ECE 445

Design Document

Team 27

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Firefighter Life Monitor

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Table of Contents

1 Introduction:

1.1 Objective:

According to the National Fire Protection Association approximately 59% of injuries for firefighters are a result of overexertion, stress, and medical difficulties compared to other injuries such as crashes, getting hit by objects, or falling [1]. The goal is to create a device that can monitor heart rate, temperature inside the bunker gear, and motion of firefighters in the field and send the information to a display in another location. The device would be attached to the arm under the firefighter's uniform. This would allow a response team to take appropriate actions if a firefighter was in danger.

1.2 Background:

Previous projects for firefighters have involved hazard detection and wireless heart rate transmission [2]. Our project would be different in that we are focusing on more than just heart rate. We would also monitor the temperature inside the firefighters bunker gear and whether they are moving or not. A distress signal will be sent if no motion is detected after a short while. This device could also be adapted for more than just firefighters in the future.

1.3 High Level Requirements:

- The life monitor must be able to sense heart rate, movement, and temperature of the firefighter
- The life monitor must detect when the values taken indicate abnormal heart rate, motionlessness, or hyperthermia and send a distress signal
- The life monitor must work in at least 140°F environments and moist conditions inside a firefighter's bunker gear

2 Design:

The firefighter life monitor has three main functions: movement detection, temperature reading, and heart rate monitoring. This is accomplished with a four part modular design consisting of a power supply, control unit, sensor unit and RF display. Sensors will obtain the necessary data and the control unit will process this data and wirelessly transmit it to a display.

2.1 Block Diagram:

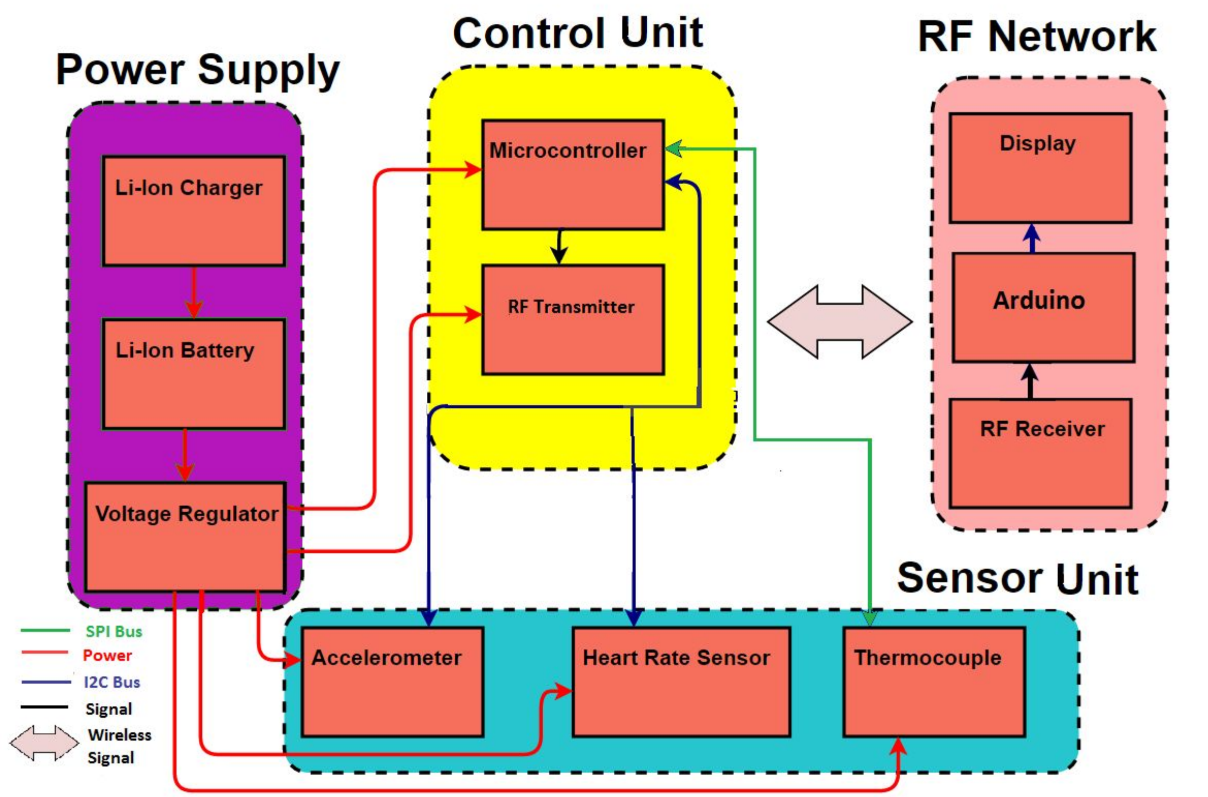

Figure 1: Block Diagram

2.2 Physical Design:

The circuitry must be contained in a light weight, easy to put on and remove armband. Velcro will be used in order to attach the device to the user's arm. The circuitry will be housed in a fire resistant fabric. This fabric will be nomex, a fire resistant fabric, which is one of the materials used in firefighters' bunker gear.

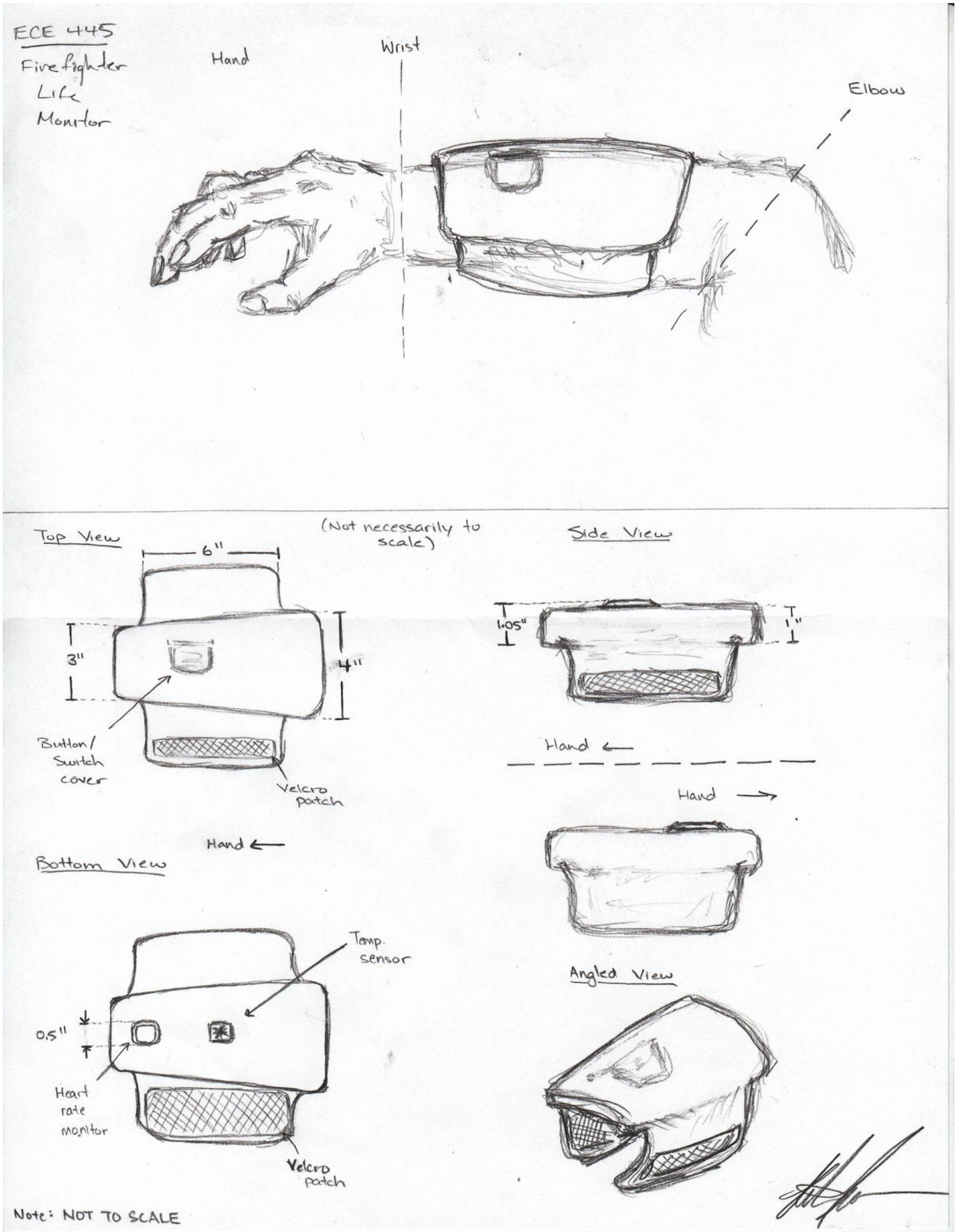

Figure 2: Physical Design

2.3 Functional Overview:

2.3.1 *Power Supply*

A power supply is required to keep the life monitor operable. Power will come from a rechargeable lithium-ion battery. Through the use numerous voltage regulators, the microcontroller and sensor circuits will be powered.

