PPE and Worker Tracking System

Team 31 — Dennis Wong and Joydeep Ganguly
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TA: John Capozzo

1 Introduction

1.1 Objective

Workplace safety is a serious concern. Without proper Personal Protective Equipment (PPE), workers are a risk. A risk to themselves, their coworkers, and their employers. However, a common issue in moderate risk workplaces is a lack of personal protective equipment discipline. Workers do not wear this equipment for a variety of reasons, and this leads to liability for employers, more danger for workers and overall greater risk.

Our solution is to gather data on worker PPE habits, positions, and working conditions. This data would include where workers are throughout the day, if they wear the appropriate PPE for their workstations, and workplace conditions that can lead to negative health effects. Specific workplace condition data includes but is not limited to temperature and humidity (through which heat index can be calculated), and luminosity.

The concrete product that we would like to make is: a wearable vest with embedded sensors to track worker position and working conditions, as well as a set of wearable circuits that can detect if PPE is being worn, and broadcast that information over WiFi to a central database for logging and analysis. Each of these wearable devices will have a memory unit, a processing unit, a small battery, and a wifi chip for wireless communication to the server.

Currently there is no technology that collects any form of this data, but the data has practical application as it can enable more intelligent PPE policy from management, as well as the identification of "at-risk" workers who may wear PPE less often than safety regulation requires. Effective data gathering on worker safety habits also has the potential to significantly reduce company liability, and lead to safer workplace practices.

1.2 Background

According to the National Safety Council, a worker injury can cost the company up to $30,000 in damages and an OSHA fine can cause a company up to $7000 for minor infractions, including not wearing personal protection equipment (PPE) or operating machinery in an unsafe way[1].

Regardless of how serious the infringement or injury is, the company's reputation for having safe working conditions will deteriorate with each infraction. A common solution

[1]http://www.safetyservicescompany.com/industry-category/construction/top-10-osha-fines-for-small-companies/

to this problem is the use of large signs that say things along the line of “no ppe, no work, no pay”. The problem with this is that in a bigger warehouse, managers can not keep tabs on everyone. Sensing workplace conditions for each worker allows management to make intelligent on the fly decisions about the amount of break time and adapt working conditions.

1.3 High Level Requirements

- The system must be able to recognize when a worker is within 2 meters of a station that requires PPE, in an otherwise unobstructed area. As the number of workers increases, the accuracy of this measurement can decrease.
- The wearables must cost the lesser of $500 per unit, or a 50% profit margin on the cost of materials[2].
- The wearable must be able to report a full 8 hours of data from the sensors embedded into the PPE. Data can be reported in 5 minute chunks or continuously, and therefore the MCUs must have up to 5KB of flash memory .

[2] http://csimarket.com/Industry/Industry_Profitability.php?ind=1010. The profit margin for the semiconductor industry is between 20 and 60%, and since this is an emerging technology, we would want a high margin to recoup investment and distribution costs

2 Design

2.1 High Level System Block Diagram

As shown by figure one below, the PPE tracking project has five main components: three wearable devices, a bluetooth tracking module, and a server do do analysis on the data. Each separate module has a power component which is a lithium ion battery with build-in protection circuitry to ensure the battery stays between 2.8V and 4.2V. This protects against over charging and discharging past 2.8 volts. The power component also includes a power circuit to charge the battery using usb and a buck-boost converter so that the battery can continue to power the wearable even when the lithium-ion battery is below 3.3V. The microcontroller will be a P1 WiFi enabled microcontroller which serves as a preprocessing unit to collect sensor data before sending to a web server where analysis occurs and is written out in a human-readable format. The sensors communicate using analog reads which are stored as integers, while the bluetooth modules communicate with the MCU using UART protocols at 3.3V. The bluetooth modules communicate with each other using Bluetooth Low Energy (BLE).

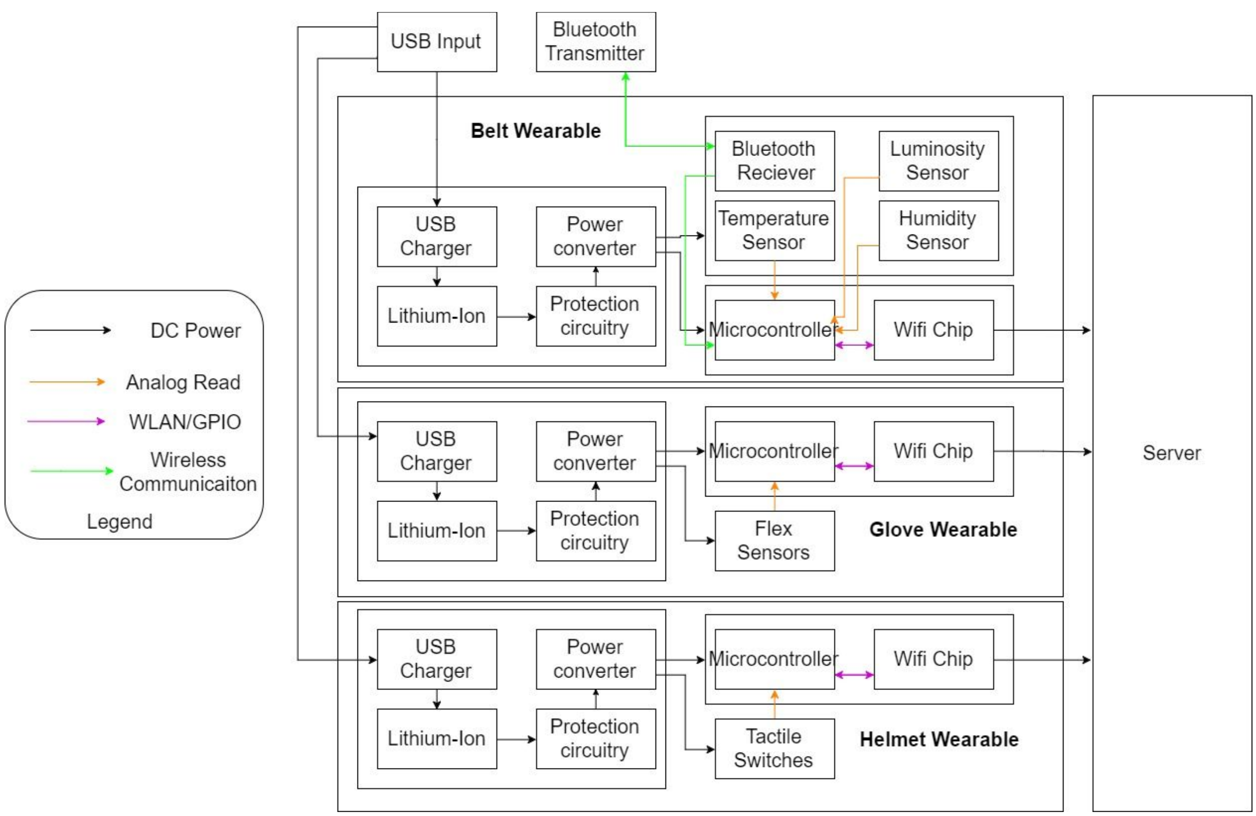


Figure 1: System Block Diagram

2.1.2 Glove Wearable Summary

The purpose of this wearable is to collect data from the flex sensors to detect whether someone is wearing the glove after information has been sent to a server and has been analyzed. This will be achieved by measuring the amount of “flex” over time, under the assumption that when gloves are worn, fingers move, which results in more scattered and varied data.

