the LCD.

4.1 Mechanical Design

The main concern with designing of the Vital Band is to have a compact and lightweight system to be worn around the wrist. Following sections explain the physical characteristics and layout design of each part in the system.

4.1.1 Physical Characteristics

The physical characteristic of each part is important to design the system in SolidWorks, which is used to print the hardware with a 3-D printer.

4.1.1.1 LCD

The LCD consists of a glass on top and a PCB, which has all the electronic components soldered on it. The weight of the LCD is 7.94 grams and the dimensions for the glass and PCB are 24.192 mm x 24.192 mm and 39.96 mm x 39 mm x 5.15 mm respectively. Figure 3 shows the physical characteristic of LCD.

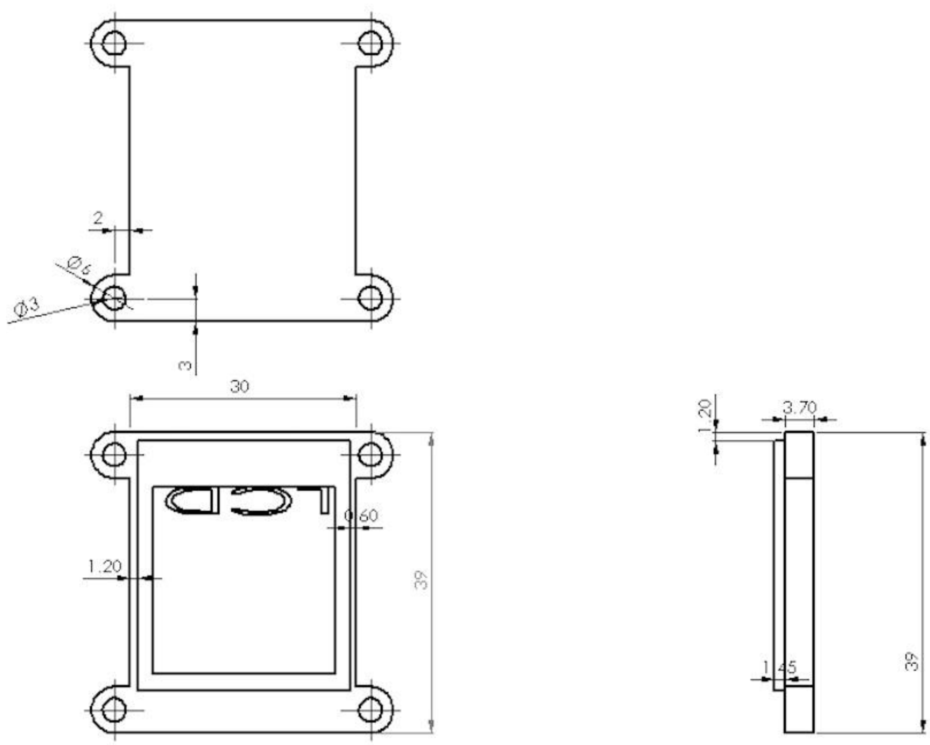


Figure 3: Physical Characteristics of SHARP LCD

4.1.1.2 Pulse Sensor

The pulse sensor consists of a LED and a photosensor that are soldered on one side of the PCB and the rest of the electronic components are soldered on the other side. The pulse sensor has dimensions of 15.875 mm x 3.175 mm. Figure 4 shows the physical characteristic of pulse sensor.