Lithium-Ion Battery Charger

The battery will be charged via a charging IC. There are three phases for charging the battery. First, there is a preconditioning charge, a constant-current fast charge, and finally a constant-voltage trickle charge to keep the battery topped.

Lithium-Ion Battery

A lithium-ion battery will power the microcontroller and each individual circuit that connects to the sensors. The battery should be able to keep the circuit continuously powered until switched off.

Voltage Regulators

Multiple voltage regulators will be used to step down voltage from the battery. 3.3 volts will be regulated to power the microcontroller, temperature IC, LEDs for the HR sensor, and RF Transmitter. 2.5V will be used to power the accelerometer. 1.8 volts will power the HR sensor and power the VDDIO rail for the I2C bus.

In order to calculate the resistor values needed for the voltage regulators we used the following equation [3]:

$$V_{out} = V_{FB}(1 + \frac{R_1}{R_2})$$

Where R_1 and R_2 are the resistors connected at the output of the voltage regulator and VFB is 0.5V. Equations for output capacitors was also needed. The following equations were used for the two capacitors [3]:

$$C_1 = \frac{1}{2\pi * R_1 * 45000}$$

$$C_2 = \frac{1}{2\pi * R_2 * 45000}$$

Given that we need voltages of 1.8V, 2.5V, and 3.3V, the following resistor values and capacitor values were obtained:

Voltage	R_1	R_2	C_1	C_2
1.8	260 kΩ	100 kΩ	13.6 pF	35.4 pF
2.5	400 kΩ	100 kΩ	8.84 pF	35.4 pF
3.3	560 kΩ	100 kΩ	6.31 pF	35.4 pF

Table 1. Calculated Resistor and Capacitor Values

In LTspice we simulated the output of three buck converters. Vin was swept from -1V to 10V and the output of the regulators was plotted.

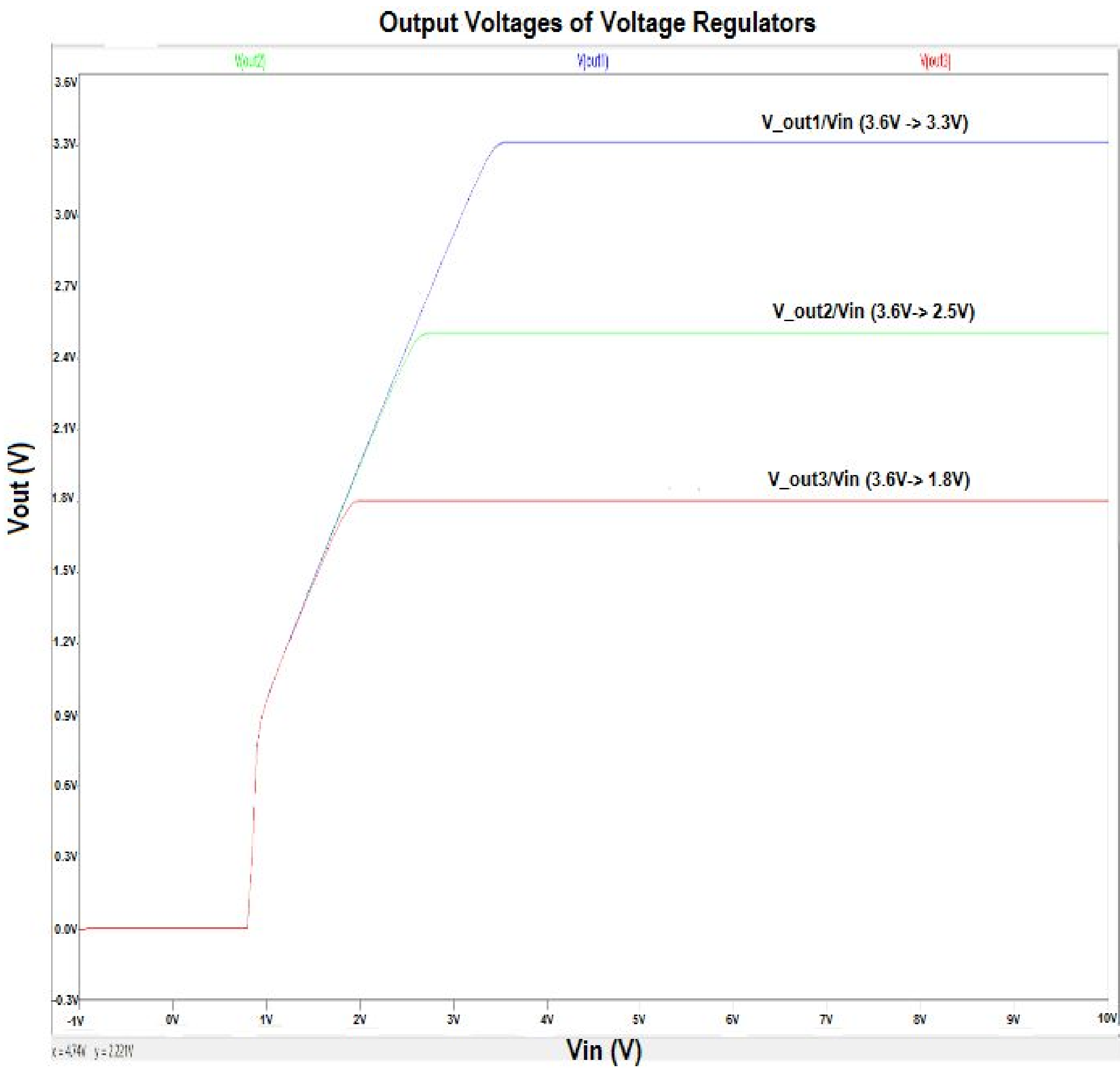

Figure 3. LTspice voltage regulator simulations

2.3.2 *Control Unit*

The control unit will manage the signals in the circuit and manage data transmission to the display. It will be made up of a microcontroller and an RF transmitter. It also establishes communication between the sensors and the RF transmitter.

Microcontroller
The microcontroller will communicate with the sensors using SPI and I2C buses.

RF Transmitter
The RF Transmitter sends data from the microcontroller to the RF Receiver. Allows for a display outside the fire to monitor the Firefighter's vitals. We will be using a frequency of 434 Mhz at a max data rate of 4.8kbps

2.3.3 *Sensor Unit*

The sensor unit will collect all data necessary that we need to monitor the firefighters. Three sensors will be used along with appropriate circuitry to process the data and send it to the control unit.

Accelerometer
An accelerometer array will be implemented in order to detect movement of the wearer's arm. We will use one accelerometer which will communicate with the microcontroller using I2C.

Heart Rate Sensor
A small heart rate sensor will be placed on the bottom of the device to monitor heart rate on the forearm. It will communicate with the microcontroller using I2C.

The ranges of the heart rate sensor was calculated using the following formula [4]:

$$(220 - \text{Age}) = \text{ Max heart rate}$$

The maximum of the healthy range where heart is being exercised but not overworked during vigorous exercises [4]:

$$0.85(220 - \text{Age}) = \text{ Max of range}$$

The normal resting heart rate is 60-80 beats per minute, but during a heart attack, the heart rate is altered due to the disrupted heart flow, the lowest heart rate of our range will be 60 bpm, assuming the firefighter does not have a lower resting heart rate[5].

"Firefighter statistics categorized by age group: 16-19 (3%), 20-29 (21%), 30-39 (28%), 40-49 (26%), 50-59 (16%), 60 and over (6%)"[6]. Based on these statistics, we choose the age range to be 30-49 years old for the max heart rate, giving us a max heart rate of 180 bpm and 153 bpm for the healthy exercising range for a 40 year old . Thus, our design should test for when the heart rate is outside of 60-153 bpm, indicative of stress on the heart.

Temperature Sensor
A small thermocouple or a thermistor will be placed near the skin of the forearm. The thermocouple will measure the internal temperature of the suit and send the information to the microcontroller using a SPI bus.