There will be flex sensors sewn into the fingers of the gloves and directly connected to the MCU. The housing for the MCU and power circuit will also be sewn in between the layers of the gloves on the back of the hand. Dimensions and electrical properties for the PCB, battery, and flex sensors will be provided later in section two.

The flex sensor readings are analog and will be read by the microcontroller and stored into the on-chip flash memory. The readings will then be sent out to the server periodically with a timestamp to the server to determine when the person was wearing the glove. The reason packets of data will be sent out rather than continuously sending data is to save battery life by utilizing the on chip memory and sending once every five minutes. This would increase efficiency of the battery immensely.

The flex sensors have a straight resistance of 10kOhms (+- 30%), with a bend resistance at minimum of double this. Each flex sensor is 4.5 inches in length, and cannot be bent past 90 degrees without permanently damaging the sensor. To avoid these problems, the flex sensors will be place such that one end is on the middle of the hand, while the other end stops before the second knuckle. The resistance increases linearly with the bend degree, up to a maximum of around 90 kOhms. During initial testing, the resistance was measured (by using a voltage splitting circuit) while the sensor sat idle, and while the sensor was manipulated, similar to a human figure. It was found that the resistance readings of the sensor had significantly higher standard deviations than the idle circuit, and this will be the basis for human-detection from gloves.

To power this wearable, a 3.7V 2000mah lithium ion battery will be used. The microcontroller and flex sensors can be powered with 3.3 volts with a maximum current draw of just over 600ma when it is initially starting up with the WiFi chip. On average, the P1 Microcontroller will draw between 80-100ma of current at 3.3V with the Wifi on and current draw from the flex sensors are negligible. A more detailed power calculation will come in the battery section.

2.1.3 Helmet Wearable Description

The purpose of this wearable is to collect data to detect whether someone is wearing the helmet after data has been sent to a server. This will be achieved by comparing the mean force recorded for specific timeslices against the mean force recorded for a helmet not being worn, and the distribution of forces recorded from one being worn. A maximum likelihood estimator will do the classification.

Similar to how the glove detection circuit works, there will be push button switches on the inside of the helmet which will be calibrated to each worker when the helmet is first used. The reason for this is because every worker will fit into their helmet differently so it would be important to get this benchmark reading. The most important sensor will the on the top of the head to measure the weight of the helmet when it is in use.

Each of the switches will be placed inside the helmet with the sensitive region facing outward so when the head presses on it a reading will be taken. The weight of the helmet should push down on these buttons with enough force to register as a “push”. The most sensitive of the buttons respond to a push of .98N which is well under the amount of force we expect a hat to exert on a worker’s head. Since analog reading from sensors on the P1 microcontroller can range from 0 to 4095 using a switch to connect two resistors and having it go to an analog read pin will yield fairly consistent values when the helmet is worn.

The switches that will be used are momentary-off tactile switches so if the button is pushed down then the circuit will be closed and the analog read pins can read the voltage through the analog pins. There will be five switches, one at the very top of the helmet and four others in the surrounding area where it will be least distracting. There will be wires going along the side of the helmet and it will be connected to resistors on the pcb board.

To power this wearable, the same method used to power the glove will be used because of its small size and ability to recharge via usb while having enough power to keep the system running for over an entire workday.

2.1.4 Belt Wearable Description

The purpose of the vest wearable would be to gather data on the working conditions of each worker. The data that will be gathered will include but not be limited to luminosity, temperature, and humidity data.

The same scheme where the microcontroller takes inputs from each sensor, stores it, and send it out periodically will be used as a means to conserve battery life. The purpose of the temperature and luminosity sensor would to to provide worker data on working conditions to comply with health and safety regulations.

The most important function of this wearable device is to continuously calculate distance to bluetooth beacons and periodically send this timestamped data to a server for analysis with data gathered from the glove and helmet wearable later. Readings will be taken every five seconds since that is the calculated safe threshold for the time for a worker to travel across the beginning of the hard hat zone to the center which is where the dangerous machinery is.

In terms of how portable and ergonomic this wearable will be, the pcb with bluetooth module will be able to fit into a case that is easily attachable to a belt. The casing will have a small hole for the luminosity and temperature sensor.

To power the wearable, a 2000mah 3.7V lithium ion battery will be used with the same power electronic circuit to both provide charging capabilities and to keep the output at a constant 3.3V.

2.2 Bluetooth Module Description

The purpose of this module will be to track the proximity of workers to “dangerous” areas. This will be achieved by using the iBeacon protocol and having “sending” beacons in the center of “dangerous” areas. Dangerous zones will be defined as places within some radius, r of each beacon, and worker position data, as gathered from iBeacons throughout the day will be logged and correlated with PPE data.

To detect whether a worker is in proximity of a station that requires protective equipment, a microcontroller and a bluetooth low energy module will be at the station. The bluetooth module will use iBeacon technology to determine the proximity to various areas demarcated within buildings.

iBeacon is built on low energy bluetooth that can run for up to three months on a single coin battery, meaning that once beacons are placed, there will be minimal replacement; the cells also have a range of up to 100m which is sufficient for this project’s needs (iBeacon). With the correct low power settings, this system will draw .18mA at 2 to 3.7V. A single coin-cell battery has around 670mAH, at 3.5V, so this will last almost 3000 hours, or 3 months.

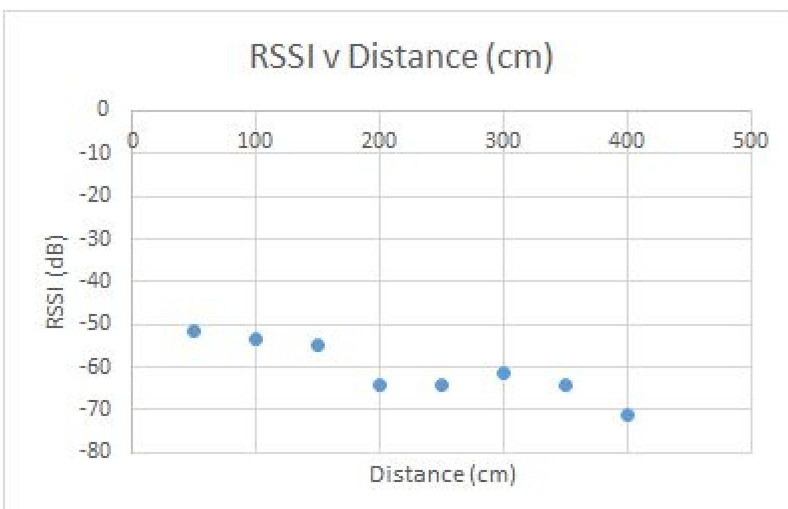


Figure 7: RSSI v Distance. There is a clear trend between distance and RSSI, off of an admitted small number of points. There is promise in using this to detect

iBeacon Technology (iBeacon)

iBeacon is a standards platform developed by Apple for use with Bluetooth low energy. Senders, or beacons periodically broadcast a message with four parts: a unique identifier, a major and minor -- for hierarchical ordering, and the power the message was broadcast with. The receiver can calculate the power the message was received with, and based on attenuation, estimate the distance to the beacon (iBeacon).