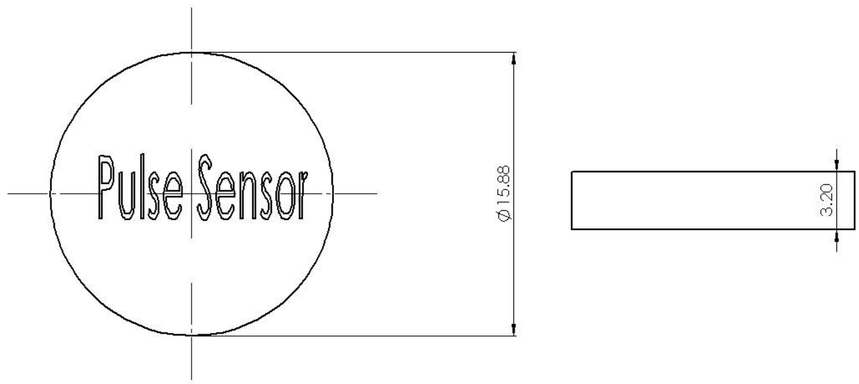


Figure 4: Physical Characteristics of Pulse Sensor

4.1.1.3 Thermistor

The thermistor model number is MA300TA502 with dimensions of 9.7 mm x 3.5 mm. Figure 5 shows the physical characteristic of the thermistor.

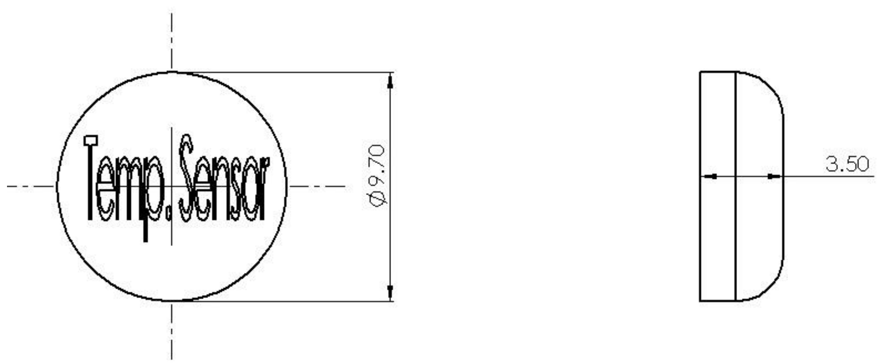


Figure 5: Physical Characteristics of Thermistor

4.1.1.4 Arduino Pro Mini

The Arduino Pro Mini has relatively small dimensions, which can be fit on the wristband. The dimensions of the Arduino are 17.78 mm x 33.02 mm. Figure 6 shows the physical characteristic.

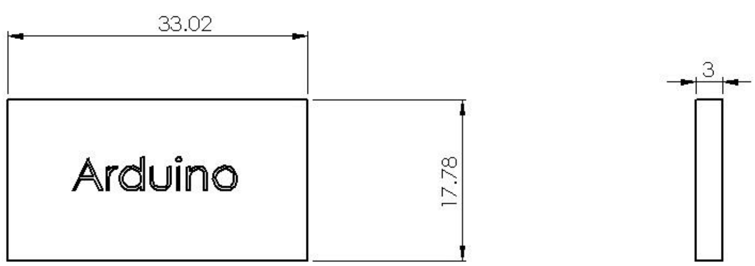


Figure 6: Physical Characteristics of Arduino Pro Mini

4.1.1.5 Other Components

A polymer Lithium Ion battery and a sliding switch are used to turn on and off the system. The dimensions of the battery and the sliding switch are 2 mm x 12 mm x 5.7 mm and 9 mm x 3.5 mm x 3.3 mm respectively. A push button is used for settings selection and it has dimensions of 6.3 mm x 3.5 mm x 3 mm.

PCB debouncing hardware is designed with dimensions of 20 mm x 15 mm x 6 mm that resolves the debouncing issue with the push button.

4.1.2 Layout design of all components

After drawing each part of the Vital Band separately, and trying different approaches to assemble the system, it is decided to have a base and add the parts on top of it in two levels. The Arduino, battery, charger socket, push button, sliding switch and Schmitt trigger circuit are placed on the base level and the thermistor is under the base to be in contact with skin. The LCD and pulse sensor are placed on the top level to let the user measure the heart rate and observe the information on the LCD. Figure 7 shows the overall system designed in SolidWorks.