2.3.4 *Display Unit*

The display unit will receive data sent from the control unit and output the data on a small screen.

Display
The display will be a small LCD display that will simply show the data being sent from the wearable device. It will display a distress signal if the data is outside of permissible ranges. The LCD will connect directly to the Arduino and use I2C to receive the data.

Arduino Uno
The arduino will compute the data associated with heart rate, motion, and temperature, and sift out the data out of the permissible ranges. Heart beat permissible range of 60-153 beats per minute, temperature permissible range range of less than 140° F, and motionlessness for less than 20 seconds.

RF Receiver
Receives data from microcontroller so that it can be displayed. Allows for a display outside the fire to monitor the Firefighter’s vitals. We will be using a frequency of 434 Mhz at a max data rate of 4.8kbps. The digital data from the microcontroller will be sent using amplitude-shift keying.

2.4 Requirements and Verification

2.4.1 Power Supply

Component	Requirement(s)	Verification
Lithium-Ion Battery Charger	● Able to charge the 3.6 volt battery ● Input voltage: 3.75 - 6 DC volts (used for AC adapter)	● Connect battery to 10kΩ resistor ○ Use multimeter in parallel with the resistor to measure the voltage difference across it ■ Verify the voltage across is 3.6 ±0.54V ● Connect DC voltage supply to input of battery charger to input of charger ○ Verify voltages below 3.75 and above 6 do not operate ■ Connect output to oscilloscope
Lithium-Ion Battery	● Able to deliver minimum 3.6 Volts to voltage regulator. ● Has to be rechargeable and supply 3.6 volts after charging ● Has to be able to deliver 3.6 volts in 60° C environment	● Connect battery to 10kΩ resistor ○ Use multimeter in parallel with the resistor to measure the voltage difference across it ■ Verify the voltage across is 3.6 ± 0.54V ● Recharge the battery via battery charger ○ Connect the battery to the voltmeter ■ Check if the output value equals to 3.6 ± 0.54V ● Connect battery to 10kΩ resistor in 60° C environment ○ Use multimeter in parallel with the resistor to measure the voltage difference across it ■ Verify the voltage across is 3.6 ± 0.54V

Voltage Regulators	● Accepts minimum input of 3.6 voltage ○ Step down to 3.3 ±2% V ○ Step down to 2.5 ±2% V ○ Step down to 1.8 ±2% V ● Maximum output current of 0.5 amps	● Send 3.6 volts into each individual voltage regulator ○ Use a multimeter to determine output voltages: 3.3±2%, 2.5 ±2% V, and 1.8 ±2% V ● Connect a resistor in series and measure the voltage across resistor ○ Use Ohm's law to determine current does not exceed 0.5 A

Table 2. Power Supply Requirements and Verification

2.4.2 Control Unit

Component	Requirement(s)	Verification
Microcontroller	● Communicates through I2C and SPI interfaces simultaneously ● Interfaces with sensors to determine when data collection begins	● Run a simple program through the microcontroller. Have program require both I2C and SPI interfaces to be operated together ● Configure sensors to microcontroller ○ Test for 1's and 0's just operation capabilities with microcontroller
RF Transmitter	● Transmits data with a minimum of 3 kHz to a maximum of 1 GHz ● Transmits data at a rate of 3 kbits/s minimum	● Connect RF transmitter to a digital oscilloscope ○ Send any type of data and measure frequency from oscilloscope channels ● Write software that sends a specific data size and sends to a receiver or MCU and measure the required time to transmit

Table 3. Control Unit Requirements and Verification

2.4.3 Sensor Unit

Component	Requirement(s)	Verification
Accelerometer	• Able to detect acceleration when an object moves and sends a notification or signal	• Move the sensor, verify that it can detect movement with an oscilloscope • Leave the sensor motionless. Verify that it can detect no motion with an oscilloscope.

Temperature Sensor	• Can measure temperatures with a maximum 140°F
	  ○ Desired temperature of 140$\pm$4°F
		• Use high heat zone (oven that supports at least 140°F)
		  ○ Verify sensor measures accurate temperature values
		
		• Place sensor in an environment that is 140° F. Verify that the sensor can detect that temperature with an oscilloscope.
		  ○ Decrease the temperature to 136° F. Verify that the sensor can detect 4°F change in temperature with an oscilloscope.
		  ○ Repeat for an increase to 144°F

Heart Rate Sensor	• Able to detect heart rate of firefighter with permissible zone of ages 30-49 during vigorous exercise with a range of 60-153 beats per minute.	• Place the sensor on skin, induce a heartbeat higher than 153 bpm by exercise, verify that the sensor can detect a range higher than 153 bpm with an oscilloscope ○ Repeat process for 60 BPM (below 60)

Table 4. Sensor Diagram Requirements and Verification

2.4.4 Display Unit

Component	Requirement(s)	Verification
RF Receiver	• Able to receive data from the RF transmitter at 100-200 feet • Can receive a minimum of 3 kbits/s	• Send data from the transmitter 100 feet away. Verify that the transmitter can receive data 100 feet away ○ Repeat for 150 feet and 200 feet • Write software that sends a specific data size and sends to a receiver or MCU and measure the required time to receive
Display	• Supports 5 volts for operation with a fluctuation of 2% • Able to display the English alphabet characters (capital and lowercased) as well as numerical values - character monitor vs graphical monitor	• Connect a 5v input from a DC supply into the power pins for display unit • Connect display unit to a programmable MCU and write small program that displays text written ○ Send English alphabet sentences and numerical values

Microcontroller	• Interface with LCD panel to display user information
	
	• Can communicate with RF receiver units
	
	• Minimum of 10 digital I/O pins
		• Load proper LCD drivers with microcontroller
		    ○ Send numerous messages to LCD to test for integrity
		
		• Connect RF receiver with microcontroller
		    ○ Write program that checks if information is received from receiver
		        ■ Send information from transmitter to receiver and check for functionality