2.2.1. Kalman Filtering

After the bluetooth beacons were developed, it was clear that the data was too noisy to differentiate distances from one another. Because there was so much variation in the received RSSI for fixed distances, it was clear that there was a significant amount of noise -- either in the measurement devices, or in the characteristics of the testing room. Something needed to be done to remove this noise.

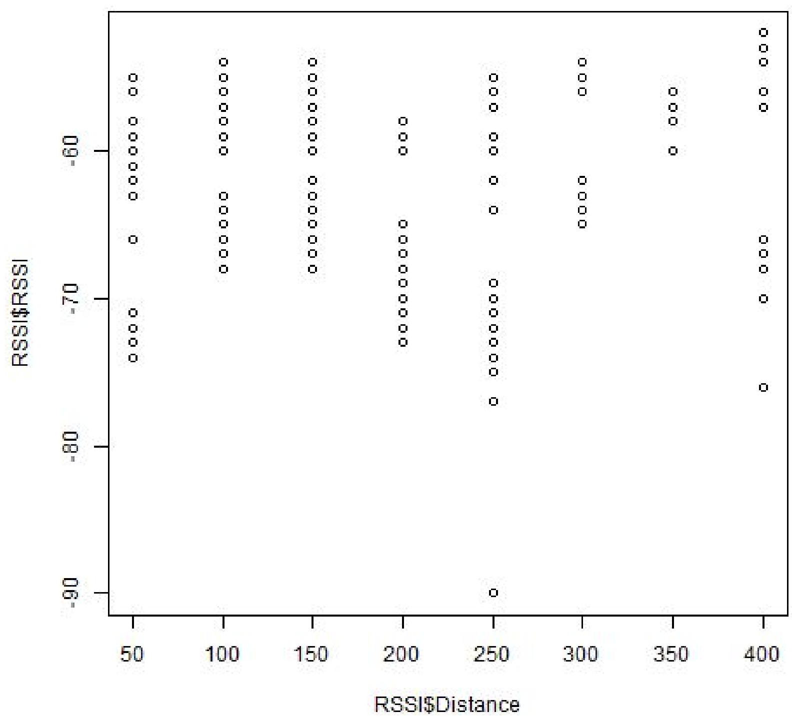


Figure ###: The distribution of signal strength makes predicting location impossible

After surveying the available research on noise filters, as well as evaluating the current research, a Kalman Filter was implemented and selected to reduce the noise within the signals taken. A Kalman Filter was a good choice because of the statistical assumptions inherent in the model -- we could exploit the model for better accuracy than was otherwise calculated.

The algorithm for a Kalman filter is a two-phase process: first a predicted state is calculated, based on the last state, the process model, the process noise, and known inputs to the system. Then, a Kalman Gain is calculated, based on the uncertainty in the process model (denoted as process noise), and uncertainty in the measurement (known as measurement noise) which is based off of the covariance of all the quantity in the state vector. Then, a measurement is taken. A calculated, filtered value is arrived at, by averaging the prediction and the measured process, weighted by the Kalman Gain, or the confidence in the recorded measurement. The governing equations for the Kalman Filter in general are below.

$$\hat{\mathbf{x}}_k = \mathbf{F}_k \hat{\mathbf{x}}_{k-1} + \mathbf{B}_k \overrightarrow{\mathbf{u}_k}$$
$$\mathbf{P}_k = \mathbf{F}_\mathbf{k} \mathbf{P}_{k-1} \mathbf{F}_k^T + \mathbf{Q}_k$$

Figure### Equations governing the predicted state of a model, x_k

$$\hat{\mathbf{x}}'_k = \hat{\mathbf{x}}_k + \mathbf{K}'(\overrightarrow{\mathbf{z}_k} - \mathbf{H}_k \hat{\mathbf{x}}_k)$$
$$\mathbf{P}'_k = \mathbf{P}_k - \mathbf{K}' \mathbf{H}_k \mathbf{P}_k$$
$$\mathbf{K}' = \mathbf{P}_k \mathbf{H}_k^T (\mathbf{H}_k \mathbf{P}_k \mathbf{H}_k^T + \mathbf{R}_k)^{-1}$$

Figure ###: Equations governing the update step of a Kalman Filter, where K is the Kalman Gain

This implementation of a Kalman filter used one quantity for state -- the recieved RSSI value. Our process model was simple: no recieved input, and no change in RSSI. As a result, the covariance matrix simply became the variance, as calculated by measuring the standard deviation of RSSI readings across 1500 data points. As a result, there was no need for matrix inversion, and the entire filter was implemented in Java, from scratch.

This transformation of the data led to significantly reduced variation in the RSSI readings, making it possible to classify the data, as shown below.

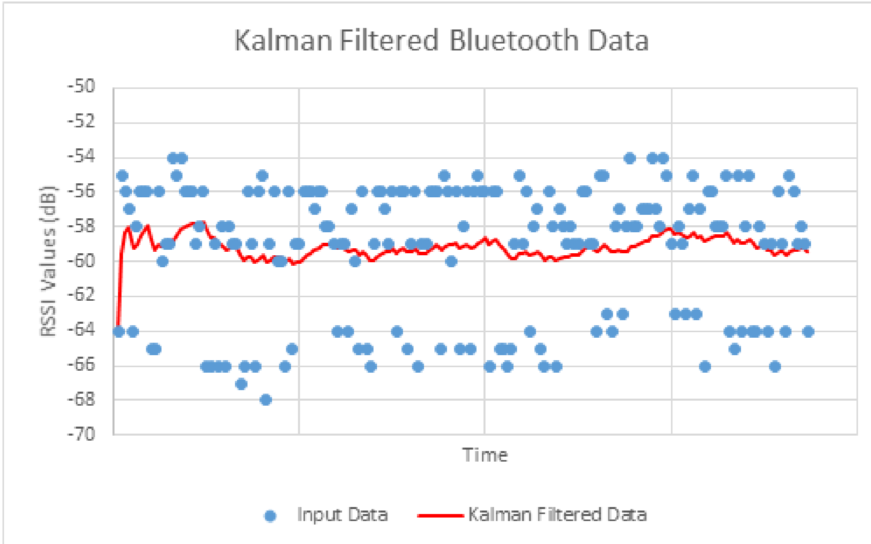


Figure ###: Comparison of Raw data and Kalman Filtered data. Note the preservation of signal characteristics (trends, minimums and maximums), but much less signal noise

After the successful implementation of the Kalman Filter, all that remained was to estimate distance from the data.

2.2.2 Classifying

Initial analysis of the data showed that linear regression based on the data would not be an effective fit, as the regression coefficients and R2 values were too low and inconclusive to predict from. Given that physics based assumptions were not sufficient (due to multipath and other complicated signal geometries), it was necessary to use a statistical approach to correctly estimate, or rather, classify the data.

