# PPE and Worker Tracking System

Team 32 — 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 protection, 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. Workers do not wear this equipment for a variety of reasons, and this leads to liability for employers.

A solution to this problem would be to create a line of wearable devices to gather worker position, working conditions and worker health data to enable better management decisions in warehouse or factory environments. The concrete product that we would like to make is: a wearable vest with embedded sensors to track worker position and working conditions, including but not limited to temperature, luminosity, humidity, and the presence of safety equipment in designated “unsafe” areas, e.g. “hard hat zones”.

To track if the proper equipment is worn at a certain time a system we will create a wearable device that can integrate itself into a glove or helmet to detect if it is in use. Each of these wearable devices will have a external memory unit, a processing unit, a small battery, and a wifi chip for wireless communication to the server. 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. Common solutions to this problem is by using 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 so sensing workplace conditions on each worker allows management to make

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

intelligent on the fly decisions about the amount of break time, and adapt working conditions.

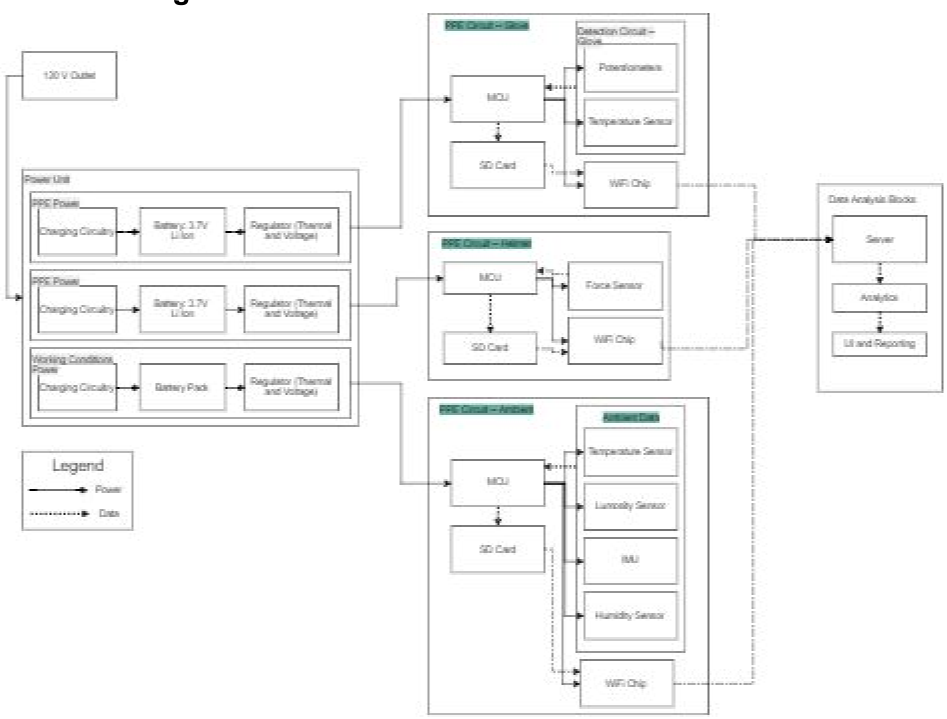
**High Level Requirements**

- The wearable vest must be able to recognize when a worker is within 1 meter of a station that requires PPE
- The wearables must cost less than $500 per unit
- The wearable must be able to communicate a full 8 hours of ambient working conditions data from the sensor circuit and IMU to a server wirelessly.

## 2. Design

For this product to operate successfully, a power supply, data collection system, wireless communication capabilities, and a server to store data and analyze it using machine learning will be used. The power unit will be able to supply 3.3v  for the entire work day and the SD cards will contain at least 8gbs of memory. The MCU unit will interface with the wifi card to selectively send data when memory is full and will do basic processing of data gathered from the sensor system and detection circuits. The detection circuits will determine whether the worker is wearing gloves or a helmet.