Table 5. Display Unit Requirements and Verification

2.5 Schematics

2.5.1 Power Supply

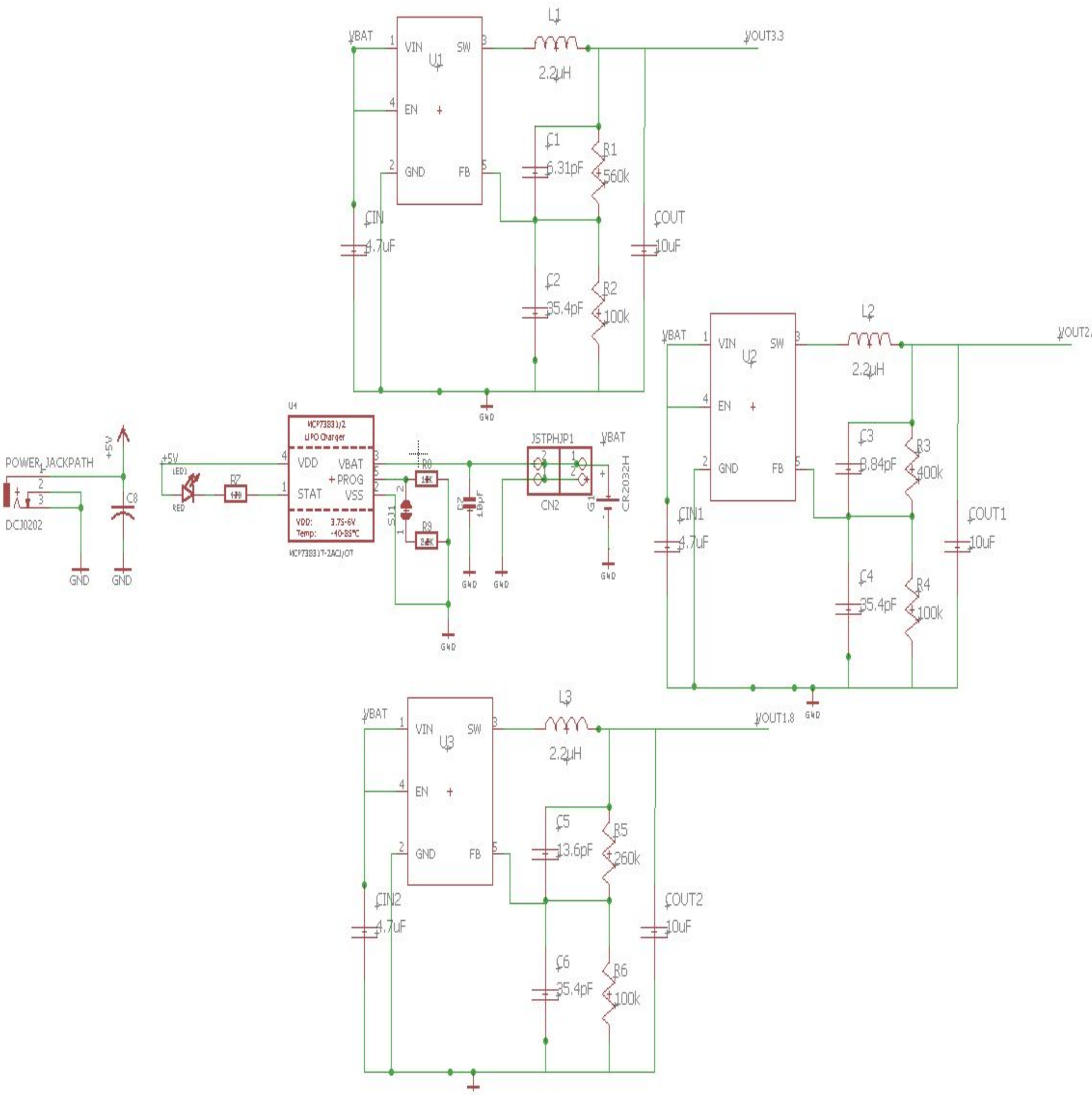

Figure 4. Power Supply Schematic [3] [7]

2.5.2 Control Unit

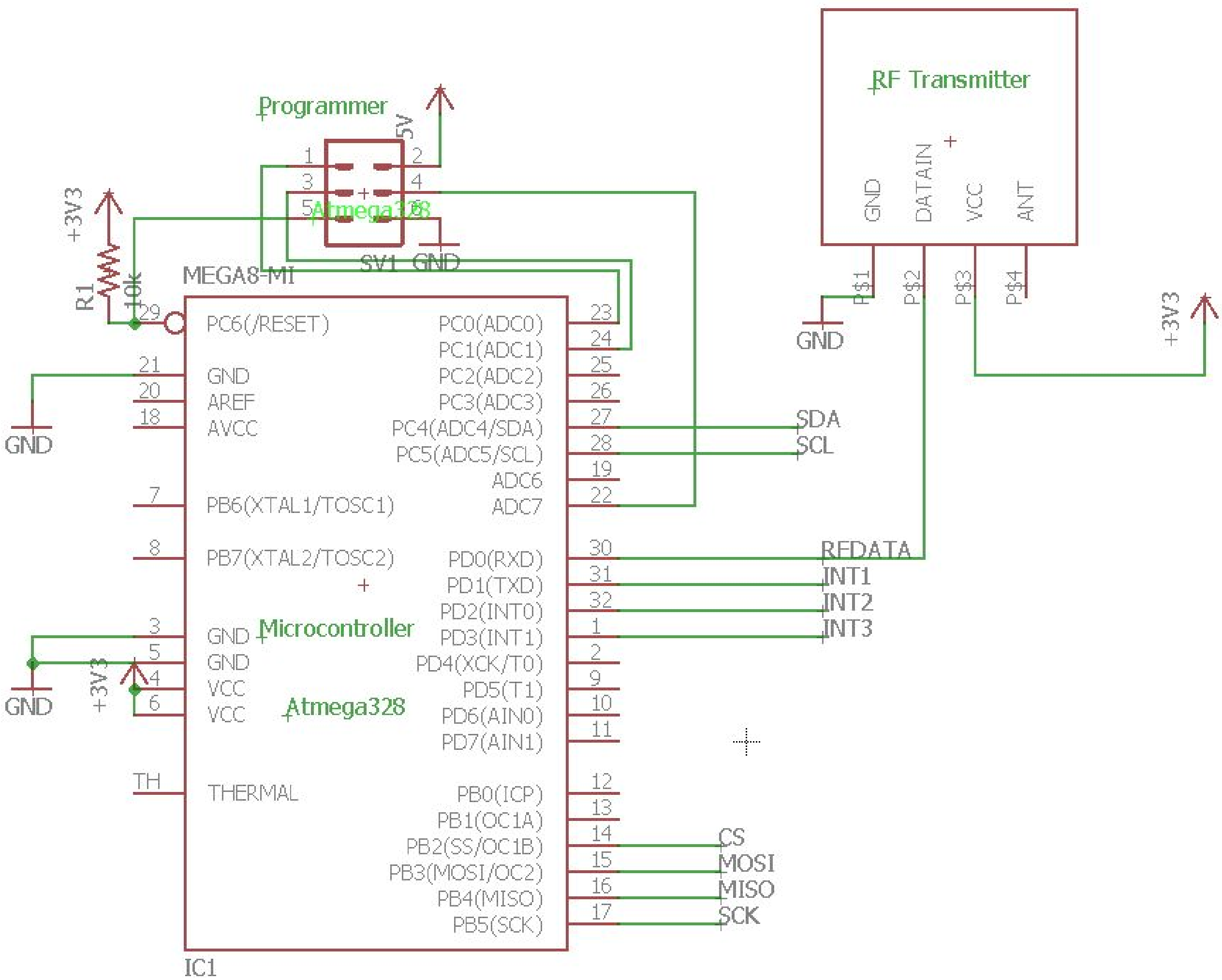

Figure 5. Control Unit Schematic [8] [9]

2.5.3 Sensor Unit

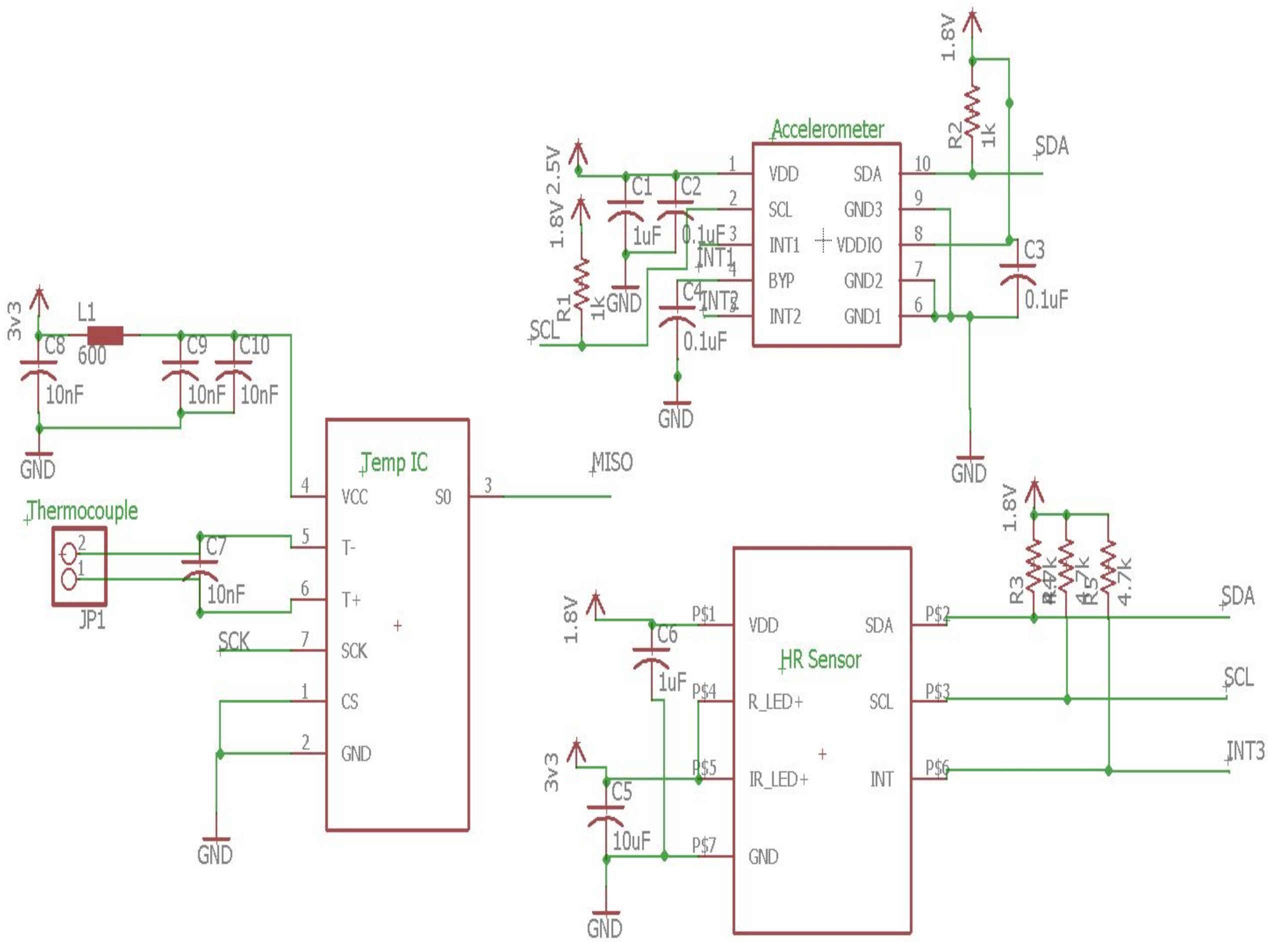

Figure 6. Sensor Unit Schematic [10] [11] [12]