Labeled training data was collected, with samples being associated with a measured distance from the bluetooth emitter. The data was portioned into training and test sets. The test set was used to build a characteristic distribution for each discretized distance from the emitter. For example, there was a calculated mean and standard deviation for samples one meter away from the emitter, 2 meters and so on. After these distributions were built, the training data was classified according to a maximum likelihood estimator rule. The quantity estimated was the probability that each observation came from each distribution, and the distribution with the highest probability was chosen.

There were three quantities used to measure error rates of this classifier. All quantity were measured using 10-fold cross validation, with the data being randomly sorted into test and training data each time, following a 90%-10% ratio. The first quantity measured was “miss rate”, or the odds that the classifier would sort an observation into the wrong bin. This was found to be approximately 11%, which is a low miss rate for this sort of application, though it is not directly comparable to our requirements. The second measured quantity was classification error margin, or how much the classifier was off by, when it misclassified. This error margin was found to be 60cm, well within the requirements of 2 meter accuracy. The final metric measured was overall error rate, or the average misclassification rate for all observations. Because the classifier was correct almost 90% of the time, the overall error margin was 8cm. However, this is not a good error margin to use, because it does not properly indicate the accuracy of the classifier.

A statistical approach to measuring distance, combined with Kalman Filtering of our bluetooth RSSI values was sufficient to exceed our design requirements for the indoor localization module.

2.3 Power Circuit

2.2.1 Lithium Ion battery

To power each wearable, a 3.7 volt 2000mah lithium ion battery from sparkfun will be used. The reason for picking this battery is because it is lightweight, thin, and 2000mah is more than enough to power the wearables for at least 8 hours. The physical dimensions of this battery are .25 inches by 2.1 inches by 2.4 inches and can be slid into a construction glove with minimal distraction to the user (Sparkfun).

Additionally, this battery comes with built in protection to ensure that battery stays in between 2.8-4.2 volts (Sparkfun). Other options we looked into are cylindrical versions of the same battery but those do not come with overcharge protection are are more bulky. 12V batteries were also an option for the vest wearable but their size and weight make them a less practical option. Mobility is very important for the workers and the smaller the battery, the less distracting the device will be.

2.2.2 Power analysis

Device	Operating Mode	Number of Devices	Current Draw	Usage Percent When Not Charging
P1	Active mode,	1	40mA	95%

Microcontroller	WiFi off			
P1 Microcontroller	Active mode, WiFi on	1	80mA	5%
Flex Sensor	Active mode	3 (only for Glove)	Decreases depending on amount of bend. Can range from .33mA to .033mA	100%
Buck-Boost Converter	Active mode	1(all wearables)	80uA quiescent current	When not charging
USB Charger IC	Active mode	1 (all wearables)	N/A	While charging
Temperature/ Humidity Sensor	Active mode	1 (only vest wearable)	1mA	100%
Photodiode	Active Mode	1 (only vest wearable)	1mA	100%
HM-10 Bluetooth	Active Mode	1 (only vest wearable)	8.5mA	100%

Given each part's current draw we can calculate the theoretical battery life of the 3.7V lithium polymer rated for 2000mah following this equation:

$$Estimated\ battery\ life\ = \frac{Battery's\ capacity\ in\ amp-hours}{Current\ draw\ of\ each\ \ device}$$

Glove Wearable:

$$42\ hours\ of\ battery\ life\ = \frac{2000mah}{40ma*.95+.05ma*80+3*1ma}$$

Helmet Wearable:

$$34\ hours\ of\ battery\ life\ = \frac{2000mah}{40ma*.95+.05ma*80}$$

Vest Wearable:

$$37\ hours\ of\ battery\ life\ = \frac{2000mah}{40ma*.95+.05ma*80+1ma+1ua+1ma+8.5mA}$$

Our current pick for a lithium ion battery is rated for 2000mah hours at 3.7 volts. An option to make the wearable more ergonomic would be to reduce the size to 1000mah which would, halving the expected battery life. However, the 2000maH battery provides redundancy, in case the worker forgets to charge their safety equipment. All three wearable devices can last for at least a full work day as shown by the expected battery life calculations.

2.2.2 USB Charger

To provide charging capabilities to the battery the max1551 USB adapter integrated circuit will be used to output a constant 220mA of current at 4.2 volts to charge the battery. This chip is ideal for the wearable application because it can safely take between 3.7V -6V usb voltage range to a safe 4.2 volts and charge the battery at a safe current draw of less than .5C.

2.2.3 Buck-Boost Converter

Since the lithium ion battery has a voltage that decreases as it discharges, any voltage outside of the acceptable voltage range of 3 to 3.6 volts is useless. Any voltage above 3.6 volts could burn out the microcontroller and anything lower would not power it. Additionally, the P1 microcontroller has a very large inrush current when first starting up. Using any chip not rated for such a high current draw could cause the chip to overheat. Because of these reasons, a chip that fits all these requirements is the TPS63000-Q1 high efficiency buck-boost converter which can handle over 2 amps of current draw.

2.2.4 Circuit Design

When designing the power circuit, the requirements were that voltages above 3.6 volts and below 3 volts were not direct inputs into microcontroller. To fix this, a buck-boost converter is needed since the charge of a lithium ion battery can range from 2.8-4.2 volts. Additionally, in the workplace the wearable needs to be able to fit onto the safety equipment with minimal distraction to the worker. This implies a smaller battery to power the wearable and having the ability to recharge it would be much cheaper than getting a new one once it dies.

The Max1551 IC was chosen for this because it can charge the battery at a safe 300ma at 4.2 volts, has an input to charge the battery via DC voltage at 3.7 volts to 6 volts, and a power ok output pin that feeds into a logic rail to turn off the converter when charging the battery. The power ok pin pulls low when either charging source is present and since this is connected to the Enable pin, it will also pull low, turning off the converter. When no USB or DC power source is present, the power ok pin is an open circuit and the power from the battery will drive the enable pin high on the power converter and put it in active mode. The capacitor in parallel with the battery is a sufficiently large decoupling capacitor.

The buck-boost converter IC that is used in this circuit is the TPS63020-q1. The IC is rated to withstand up to 800 milliamps of current draw and deliver 3.3 volts which is within the required 3-3.6 volts to power the microcontroller. Another advantage to using this converter is that the output voltage can be reconfigured according to this equation which can be obtained by using a voltage divider and replacing the resistors at the output.

The 3.3 volt output will be used to power the microcontroller, bluetooth chip, and sensors. The microcontroller will have three status led's to show the connectivity status and also buttons to enter different device modes.

To choose the inductor current rating, the duty cycle must first be calculated. It can be done with this equation:

$$Duty\ Cycle\ Boost\ (D)\ =\frac{V\,out-V\,in}{V\,in}$$

Peak current running through the inductor is given by this equation:

$$Ipeak\ =\ \frac{Iout}{Efficiency*(1-D)}+\frac{V\,in*D}{2*f*L}$$

Where the switching frequency is 2.5MHz, inductor value is 2.2uH, efficiency is .85, duty cycle is .15, and the maximum current is approximately 800mA. The peak current flowing through the inductor will be 1.14A and the inductor used can stand 1.2 amps. Power schematic can be found in the appendix.