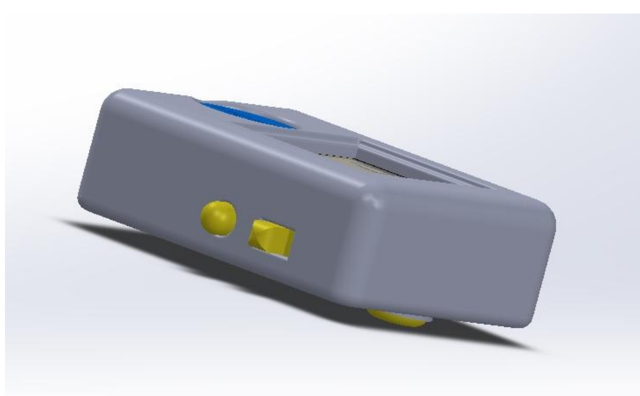


Figure 7: Layout Design of the System (GE thermistor shown in yellow at the bottom)

Figure 8 illustrates the details of how the components are placed at each level of the device.

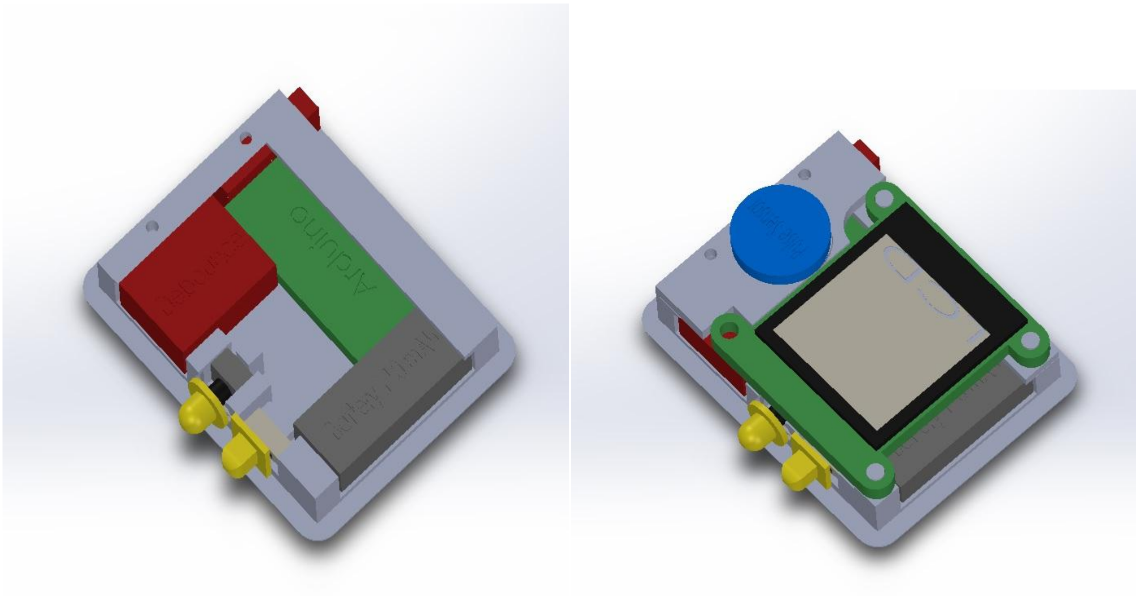


Figure 8: Detailed Design of the Hardware (Push button and sliding switch are shown in yellow, battery in red, Arduino in green, Pulse sensor in blue and LCD in gray)

4.2 Electrical Design

The main components of the prototype's electrical design are outlined in the schematic in Appendix A. In this section, some key design notes are discussed for each component.

4.2.1 Pulse Sensor

This sensor comes with a built-in Light Emitting Diode (LED) and a photodiode which detects the light emitted from the LED. It also comes with a Low-Pass filter and an ambient light sensor. The filter amplifies the signal and also filters the high frequency noise. Ambient light sensor detects the amount of lighting in the surroundings and adjusts the light emitting from the LED accordingly. The signal processed pulse reading is then read through the analog pin A0 with 2 ms hardware interrupts. This is explained in depth in the Software Design section of this document.

4.2.2 Skin Temperature

In order to measure the forearm's skin temperature, a thermistor is used in conjunction with a 1 kΩ resistor in a voltage-divider configuration (refer to

Appendix A). The voltage is then continuously read through the analog pin A1 of the Arduino processor and converted into readable temperature via software.