2.5.4 Display Unit

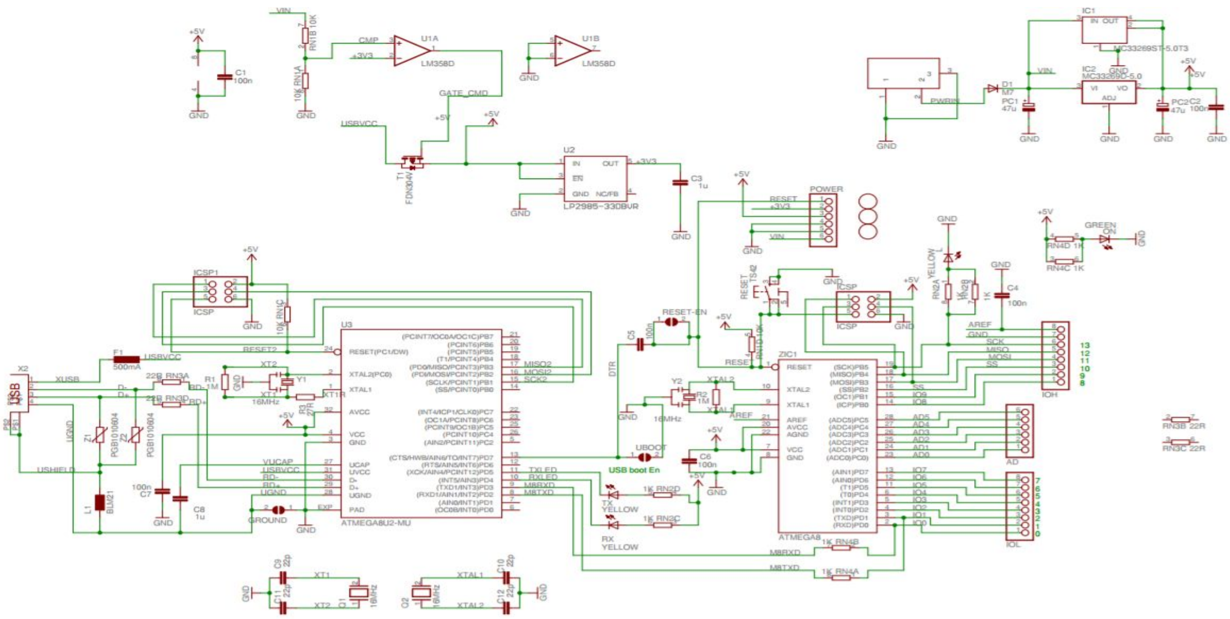

Figure 7. Arduino Uno Schematic [13]

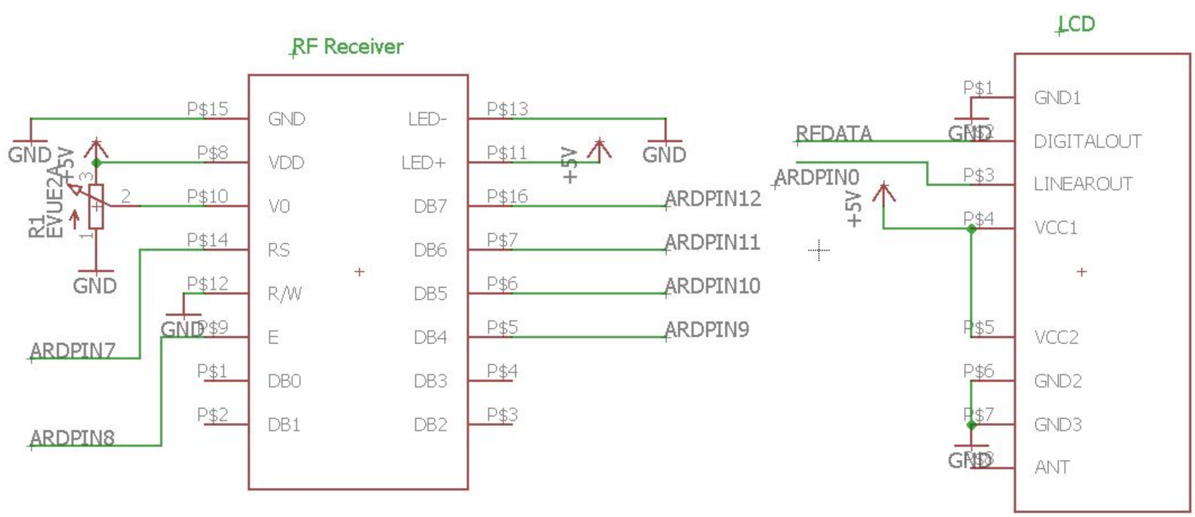

Figure 8. LCD Display & Receiver Schematic [8][14]