3 Block Level Requirements and Verification

3.1 All Data Collection Blocks

Requirement	Verification	Points	Results
Sensors should be able to differentiate between a glove that is worn and not worn during typical activity. The circuit and classifier must be able to correctly label data points 75% of the time.	Without any bend, the analog read values from the voltage across the sensor should be 1800 with a tolerance of +/- 100 units. When gripping a water bottle or typing, the values should be different enough to be classified and differentiated from not moving. Values at least 200 units lower than the not moving	5	Glove can be differentiated with 94% accuracy using statistical methods to detect changes in the voltages at the flex sensor. REsults shown in appendices

	scenario are needed.		
Push button switches must be able to detect when helmet is worn.	When not in use the voltage at the switch should be 3.3v or 4095 at the analog read pin with a tolerance .3 volts. If worn, the voltage at the analog pins will be 2000 with a tolerance of 500 units. The data will be ported to a server for viewing.	5	The circuit can detect whenever someone is wearing the helmet with 100% accuracy since it is just a switch.
Accuracy: The luminosity sensor must be able to differentiate between a well lit room and a dark room.	All sensors' inputs will be compared against the room's conditions and voltages across a photodiode at different lighting conditions will be recorded . Voltage readings across the photodiode at scenarios of low light , no light, and a well lit room will be collected and compared against each other to be differentiated	5	The voltage values across the photodiode can be differentiated at varying light conditions.

3.2 Localization

Requirement	Verification	Points	Results
The average error in	Readings will be	35	Average error is

localization must be no more than 2 meters	taken at fixed distances from an iBeacon. The calculate distance will be compared to the physical distance and the average error will be computed		much less than that. Refer to section 2.2.
The HM-10 chip must communicate with the microcontroller over UART protocol (RX/TX)	The photon will broadcast all data it receives from the HM-10 to a server. The sent data will be compared to what “should be” sent for static fields, and if these are correct, the requirement is met	5	Data would not be collected if this wasn’t the case
The Photon must broadcast the data received over WiFi to a server. Must operate on 2.4gHZ at 10 meters and works 100%. TRansfer over wifi should result in less than 10% of data corruption.	Logs of the particle servers will be displayed, and checked for the presence of photon events	5	Data was able to be broadcasted to the server via publish commands and server displayed bluetooth dataat least every 10 seconds.
Kalman Filter must be implemented on the micro	Verified, let to design change	5	N/A

3.3 Power System Requirements

Requirement	Verification	Points	Results
The Lithium Ion battery will be able to power each wearable for a full 8 hours.	A 150ma load will be connected to the power circuit to ensure the battery lasts 8 hours or more.	10	Voltage across battery while supporting a 150mA load at 8 hours is 378 volts and 3.55 volts at

	Battery will be checked after 8 hours.		13 hours. This exceeds the requirement to last an entire workday.
The Buck-Boost Converter shall be able to convert input voltage ranges from 2.8 volt to 4.2 volts to a constant 3.3V with a plus/minus 3 volt tolerance at a 650mA load.	Using a multimeter, the input voltage and output voltage will be plotted against each other to verify that a 3.3V output voltage is kept constant as the battery is discharged to 2.8 volts. Device will be checked after an hour to ensure it is not burned out or exceeds temperature.	10	Microcontroller was successfully powered when input voltages were below and above 3.3 volts with an output within 2% of 3.3V and chip did not burn out with a heavier load.
The PCB shall be able to detect a USB input and begin charging the battery or operate normally when there is not a DC source active within 1 second.	A power supply will supply 3.7v to the battery input and the usb will be used to show the different operating modes of the pcb. Probe inputs and verify.	15	The pcb was toggled between charging and normal operation mode multiple times in an hour and was able to operate normally.

3.4 Tolerance Analysis

Component	Current Consumption (mA)	Percentage it is in Operating Mode Per Hour	Operating Mode	Voltage (volts)
Particle Photon	150	10%	Wi-Fi on	3.3
DHT11	2.5	100%	Active Mode	3.3
Photodiode	1	100%	Active Mode	3.3
HM-10	8.5	100%	Active Mode	3.3

Being able to power the device when it is in use and charge it while it is not is important for the wearable device to function properly. The table above shows the power consumption for the portable wearable device that is supposed to fit in the worker's pocket. Since the battery is a 3.7 volt, 2000mah lithium ion battery, estimated battery life can be calculated as follows:

Number of milli amp hours = (150ma + 2.5ma + 1 +8.5 ma) * 8 hours of use

Number of milli amp hours in battery = 2000mah

Estimated battery consumption at higher load= 12.42 hours of continuous use at an average of 161ma current draw

22.97 hours of continuous use is more than a standard 8 hour shift with power left over to support part of the next shift which fulfills our requirement of being able to function for a work day. The IC usb charger charges at 280ma which can recharge the battery fully in less than 8 hours right in time for the next shift of workers that come in since the capacity of the battery can last for well over a work shift.

4 Costs and Schedule

4.1 Schedule

The full schedule can be viewed at https://docs.google.com/spreadsheets/d/1UvNEJs1802vfGnPApxOqL5L2RDcDG5ZKkUanAp4LDbo/edit?usp=sharing. A picture is in the appendices.

4.2 Costs

Glove Wearable (both hands)			
Product	Quantity	Price per Unit	Price
Max 1551	1	2.03	4.06
TPS 63020-q1	1	1.9	3.8
P1 Microcontroller	1	12	24
Lithium Ion battery 2000mah	1	12	24
LED- blue	1	0.5	1
LED - green	1	0.5	1
LED - red	1	0.5	1
ceramic Capacitor- 10uF	4	0.13	1.04
ceramic Capacitor- .1uF	6	0.1	1.2
ceramic Capacitor- 1uF	2	0.1	0.4
ceramic Capacitor- 20uF	1	0.17	0.34
ceramic Capacitor- 100uF	1	0.13	0.26
Resistor - 1M ohm	2	0.1	0.4
Resistor - 10K ohm	1	0.1	0.2
Resistor - 180K ohm	1	0.1	0.2
Resistor - 1K ohm	1	0.1	0.2
Resistor - .1K ohm	3	0.1	0.6
Micro USB Female Connector	1	1	2
Flex Sensor- 4.5"	3	12.95	77.7
		Total	143.4

Helmet Wearable			
Product	Quantity	Price per Unit	Price
Max 1551	1	2.03	2.03
TPS 63020-q1	1	1.9	1.9
P1 Microcontroller	1	12	12
Lithium Ion battery 2000mah	1	12	12
LED- blue	1	0.5	0.5
LED- blue	1	0.5	0.5
LED- blue	1	0.5	0.5
ceramic Capacitor- 10uF	4	0.13	0.52
ceramic Capacitor- .1uF	6	0.1	0.6
ceramic Capacitor- 1uF	2	0.1	0.2
ceramic Capacitor- 20uF	1	0.17	0.17
ceramic Capacitor- 100uF	1	0.13	0.13
Resistor - 1M ohm	2	0.1	0.2
Resistor - 10K ohm	1	0.1	0.1
Resistor - 180K ohm	1	0.1	0.1
Resistor - 1K ohm	1	0.1	0.1
Resistor - .1K ohm	3	0.1	0.3
Micro USB Female Connector	1	1	1
Force Sensor	3	6.95	20.85
		Total	53.7