4.2.3 Arduino Pro Mini

The board contains the main processing element (ATmega328), a voltage regulator and a Reset button. The battery voltage is fed through the RAW pin in the Arduino and regulated inside the board. Note that all the circuit elements are powered using this regulated voltage, since otherwise the readings from the sensors would be unpredictable as the battery is drained through time.

4.2.4 Mode Push Button

The schematic in Appendix A also illustrates the circuit configuration and the debouncing technique used for the MPB. An inverting Schmitt trigger is used with a 10 kΩ resistor and a 10 μF capacitor in order to generate a sufficient amount of delay (10 kΩ X 10 μF = 0.1 s) for debouncing the button.

4.2.5 LCD Display

The Sharp Memory display is connected with the processor through the appropriate ports. The timing of the LCD and the refresh rate is provided via the clock pulse generated by the RC oscillator circuit inside the ATmega328 chip.

4.2.6 Battery and On/Off Switch

A 3.7 V Lithium Ion battery powers the whole system. An On/Off switch turns the power on and off depending on the user's need. A 10 μF capacitor is used in parallel with the switch such that when the switch is turned off the circuit would not power down abruptly; thus the electronic components are saved from potential damage over time.

4.3 Software Design

The software for the Vital Band is designed to let the user interact with the device and display the information on the LCD.

4.3.1 Display

The LCD displays four different screens, which are the following:

1- The name of the company (Snail Tech)
2- Settings (age group assignment)
3- Heart rate measurement
4- Thermistor

When the user turns on the switch, the screen goes on and the name of the company is displayed for 0.5 second and then the settings page is displayed. In the latter page four different age groups with specific heart rate target are displayed as shown in table 1. The user can navigate through the settings page pressing the MPB and select the desired group by holding the button for 3 seconds. After choosing the group, the default is to display the heart rate, however the user can change the mode to temperature by pressing the MPB once. In this stage, pressing the MPB changes the display between heart rate and temperature interchangeably.

The screen on the LCD is refreshed every 0.5 to 1 second to show the new measurements coming from each sensor. The refresh rate of the screen is not specific because of the interrupts for push buttons and pulse sensor.

Note that the processor's SRAM capacity is 2 KBytes, and the LCD uses relatively high amount of Arduino's memory (up to 1 KBytes of SRAM) to process its data, therefore the refresh rate and the amount of data to be displayed is set to minimum possible.

4.3.2 Heart Rate

When in heart rate mode, the user places his/her fingertip on top of the pulse sensor to cover the green light. When placed, the heart rate will be displayed between 5 to 10 seconds. To determine the heart rate, a clock interrupt is used to get sample data every 2 milliseconds from the pulse sensor. The software calculates the average of 10 samples and displays the result on the screen.

When the heart rate is measured, Equation 1 and Table 1 is used to calculate the age-compensated average maximum heart rate (MHR), and should the user's heart rate exceed this value, he/she will be notified with a warning message on the screen.

4.3.3 Skin Temperature

When the user is in temperature mode and the sensor is in contact with user's skin, the temperature is displayed in degrees Celsius. Equation 2 is implemented in the software to calculate the skin temperature from the raw data coming through the analog port.

$$\text{Temperature } (^\circ C) = (\text{Signal } (V) - 528.49)/6.83 \qquad \text{(Eq.2)}$$

This equation is found via resistance vs. temperature data provided in the sensor's datasheet (reproduced in Appendix A), taking into account the circuit configuration in which the thermistor is placed in (Appendix B).

5. Test Plan

The test will be done to make sure that the device meets the functional and design specifications. The test procedure will be divided into three sub-groups based on specific components in the system, which include the pulse sensor and thermistor and the software.

To test each component, the following procedure will be done.

5.1 Pulse Sensor

The wristband will be worn around the wrist and it will be turned on using the On/Off switch. The green LED on the sensor will go on and the fingertip will be placed on top of the sensor to cover the green light and the heart rate will be displayed on LCD in less between 5 to 10 seconds. The pulse palpation technique will be used to verify the heart rate displayed on the LCD.