2.6 Software

2.6.1 Transmitter

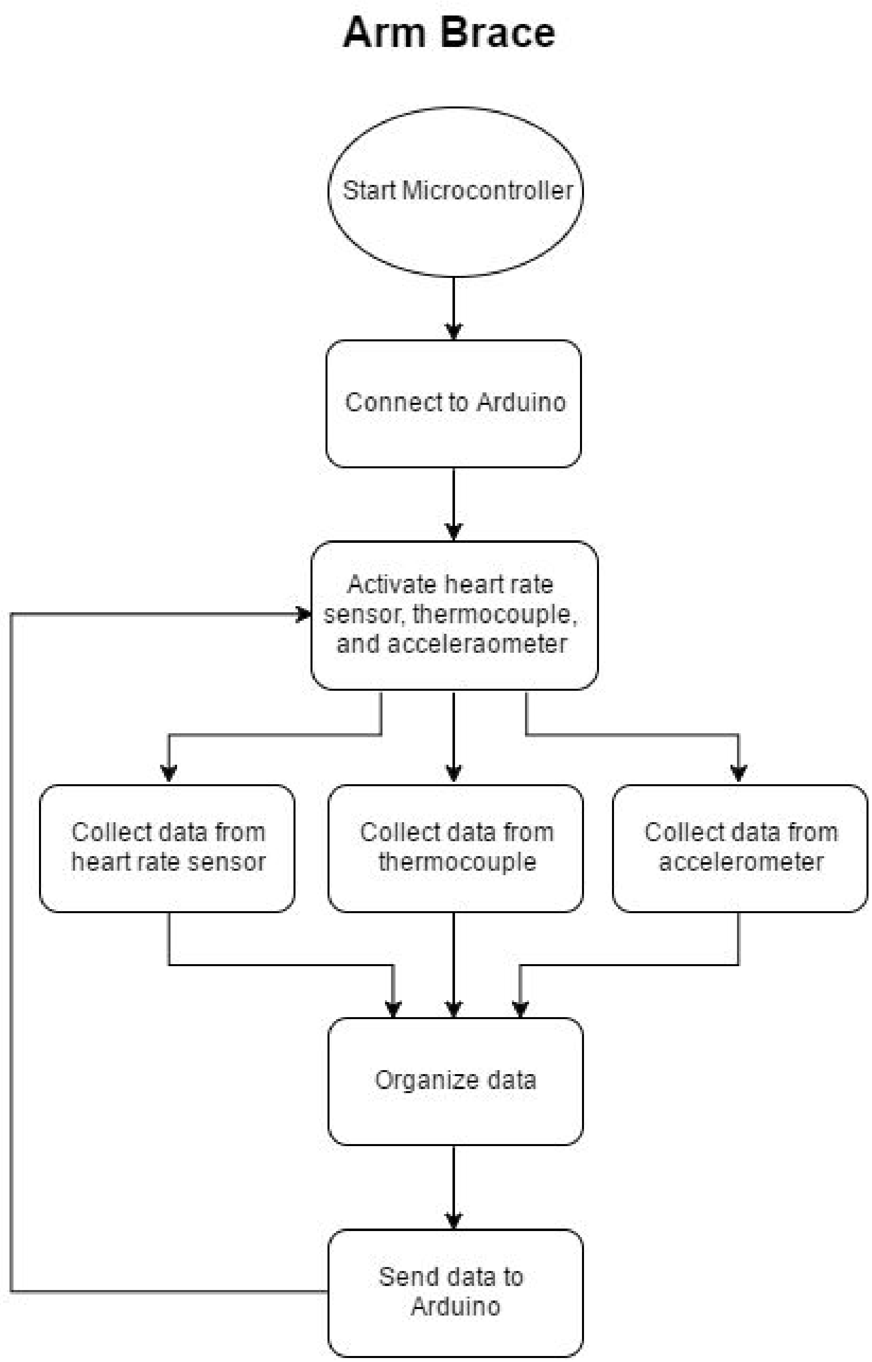

Figure 9. Software flowchart for arm brace / transmitter circuit

2.6.2 Receiver

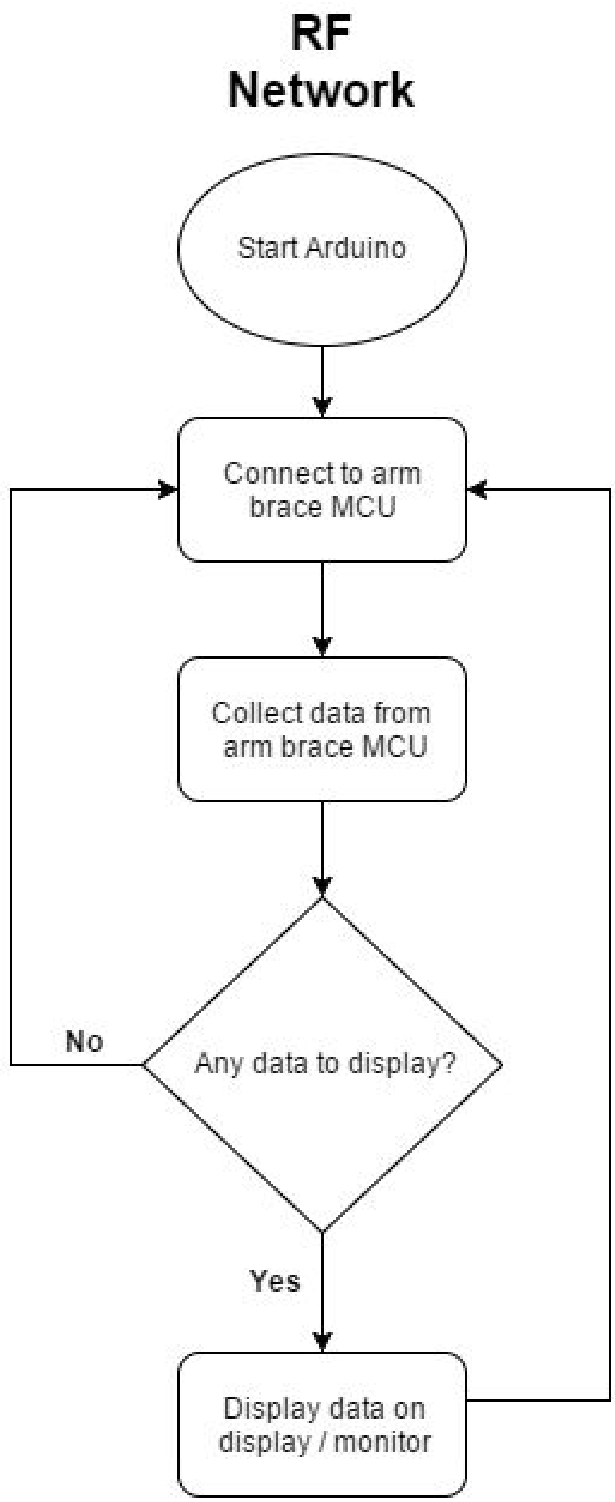

Figure 10. Software flow chart for receiver / display unit

2.7 Tolerance Analysis

Every person has unique skin and specific artery and vein locations. As such, the most important tolerance requirement for the Firefighter Health Monitor is the heart rate monitor sensor. By having the system on the forearm, there is an inherent obstacle of finding a proper location to measure the heart rate for accurate readings.

The heart rate sensor has to be on top of an artery or vein in the arm that is close to the surface. Because arteries and veins only take up a small portion of the surface area of the forearm, there is a good amount for room of error. The main arteries on the forearm include the *radial* and *ulnar* arteries [15]. Similarly, the main veins include the *basilic*, *antebrachial*, and *accessory cephalic* veins. The average sizes of smaller arteries range from 0.1-10 mm in diameter whereas larger arteries are greater than 10 mm. Meanwhile, the size of veins can range from 1 mm to 1-1.5 centimeters in diameter [16][17].

The heart rate monitor sensor has a radius of 0.95 mm [8]. Due to this size, the physical positioning of the sensor is critical to whether there will be any data collected at all. The best case scenario occurs when the sensor is directly on top of the vein or artery. However, because everyone's veins and arteries will be located differential, no matter how slight, the consideration of how we set up the arm brace is extremely important. Due to this, the maximum distance the sensor can be misaligned will be 0.475 mm.

To evaluate the functionality of the positioning of the sensor, there would be a test by placing the sensor on top of the radial artery. Then, by slightly moving the sensor perpendicularly with the artery, the heart rate functionality will be tested.

3 Cost and Schedule

3.1 Cost

Labor

Name	Hourly Rate	Total Hours	Total $
Nick Lau	$30.00	100 hours	$3000.00
Seth Groharing	$30.00	100 hours	$3000.00
Mary Bucki	$30.00	100 hours	$3000.00
Total	n/a	300 hours	$9000.00

Table 5. Labor for all the group members

Parts

Item	Manufacturer	Part #	Quantity	Cost $USD
Heart Rate Sensor	Maxim Integrated	MAX30100EFD+-ND	1	4.91
Accelerometer	STMicroelectronics	497-10189-1-ND	1	8.64
Thermocouple Wire	Digilent, Inc.	1286-1099-ND	1	9.99
Pocket AVR programmer	SparkFun Electronics	1568-1080-ND	1	14.95
AVR Programming cable	SparkFun Electronics	1568-1361-ND	1	1.95
IC MCU 8BIT 32KB FLASH 32TQFP	Microchip Technology	ATMEGA328PB-AU-ND	1	1.38
Arduino Uno	Arduino		1	24.95
RF Transmitter	Wenshing	TWS-BS	1	3.95
RF Receiver	Wenshing	RWS-371	1	4.95
3 pin header	Wurth Electronics Inc.	732-5316-ND	2	$0.26
Li-Ion Battery	Samsung	SAMSUNG 18650 25R 2500mAh SINGLE	1	11.00
Battery Charger IC	Microchip Technology	MCP73831T-2ACI/OTTR-ND	1	0.58

Standard LCD 16x2 + extras - white on blue	Ada fruit	181	1	9.95
Power Jack	Conec	626-1968-ND	1	0.78
Voltage Regulator	Texas Instruments	LM3671MF-3.3/NOPBCT-ND	3	2.76
Connector	Phoenix Contact	277-1667-ND	1	0.39
10k Resistor	Yageo	311-10KGRCT-ND	2	0.10
2.5k Resistor	Vishay Thin Film	764-1254-2-ND	1	1.31
470 Resistor	Yageo	311-470GRCT-ND	1	0.10
560k Resistor	Yageo	311-560KGRCT-ND	1	0.10
100k Resistor	Yageo	311-100KGRCT-ND	3	0.10
402k Resistor	Yageo	311-402HRCT-ND	1	0.10
260k Resistor	Yageo	311-261KHRTR-ND	1	0.10
4.7k Resistor	Yageo	311-4.7KGRCT-ND	3	0.10
1k Resistor	Yageo	311-1.0KGRCT-ND	2	0.10
10uF Capacitor	Murata	490-10474-1-ND	7	1.26
4.7uF Capacitor	Murata	490-10477-1-ND	3	0.91
36pF Capacitor	Murata	490-1416-1-ND	3	0.68
9pF Capacitor	TDK Corporation	445-14103-1-ND	1	1.11
13pF Capacitor	Murata	490-1406-1-ND	1	0.68
6.61pF Capacitor	Samsung Electro-Mechanics America, Inc.	1276-1793-1-ND	1	0.42
10nF Capacitor	Murata	311-1085-1-ND	2	0.18
1uF Capacitor	AVX Corporation	478-1215-1-ND	3	0.17
0.1uF Capacitor	Kemet	399-1061-1-ND	4	0.30
10k Potentiometer	Bourns	3310Y-001-103L-ND	1	2.90
2.2uH Inductor	TDK Corporation	445-6385-1-ND	3	0.17
Ferrite Bead	Wurth Electronics INC.	732-1593-1-ND	1	0.20
Nomex Fabric(60”x60”)			1	9.95
Total parts cost				122.43