Vest Wearable			
Product	Quantity	Price per U	Price
Max 1551	1	2.03	2.03
TPS 63020-q1	1	1.9	1.9
P1 Microcontroller	1	12	12
Lithium Ion battery 2000mah	1	12	12
LED- blue	1	0.5	0.5
LED- blue	1	0.5	0.5
LED- blue	1	0.5	0.5
ceramic Capacitor- 10uF	4	0.13	0.52
ceramic Capacitor- .1uF	6	0.1	0.6
ceramic Capacitor- 1uF	2	0.1	0.2
ceramic Capacitor- 20uF	1	0.17	0.17
ceramic Capacitor- 100uF	1	0.13	0.13
Resistor - 1M ohm	2	0.1	0.2
Resistor - 10K ohm	1	0.1	0.1
Resistor - 180K ohm	1	0.1	0.1
Resistor - 1K ohm	1	0.1	0.1
Resistor - .1K ohm	3	0.1	0.3
Micro USB Female Connector	1	1	1
Tmp36	1.5	1	1.5
adxl377	11.2	1	11.2
		Total	45.55

Labor Estimates			
	Hours	Rate	Totals
Glove	80	30	2400
Helmet	40	30	1200
Vest	100	30	3000
Analysis	20	30	600
		Total	7200

Total Cost	
Total Material Cost	242.65
Total Labor Cost	7442.65
Total Cost	7685.3

5 Conclusion

5.1 Accomplishments

The biggest accomplishment for team 31 was being able to secure the Leung Fund and show that the project works for the final demo. Team 31 is also very proud of being able to graduate with a working project for possibly the hardest course in the undergraduate ece curriculum.

5.2 Uncertainties

Since this is just a prototype, plenty of assumptions were made about how a worker behaves in the workplace. Also, further testing on the indoor localization technique is needed in various environments where multiple workers are present and where there is more metallic surfaces. Since this product is designed for warehouse use, there are alot of metallic surfaces and potential points of injury. We are uncertain on how this will affect the bluetooth localization method. Additionally, an alternative means of broadcasting data may be needed if the company does not allow the use of their wifi for security purposes. Additionally, the data set gathered for helmet and glove testing is over simplistic so more realistic data will need to be gathered with workers at a plant. Since the only hand motions of gripping a water bottle and typing were used to collect data.

5.3 Future Work

There are many aspects of the project can improve upon. One is a more complex hardware component that is smaller and has more functionality. One area of improvement is implementing the microcontroller, wi-fi chip, and antennae instead of buying a wifi-enabled microcontroller. This will greatly reduce costs and reduce the size of the pcb. Next, adding switches to turn off the device will improve the user experience with this by allowing the user to turn off the glove when not in use instead of having to find a usb charging port. Another improvement that can be made is by building the circuit for lithium ion battery voltage protection rather than buying a battery that comes with it. This will greatly reduce costs as well.

The next set of improvements to the project would require team 31 to test the product on-site and gather real data instead of simulated data for the glove and helmet detection circuits. Currently the design is simply three flex sensors for the glove and a button for the helmet. The flex sensors are able to detect the movement of someone typing on a keyboard and gripping a water bottle with 94% accuracy. However, considerations for what happens when the person is wearing the glove and not moving need to be addressed. Also, the helmet detection circuit may not be comfortable for people that are balding since the button is very notiible when pressing on someone’s skin. More advanced methods for tracking when a person is wearing the helemt will be needed.

Finally, if the devices work well in a warehouse enviroemnt the next step would be to expand it to construction and tackle a whole new set of issues that construction workers face. Since injuries on construction sites are more common, a whole new line of products will be needed to sense biometrics. Additionally, there may not be wifi so a microcontroller with 3G capabilities will be needed and security will be a big issue. There are many ways this project can improve and expand to different markets and warehouse application if just the start.

5.4 Ethics

There are several potential safety hazards in this project. Lithium ion batteries can become dangerous when overcharged or brought to extreme temperatures so a regulator circuit is needed so that it does not charge to over 4.2 volts. In addition, it should also be noted that the battery should not discharge when the voltage is under 2.8 volts because irreversible damage to be battery can occur. During the prototyping and design phase, care will have to be taken to ensure that soldering is done in a safe way as well. However, because the currents and voltages are relatively low, standard lab safety protocols should ensure that the development of this project is safe.

Since this set of wearable devices has to be able to function both indoors and outdoors it has to adhere to IP67 guidelines so that no moisture can get into the circuit which can damage it. In addition, the workers will be wearing this while operating machine tools so it can not impede everyday usage of tools in a dangerous way. This means that the end product also has to be ergonomic in nature to minimize distractions to the worker.

When accidents happen to the device by dropping it or taking blunt damage the external casing must be able to shut off the device properly and disconnect the battery to minimize the risk of short circuits and exploding batteries.

This product is by no means a complete solution to the issue of workers not wearing PPE since it is still a prototype. It is simply a monitoring device that relays information to the manager to track how often safety equipment is used by each worker and to provide diagnostics on the workers safety. If the worker is not using safety equipment frequently and has become an issue in the workplace, the manager must take action and purchase less distracting and more ergonomic PPE.

To ensure the data gathered from the detection circuits are as accurate as they can be with limited time to prototype, the sample data samples gathered for machine learning will not be as thorough and more sample data will need to be collected for Bayesian machine learning. This data will be used with IBM bluemix.

A final concern for this product is that to prototype with workers successfully before selling, there may not be wifi access due to security reasons so a wifi module may be needed.

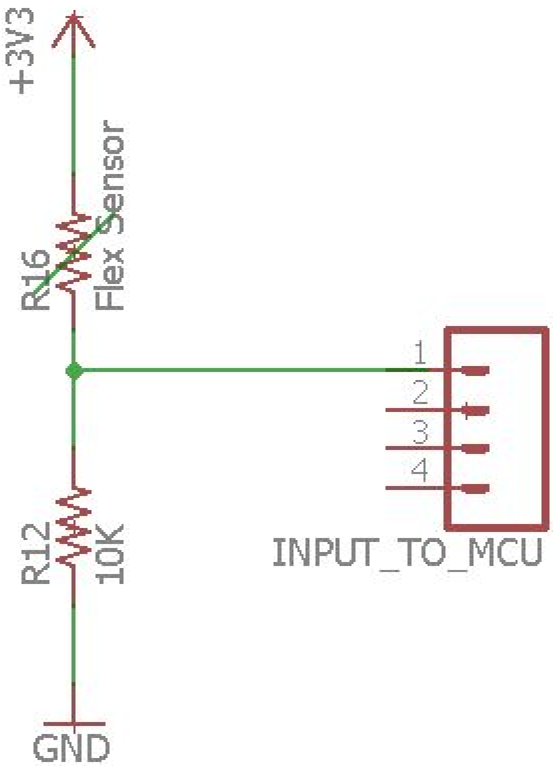
This project furthers parts of the IEEE code of ethics -- specifically, part 1 “[disclosing] factors that might endanger the public or the environment” (IEEE). Our product seeks to do this for workers in the workplace. One area of the IEEE code of ethics that should be watched out for is part 9 (IEEE). Though our product seeks to help increase accountability for workers, we should ensure that our “wearing” algorithm is as accurate as possible. This will reduce the chances of false-negatives that lead to negative consequences for workers.