5.2 Thermistor

The wristband will be worn around the wrist and it is in contact with the user's skin. The system will be turned on using the On/Off switch. The mode will be changed to temperature from default (heart rate) using MPB and the skin temperature will be displayed in degrees Celsius. A thermometer will be used to verify the temperature displayed on the LCD.

5.3 Software

1. The system will be turned on using the On/Off switch, the name of the company will be displayed for 0.5 seconds and then the settings screen will be displayed.

2. The software will prompt the user to select an age group and will save it. The user will hold MPB for 3 seconds to be able to change the age group.

3. The default mode will be in heart rate state after the age selection. MPB will be pushed once to change the mode to temperature. Every time the MPB is pushed, the mode will be changed consecutively.

4. The heart rate will be displayed when the fingertip is placed on the sensor and if the heart rate is above the group's heart rate target, a message "Warning: Heart Rate too high!" will be displayed underneath the BPM.

These tests will ensure that our prototype will meet all the requirements listed in this document in terms of functionality and reliability.

6. Final Product

The final product resembles the prototype in the major components. There are some minor changes, however, that are implemented in order to expand the functionality, avoid unnecessary complexity, reduce power consumption and cost.

6.1 Pulse sensor

Upon the completion of the main functionality for the prototype, the mentioned components of this sensor are to be manufactured separately for the final prototype. The ambient light sensor is deemed unnecessary for our product and in order to reduce costs will not be used. The low-pass filter and the optical detection will be modeled using the schematic in the Appendix C.

6.2 Skin Temperature

Due to memory constraints in the prototype of the Vital Band, exercise intensity analysis based on skin temperature is left for the final design, where in conjunction with a Bluetooth module (BLE Mini), data is continuously sent to a smartphone application. Using the memory and processor capacity of smartphone, exercise intensity could be monitored from the start to finish. The change in skin temperature will be plotted in a graph in the application, and the physiological significance of the data (as explained earlier) will be illustrated so that the user could have a better understanding of his/her body's response to exercise.

6.3 Processing Unit

For the final product, as shown in the schematic in Appendix C, only the ATmega328 chip is used for the processing unit and the voltage regulation is implemented separately via the LM7805 chip. This will enable us to reduce cost by not needing to buy an Arduino board.

7. Conclusion

The proposed design specifications for Vital Band System are presented in this document to address all the design challenges in the project. The Snail Tech team will use this document as a guide throughout the building process to keep the project on track. Hardware specifications, software specifications and test plans are all outlined in this document. The expected completion date for the proof-of-concept model of Vital Band is November 22th. 2013.

Reference

[1]. Snail Tech. , Functional Specification for the Vital Band, Simon Fraser University, Burnaby, BC, Canada, November 2013.

[2] D. A. Burton, K. Stokes, and G. M. Hall. "Physiological effects of exercise. Continuing education in anaesthesia." *Critical Care & Pain*. 2004, 4: 185-188.

[3]Atwal S, Porter J, MacDonald P. "Cardiovascular effects of strenuous exercise in adult recreational hockey: The Hockey Heart Study." *CMAJ*. 2002, 166:303–307.

[4] Sawka MN, Pandolf KB. "Physical exercise in hot climates: physiology, performance, and biomedical issues." *Textbooks of Military Medicine: Medical Aspects of Harsh Environments*. 2001, 87–133

[5] Wissler, E. "A quantitative assessment of skin blood flow in humans." *Eur J Appl Physiol*, 2008, 104: 145–157.