Table 6. Total cost of parts

Total Cost

Labor	$9000.00
Parts	$122.43
Total cost	$9122.43

Table 7. Total cost

3.2 Schedule

Week	Task	Responsibility
Feb 19	Design Document	Seth
	Design Document	Nick
	Design Document	Mary
Feb 26	Finalize Design	Seth
	Start algorithm for Microcontroller	Nick
	PCB initial design sensors	Mary
March 5	Finalize Design / Design PCB Power Supply	Seth
	Start algorithm for RF	Nick
	PCB design revised sensors	Mary
March 12	Finalize PCB Design	Seth
	Finalize algorithms	Nick
	Finalize sensor components for PCB	Mary
March 19 SPRING BREAK	Order Components	Seth
	Look for usable components from personal storages	Nick
	Look for sewing supplies and velcro from personal storage	Mary

March 26	PCB Testing/Fix Design	Seth
	Start programming microcontroller	Nick
	Connect sensors to microcontroller/ Solder	Mary
April 2	Test revisions to PCB	Seth
	Test microcontroller on PCB	Nick
	Test sensors on PCB	Mary
April 9	Prepare for Mock Demo	Seth
	Debug microcontroller	Nick
	Debug sensors	Mary
April 19	Prepare for Demo	Seth
	Debug RF network	Nick
	Prepare for Demo (sensors)	Mary
April 23	Demo / Final Paper	Seth
	Ensure functionality for Demo/ Final paper	Nick
	Final paper (sensors)	Mary
April 30	Final Paper	Seth
	Final paper	Nick
	Lab Checkout / Final Paper	Mary

Table 8. Schedule

4 Discussion of Ethics and Safety

4.1 Ethics and Safety

The firefighter life monitor is a device that is designed to detect the warning signs of a firefighter experiencing danger and stress and increase the likelihood of a firefighter surviving, however there are safety risks.

IEEE code one is "to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment"[16].The battery poses the most safety risks. The Li-ion battery must not be overcharged, a circuit must be incorporated to prevent the battery cell voltage from decaying below 3.0 V cell or exceeding 4.2 V cell, we will buy a commercially available charger. The battery cannot be exposed to excess heat, however the Li-ion batteries can work in temperatures up to 60-75°C (140-167°F). Due to IEEE code " to be honest and realistic in stating claims or estimates based on available data", we must disclose temperature inside the firefighter suit when it is made known, and if it is not within the acceptable range for the battery (see IEEE code #1)--we must pick another battery or find another way to power our circuits [18]. The hazard of the battery overheating then catching on fire is too high if the temperature inside the suit proves to overload the circuit [19]. The battery should not be charged above or below certain temperatures (0-50° Celsius).

The batteries should not be shorted circuit the batteries (avoid connecting positive and negative terminals to each other with conductive materials). The batteries should not be left in high temperature environments. This can lead to overheating and/or explosion of fire. Do not submerge or immerse batteries in water or liquids. Keep or store in cool and dry places. Prior to usage, batteries should be inspected for deformities and potential failure. Attached is the safety document for safe practices with lithium ion and lead acid batteries [20].

As an electrical device that will be inside the firefighter's bunker gear, sweat moisture could cause damage to the battery and to the nodes leading to short-circuits. The case will need to adhere to IP66 guidelines, which is protection from water projected in powerful jets from a nozzle with a 12.5mm diameter opening in any direction. The fire hose spray could accidentally seep through the protective layers of the bunker gear and induce a moist environment for the life monitor. Although this is unlikely, it is still a possibility so IP66 guidelines will work.

Lastly, the Rf frequency on the field test model might interfere with other emergency signals, endangering more lives than saving lives. We must designate a frequency that is unused or is firefighter specific to reduce the risks of RF interference and noisy signals. The device will operate in the designated frequency range for testing of our project, which will not interfere with other emergency signals.

4.2 Safety Documentation

Safe Practice for Lead Acid and Lithium Batteries

Document Prepared By: Spring 2016 Course Staff
ECE 445: Senior Design Project Laboratory
Last Revised: April 13, 2016

I. Introduction

Hello senior designers! If you are reading this document, you are probably planning on designing a project using some form of battery! Batteries are a great way to store energy for later use in portable devices or backup systems. One often overlooked problem with batteries is that they are dangerous. Additionally, different batteries are dangerous for different reasons. In this document, we will challenge students to justify why they need a battery, introduce dangers inherent to all batteries, explain the dangers that are unique to two common types of batteries (lead-acid batteries and lithium batteries), present some suggestions for charging batteries, and end with a discussion of the ECE 445 procedures for minimizing the risks of projects involving batteries.

II. Do You Need a Battery?

Due to the danger, the course staff would like to stress that students should ***avoid batteries if at all possible and use the very nice voltage supplies that are provided at every single lab bench***.

III. Dangers Inherent to all Batteries

To prevent runaway current, your batteries must always be stored in a secure location with the terminals covered by insulating material to ensure that there is absolutely no way that a short circuit can present itself. Both of these battery chemistries are capable of delivering unbelievably high currents (>5000A) and will overheat and possibly ignite (lead acid via ignition of evaporating hydrogen and lithium via decomposing cathode and eventual exposure to oxygen) if they become too hot. Additionally, proper ventilation should be allowed such that any gas can dissipate itself. If your circuit requires a battery, you must be able to demonstrate that your circuit will not have any conditions where a failure results in a short circuit.

IV. Unique Dangers of Lead Acid, SLA, Gel Mat, etc. Batteries

Lead acid batteries are the same types of batteries in your car. They are very high capacity and capable of outputting tremendous amounts of current at a reasonably low voltage. As the name implies, they are full of lead (bad) and acid (also bad). What's worse, the acid inside of a non-SLA or non-Gel Mat battery is in a liquid form and these batteries have valves to allow vapors to evaporate from the battery, meaning they pose a severe risk of spewing acid everywhere (VERY bad). For these reasons, if your project involves a lead-acid battery of any type, you will be *REQUIRED* to find the Material Safety Data Sheet (MSDS) and data sheet for your battery before you can acquire the battery and you must keep this documentation with you at all times in the laboratory. If possible, it is advised that students purchase a battery with protection against chemical spills (SLA is typically the most effective for student projects relating safety and cost) in order to minimize the risk of chemical leakage occurring.

V. Unique Dangers of Lithium-Ion, Lithium Iron Phosphate, etc. Batteries

Lithium batteries are the type of batteries found in your mobile phones and laptops. They are generally smaller and lighter than comparable capacity lead acid batteries, but they are also *substantially more flammable*. Unlike the lead acid battery where cell damage typically translates to reduced capacity, cell damage in a lithium battery translates to *a particularly nasty chemical fire*. Lithium Iron Phosphate batteries tend to be somewhat more fire resistant on account of different cathode material; however, they are still extremely flammable. For this reason, if you elect to use a lithium battery in any capacity, you will be required to complete additional fire safety and fire extinguisher training before proceeding with the course. Additionally, you will be required to incorporate some circuit to prevent your battery cell voltage from decaying below 3.0 $\frac{V}{cell}$ (2.5 $\frac{V}{cell}$ for $LiFePO_4$) or exceeding 4.2 $\frac{V}{cell}$ (3.65 $\frac{V}{cell}$ for $LiFePO_4$). Any charge or discharge tests must be performed while the battery is inside of one of the specially design lithium safety bags and any protection or charging circuits must be approved by your TA **AND** one of the power-centric TAs before they are so much as tested on a breadboard. These procedures are in place in order to protect you, others, and the brand new ECEB from being reduced to a smoldering pile of ashes. ***IF YOUR BATTERY BEGINS TO SWELL, FEEL HOT OR MAKE FUNNY NOISES: disconnect the battery IMMEDIATELY and place it in a battery bag FAR AWAY FROM FLAMMABLE STUFF. You should then report the issue to your TA and a power-centric TA IMMEDIATELY either in person or via a phone CALL to dispose of the battery as soon as possible.***

Swollen Battery = Time Bomb

There are several ways to damage a lithium cell. They include:

- Over charge
- Over discharge
- Over current (charge or discharge)
- Excessive heat
- Internal or external short circuit
- Mechanical abuse

Always check the battery specifications before purchasing or using them!
To minimize the risk associated with lithium batteries, the following precautions should be followed:

- Written work instructions and checklists should be generated for testing procedures
- Remove jewelry that may accidentally short circuit the terminals
- All dented batteries should be disposed of immediately (Contact your TA AND Casey Smith (217)-300-3722; cjsmith0@illinois.edu))
- Cover all metal work surfaces with insulating material
- Batteries should be transported in non-conductive carrying trays
- Always ensure the the open circuit voltage is within the acceptable range for your battery

VI. Charging Lead-Acid Chemistry Batteries

Charging a lead-acid battery is a non-trivial task. The course staff strongly suggest that if you must build a charger, you use some kind of integrated circuit (IC) solution. Additionally, you must familiarize yourself with the battery's charge characteristic and maximum charging current. Lead-acid batteries are inherently safer than lithium chemistry batteries. While an overcharge or overdischarge will cause extreme damage to your battery, the damage will be limited to internal calcification of the plates, reducing your capacity to a fraction of what it originally was. For this reason, ***the course staff strongly suggests that you use a lead-acid type battery if your project requires a battery and is not weight or size sensitive***.