6 Appendix

The following is a summary of the amount of data we expect to generate per worker:

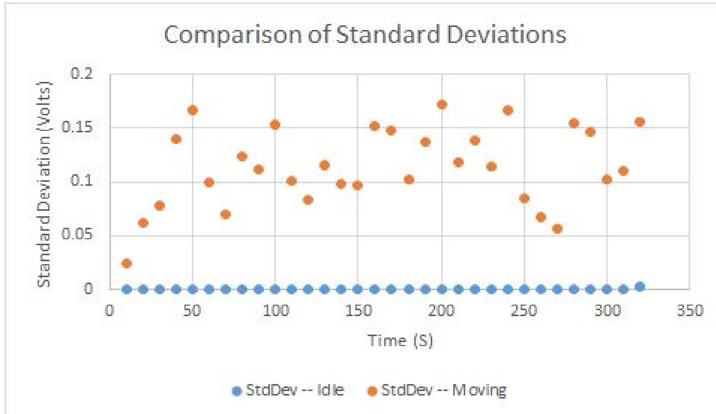
	Samples/ Min	Samples/ Day	Sample Size(B)	Data/Day (KB)	Data 5min (B)
Gloves	10	4800	2	9.375	100
Helmet	10	4800	2	9.375	100
Luminosity	2	960	2	1.875	20
Temp	.2	96	2	0.1875	2
Humidity	.2	96	2	0.1875	2
BLE	20	9600	49.5	464.0625	4950
Totals				485.0625	5174

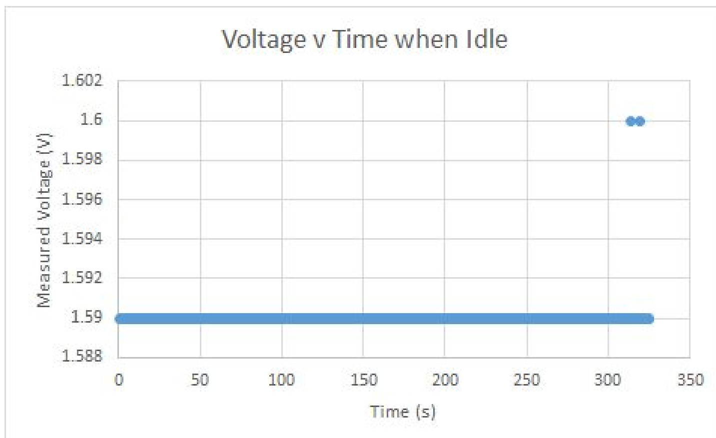
Part 1) Measurement Circuit
This is the measurement circuit for our glove wearable. The resistance in the flex sensor will change based on the degree of flex which means the measured voltage will change. Successive voltage readings can detect whether the glove has been moved or not, and the working hypothesis is that gloves that are being worn will move more often than gloves that do not.

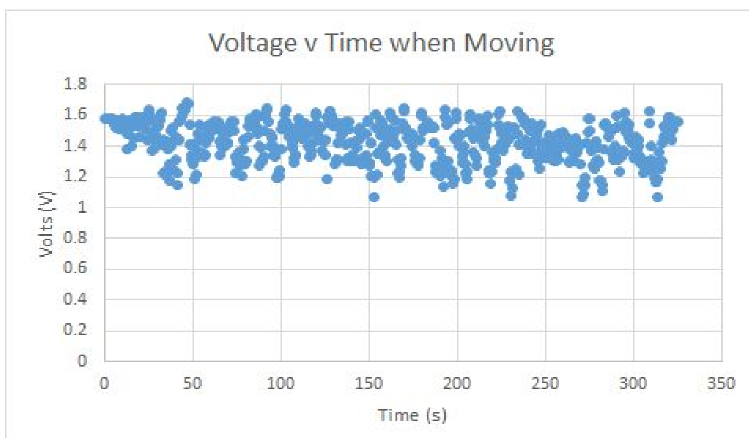


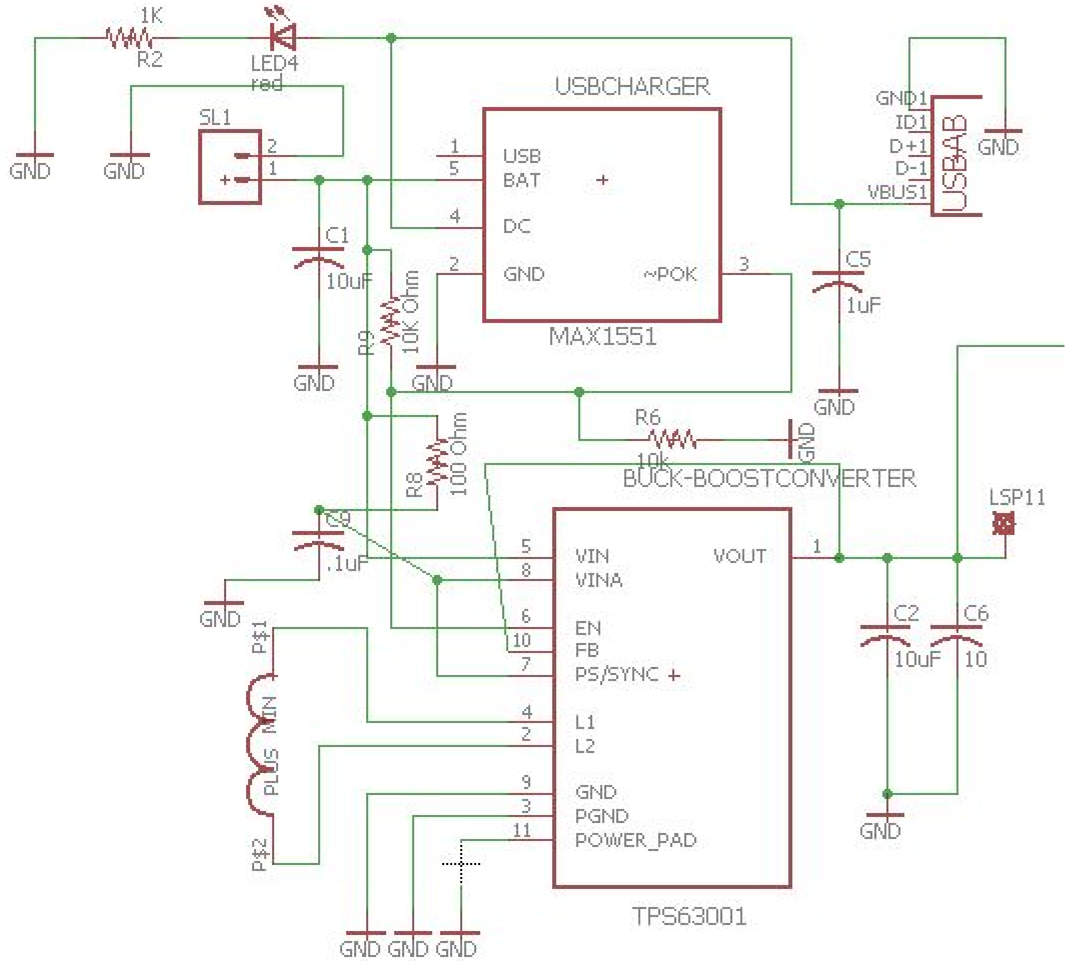
Part 2) Data collected from practice with sensors

The following graphs are a comparison of the raw resistance data, and the standard deviation of this data. It shows that when in use, the flex sensor is very accurate and has a highly variable resistance, and when idle, it does not. This suggests that a time-sliced standard deviation is a good way to detect if a human is wearing a glove.