[6] DAVIES, C. T. M. "Influence of skin temperature on sweating and aerobic performance during severe work." *J. Appl. Physiol.* 1979, 47: 770–777

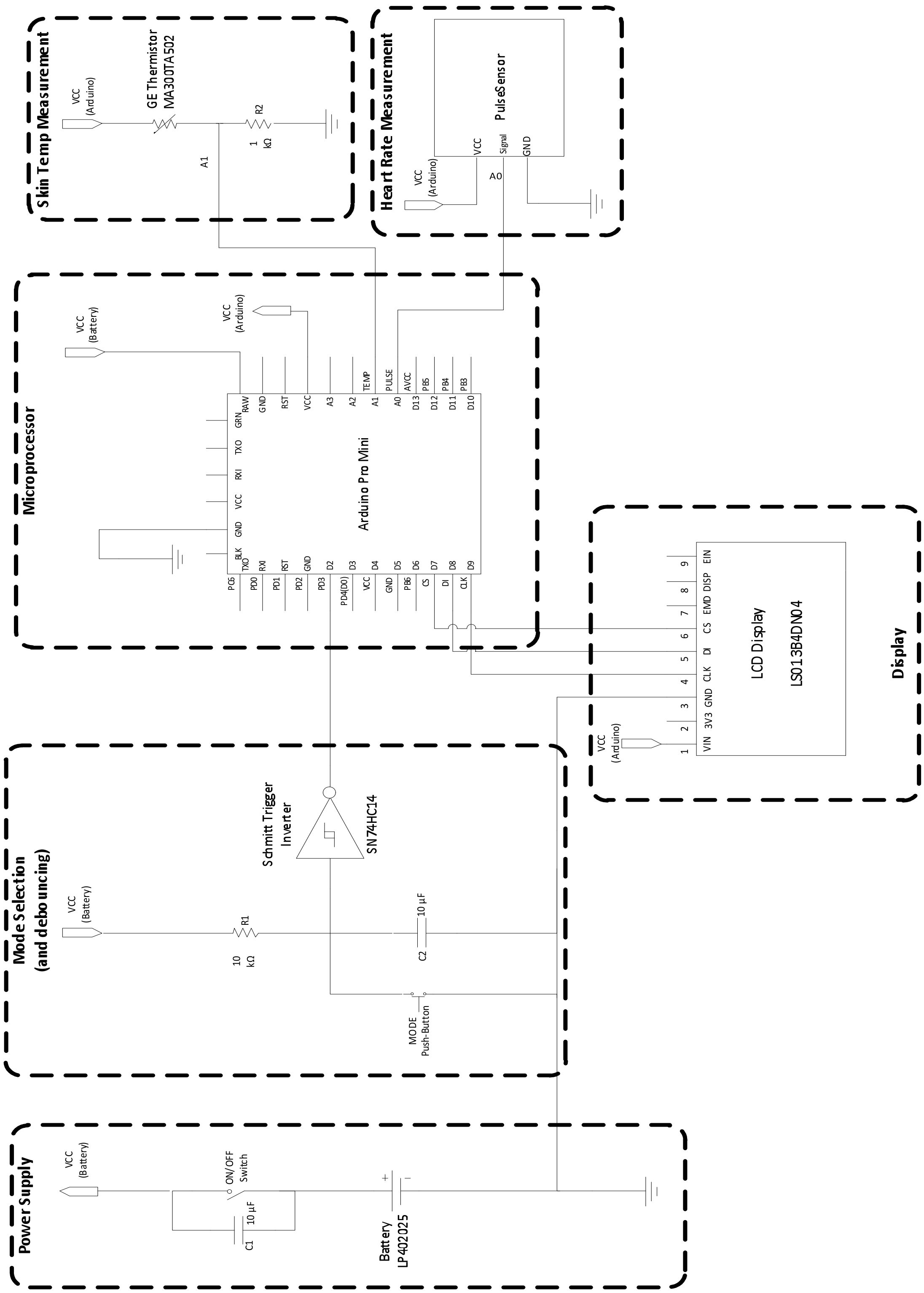
Appendix A

Temperature vs. Resistance for the thermistor (taken from the GE sensor datasheet).