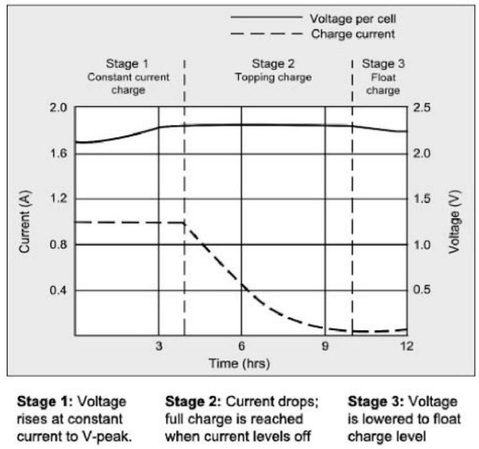

Fig. 1: The Generic Charging Characteristic of a Lead Acid Battery. Source.

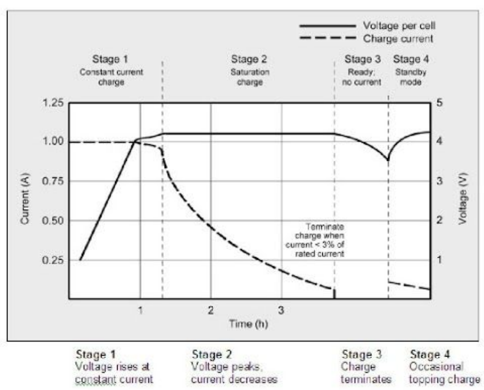

Fig. 2: The Generic Charging Characteristic of a Lithium Battery. Source.

VII. Charging Lithium Batteries

Charging a lithium battery is also a non-trivial task. The course staff continue to strongly suggest that if you must build a charger, you use some kind of IC solution. You must also familiarize yourself with the charge characteristic and maximum charge current. *Any circuitry you design that involves a lithium battery must be approved by your TA* ***AND*** *one of the power-centric TAs before they are so much as tested on a breadboard.* As an addition, it is important to note that batteries, which we can model as ideal voltage sources, charge with ideal current sources. Having an ideal current source and voltage source in parallel with the load is fine! Problems arise if we instead have two voltage sources in parallel. Any mismatch in the voltage will break KVL, which leads to a sudden rush of current from one source to the other in order to try and balance the voltages. This is a very unstable and hazardous methodology, therefore we always charge our batteries with current driving sources.

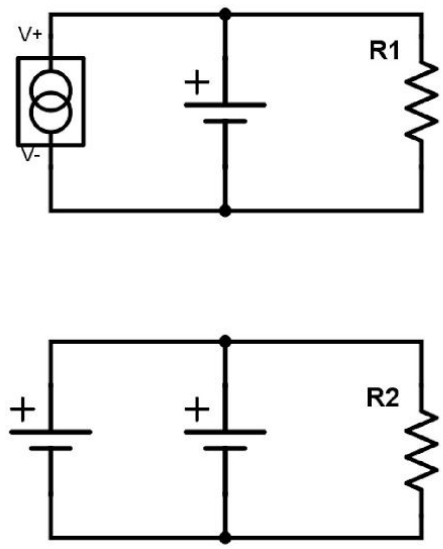

Fig. 3: Top: the proper way to think of charing your battery. Below: a risky way to do so.

VIII. Charging Suggestions and Testing Requirements

If possible, we strongly suggest purchasing and incorporating a fully featured charging suite if your project requires batteries. Those must meet rigorous safety standards in order to be sold in the USA. If this is not possible for any reason (your project is cost sensitive because it is for the developing world, you are using solar panels to charge a battery, etc.), we strongly suggest using an integrated circuit solution. As a last resort, you may attempt to design your own charging circuit. Regardless of the route you choose to take, due to the inherent danger of charging these batteries, everything must be approved by your TA and one of the power-centric TAs before you even bring your design to the breadboard. Once your charging design has been approved, its functionality must be validated to your TA in a demonstration before the battery is connected to the system. Initial testing of the charging circuit with the battery connected should be done in the senior design lab with a TA present and proper protective and emergency equipment easily accessible.

TABLE I: A Short Table of Suggested Charging ICs. (Google is Your Friend)

Chemistry	**Suggestions**
1S-2S Lithium	MAX1551/5, LM317 (see datasheet)
3S+ Lithium	LT1505, LT1512, LM317 (see datasheet)
Lead Acid	LM317 (see datasheet), LTC4020, LT3652

IX. ECE 445 Procedures

1) Justify to the course staff that your project requires a battery.
2) Determine the appropriate chemistry for your project. Spill-resistant lead acid is vastly preferred.
3) Obtain safety documents:
   a) If you are using a lead-acid battery: obtain the MSDS and battery data sheet.
   b) If you are using a lithium battery: obtain additional fire safety and fire extinguisher training
4) In this order:
   a) If your project allows for it: search for a commercially available charger.
   b) Search for ICs that will perform the entire charge algorithm for you.
   c) AS A LAST RESORT: Design your own charging circuit.
5) Simulate your circuit in SPICE, even if you plan to use a charging IC.
6) Have your TA and a power-centric TA review and approve your design.
7) Build your design on a breadboard and validate functionality to your TA before attaching a battery.
8) If using a lithium battery, place it in one of the lithium battery bags whenever charging or discharging the battery.
9) To be done only in the senior design lab with a TA present and with protective and emergency equipment easily accessible: connect a battery to your circuit.
10) If your circuit behaves correctly, congratulations! You are done. If not, close is NOT close enough and you will have to return to Step 4.

If a problem occurs in your circuit:

1) Shut off power
2) Locate problem before power is restored
3) If circuit breaker is tripped, report to ece-eshop-repairs@illinois.edu to reset
4) If help is needed, contact Casey Smith ((217)-300-3722; cjsmith0@illinois.edu) or the electronics shop for assistance
5) If the situation is an emergency, **call 911**

A. Emergency Procedures

- If a lead acid battery spills: use the Battery Acid Spill Kit located in the back of the lab to clean the spill. Contact Casey Smith and your TA immediately.
- If a lithium battery explodes, **call 911** and evacuate the area.
- If a lithium battery ignites, **call 911** and extinguish it with either of the fire extinguishers located in the lab. They are both rated to extinguish electrical fires and should be at your bench whenever you are actively working with your batteries. Contact Casey Smith and your TA immediately.
- If a lithium battery swells, feels hot to the touch, or makes funny noises but does not ignite, keep the battery in the bag and contact Casey Smith and your TA immediately. The battery cannot be left unattended until it has been properly disposed of.

By signing below, you acknowledge that you have read this document and agree to follow the ECE 445 Course Staff's guidance regarding high capacity batteries and will complete all necessary safety training and adhere to the guidelines set forth in this document as well as additional guidelines as the course staff deems necessary.

NICK LAU
Print Name

2/23/17
Date

Signature

2/23/17
Date

TABLE II: History of Revision

Revision	Date	Authors	Log
A	3/19/2016	Lenz	Creation
B	3/28/2016	O'Kane	Additonal Information, General Revision
C	3/29/2016	SP16 Staff	Collaborative Revisions
D	4/7/2016	Salz	General Revision

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MARY BUCKI
Print Name

2/24/2017
Date

Mary E. Bucki
Signature

2/24/2017
Date

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Seth Groharing
Print Name

2/24/17
Date

Seth Groharing
Signature

2/24/17
Date

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