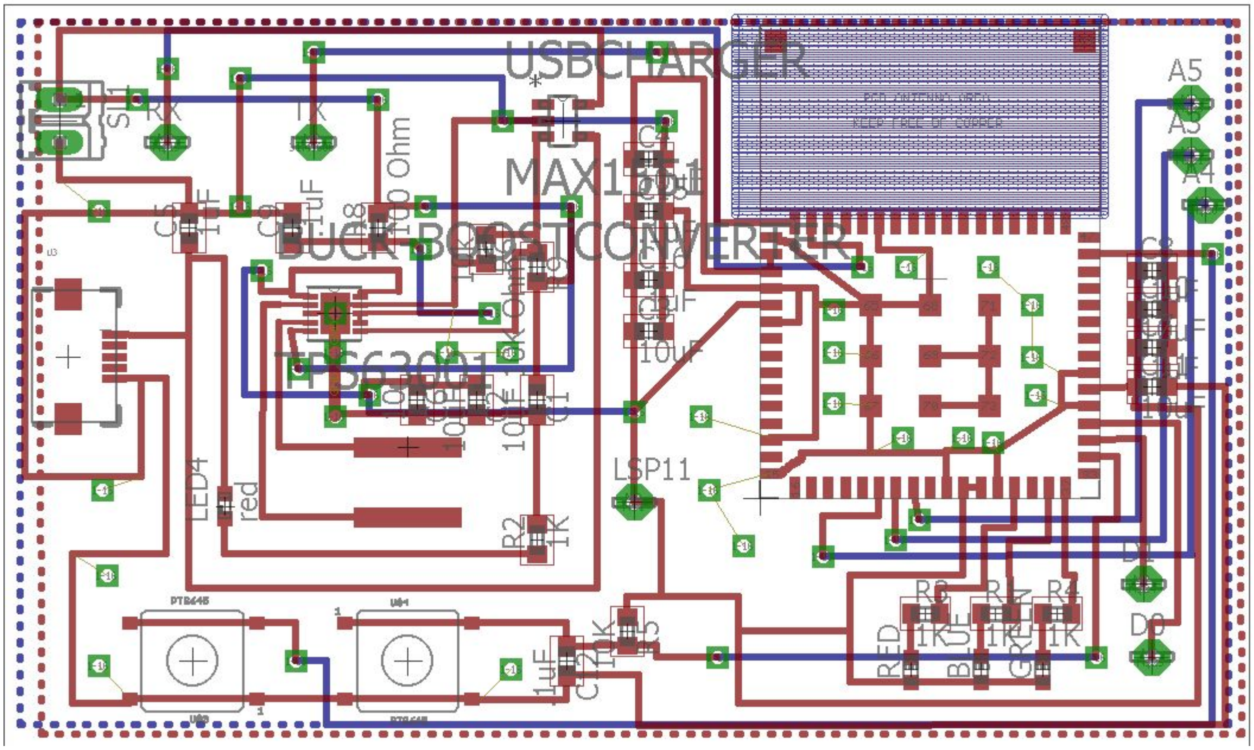




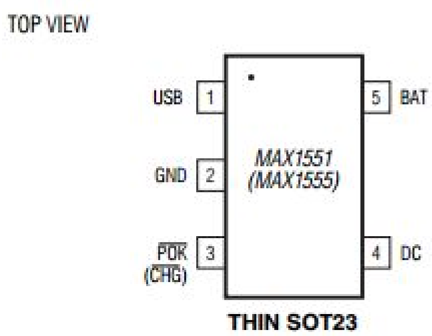




Power Circuit Schematic

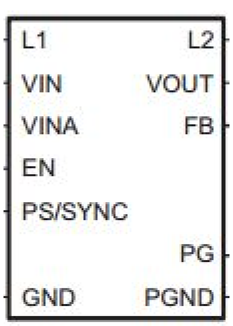


Board Layout



Pin mapping of the Max1551 IC

Picture of the IC



Pin mapping of the TI63001 IC

Picture of the IC

Project Plan

ID	Task		2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30
	Work Plan for the Semester	Lead										
1	Vest Wearable											
1.a	Heat/Temperature/Lumosity Sensors											
	Basic Reads from all three in parallel	JD										
	Integration with Power Component	Dennis										
	Testing on a vest	Shared										
	Analytics on Data	JD										
1.b	(Bluetooth?) Location Tracking											
	Research and Order Parts	JD										
	Read from an iBeacon onto a Smartphone	JD										
	Read from an iBeacon onto a low-level microcontroller and calibrate	JD										
	Create distance-aware alerts on a microcontroller, based on calculated iBeacon distance	JD										
	Integrate with vest and LEDs and Power	JD										
2	Power Components											
2.a	Design											
	Power Consumption Calculations	Dennis										
	Circuit and PCB Design	Dennis										
	PCB and Circuit Printing	Dennis										
2.b	Integration with Other Components											
	Integration with Gloves	Dennis										
	Integration with Vest	Dennis										
	Integation with Helmet	Dennis										
3	Gloves Wearable											
3.a	Measurement											
	Read from flex sensors	JD										
	Attach flex sensors to gloves and collect training data	Dennis										
3.b	Storage											
	Use microcontroller to broadcast to server over wifi	JD										
	Read/write protocols for SD card	JD										
3.c	Analytics											
	Develop binary wearing/non-wearing algorithm	JD										
	Time-Series Research	JD										
4	Helment Wearable											
	Data Collection											
	Wheatstone bridge and other configurations for Force Sensors	Dennis										
	Brainstorm and experiment with other sensor configurations for helmet wearing	Dennis										
	Integrate with physical helmet and test	Dennis										
	Data Analytics											
	Use microcontroller to broadcast to server over wifi	JD										
	Develop binary wearing/non-wearing algorithm	JD										
5	Server and Analytics											
5.a	Human Readable UI											
	Determine KPIs for wearing safety equipment	Shared										
	Learn how to work servers – read and access data	JD										
	Write Java application to perform analysis and output onto a dashboard	JD										
6	Demo and Presentation											
5.a	Presentation											
	Develop Presentation/Demo	Shared										
	Rehearse	Shared										
5.a	Paper											
	Write	Shared										
	Edit	Shared										
	Write	Shared										

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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.

Dennis Wong
Print Name

2-24-17
Date

Signature

2-24-
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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Joydeep Ganguly
Print Name

2/24/2017
Date

Signature

2/24/2017
Date

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