Temperature °F	[°C]	2252 ohm	3K ohm	5K ohm	10K ohm	10K Y ohm
32.00	[0]	7373.00	9821.93	16369.89	32739.78	29565.84
33.80	[1]	7005.80	9332.76	15554.61	31109.22	28224.84
35.60	[2]	6659.04	8870.84	14784.73	29569.47	26951.94
37.40	[3]	6331.49	8434.49	14057.49	28114.97	25743.34
39.20	[4]	6021.97	8022.17	13370.28	26740.56	24595.48
41.00	[5]	5729.40	7632.41	12720.69	25441.37	23505.00
42.80	[6]	5452.74	7263.87	12106.45	24212.90	22468.75
44.60	[7]	5191.06	6915.27	11525.45	23050.90	21483.76
46.40	[8]	4943.46	6585.43	10975.71	21951.42	20547.25
48.20	[9]	4709.11	6273.23	10455.38	20910.77	19656.59
50.00	[10]	4487.22	5977.64	9962.74	19925.48	18809.30
51.80	[11]	4277.07	5697.69	9496.15	18992.31	18003.07
53.60	[12]	4077.97	5432.47	9054.11	18108.22	17235.71
55.40	[13]	3889.29	5181.11	8635.19	17270.37	16505.14
57.20	[14]	3710.42	4942.83	8238.05	16476.11	15809.42
59.00	[15]	3540.80	4716.88	7861.46	15722.92	15146.73
60.80	[16]	3379.91	4502.54	7504.24	15008.47	14515.33
62.60	[17]	3227.24	4299.17	7165.28	14330.56	13913.59
64.40	[18]	3082.34	4106.14	6843.57	13687.13	13339.98
66.20	[19]	2944.77	3922.88	6538.13	13076.25	12793.05
68.00	[20]	2814.12	3748.83	6248.05	12496.10	12271.41
69.80	[21]	2690.01	3583.49	5972.48	11944.96	11773.79
71.60	[22]	2572.07	3426.38	5710.63	11421.25	11298.97
73.40	[23]	2459.96	3277.03	5461.72	10923.45	10845.77
75.20	[24]	2353.37	3135.04	5225.07	10450.14	10413.13
77.00	[25]	2252.00	3000.00	5000.00	10000.00	10000.00
78.80	[26]	2155.56	2871.53	4785.88	9571.77	9605.42
80.60	[27]	2063.79	2749.28	4582.13	9164.26	9228.45
82.40	[28]	1976.44	2632.91	4388.19	8776.38	8868.24
84.20	[29]	1893.27	2522.12	4203.54	8407.07	8523.96
86.00	[30]	1814.07	2416.61	4027.68	8055.35	8194.82
87.80	[31]	1738.61	2316.09	3860.15	7720.30	7880.09
89.60	[32]	1666.71	2220.31	3700.51	7401.03	7579.07
91.40	[33]	1598.18	2129.02	3548.36	7096.72	7291.10
93.20	[34]	1532.85	2041.98	3403.30	6806.60	7015.55
95.00	[35]	1470.54	1958.98	3264.97	6529.94	6751.83
96.80	[36]	1411.11	1879.81	3133.02	6266.03	6499.37
98.60	[37]	1354.41	1804.27	3007.12	6014.23	6257.64
100.40	[38]	1300.29	1732.18	2886.96	5773.93	6026.13
102.20	[39]	1248.63	1663.36	2772.27	5544.53	5804.36
104.00	[40]	1199.30	1597.65	2662.75	5325.50	5591.88
105.80	[41]	1152.19	1534.89	2558.15	5116.30	5388.26
107.60	[42]	1107.19	1474.94	2458.23	4916.46	5193.09
109.40	[43]	1064.18	1417.65	2362.75	4725.49	5005.96
111.20	[44]	1023.08	1362.89	2271.49	4542.98	4826.53
113.00	[45]	983.78	1310.55	2184.24	4368.49	4654.43
114.80	[46]	946.21	1260.49	2100.82	4201.64	4489.33
116.60	[47]	910.27	1212.62	2021.03	4042.05	4330.91
118.40	[48]	875.89	1166.81	1944.69	3889.38	4178.88
120.20	[49]	842.99	1122.99	1871.65	3743.29	4032.94
122.00	[50]	811.50	1081.04	1801.73	3603.46	3892.83

Appendix B

Schematic for the prototype



Appendix C

Schematic for the final product