### 2.1. Block Diagram




### 2.2 Functional Overview

#### 2.2.1 Charging Circuitry

To charge the lithium ion polymer batteries we will use charge management controllers which will include a converter to step down the 120V DC voltage to 5V to charge the lithium ion battery through a JST-type charging port that can be removed from the wearable and plugged into the port. This charger will supply between 150ma to 500ma to charge the lithium ion cells and will also include a status led to indicate when it is charging.  This circuit will be stored away from the wearable to recharge the battery at the end of the day by disconnecting the battery from the wearable and charging it manually.

Requirement: The charging circuit must supply between 4.2 to 4.5 volts at a rate between 150 to 500 ma through a jst-type charging port to the lithium ion battery.

### 2.2.2 Battery (3.7 V Li Ion)

The battery will store up to a maximum voltage of 4.2V and will stop discharging at 2.8V for safety purposes. The battery will power each of the smaller wearable devices to detect ppe usage and has a capacity of 2500mAh. Power consumption for the MCU and Wifi card will total less than 10ma when in sleep mode with wifi off until is is woken up. With the MCU unit on but wifi chip off, it will use 40ma at 3.3v. This will be be the main operating mode for the wearable device because data will be stored into the SD card if more memory is needed. The SD card will use 110mw of power when writing to it only when it has been detected that the worker is near the work station. When the sd card is not in use, it will be turned off so it does not take up any power.The detection circuits for both the helmet and gloves are very low power. The force sensors will use 13mw of power and the flex sensors if used at a very high bend will use 150ma at 3.3v.  The lithium ion battery should be able to power each smaller wearable device for at least 8 hours. The vest will use a much larger 12 volt power pack to support the sensor circuit the wifi chip, IMU, and the mcu.

Requirement: The Lithium ion battery for all wearables must be able to supply 250ma at at least 3.3V for 8 hours.

### 2.2.4 MCUs

The microcontroller will be the Arm Cortex 3 Microcontroller to process the information sent from the data acquisition module before it gets relayed to the wifi chip to send to the server. This will be contained inside the p0 module form the particle photon. The p0 module will be powered by lithium ion batteries which will be recharged daily and will supply 3.3V to power it. The microcontroller will also have a separate memory storage unit and transmit data only when it is full because this will reduce the power consumption of the wifi chip.

Requirement: The MCU will be able to be able to process information from the detection circuit via I2c
REquirement: The MCU must be able to communicate through SPI and URAT at at least 5MB per second

### 2.2.5 SD Card

SD cards will be used as non-volatile memory to store the data gathered from all the sensor blocks. It will depend on the MCUs to read and write to it, and with a capacity of 16GB, this card should have sufficient memory for 8 hours of the workday. Depending on how much flash memory is available on the chip, an SD card may not be necessary because it will me more power efficient to send readings once every hour once the RAM has been filled up.
Requirement: The SD card must be able to store information from the detection circuits for the entire workday and use no more than 100ma at 3.3v

Requirement: The SD card must be able to read and write at speeds above 5MB/s

### 2.2.6 Wifi Chip

The wifi chip will be interfacing with the microcontroller and will only be turned on to transmit data to IBM bluemix using MQTT which is a publish/subscribe messaging protocol. On the vest which contains the sensor circuit and imu, the wifi chip will be turned on continuously to check if bluetooth is connected when the worker is within range of the work station. Once this is detected, a message will be sent to the particle cloud and the wifi chip on the smaller wearables will turn on occasionally to check if such a message has been sent. Once this is detected, the SD card will start being written to and the sensor circuit will be powered.

Requirement: The Wifi chip must be able to communicate over both SPI and Uart over IEEE 802.11/g/n at 300mbps

### 2.2.7 Flex Potentiometers

The “Glove Detection Circuit” consists of potentiometers on each of the fingers, making 10 total potentiometers. These should respond to motion, such as flexing of the fingers, and provide reliable data on whether or not a glove is being worn. As a redundancy, there will also be temperature sensors embedded in the gloves, to confirm that there is a person using them.

The potentiometers and temperature sensors will communicate with an MCU, which will read and store the data onto an SD card, and at the end of day, this will be pushed to a server using the WiFi chip. This block will also be powered by a 3.7V Li Ion battery.

Requirement: The detection circuit must be able to communicate with the MCU over I2C and take no more than 150 ma at 3.3V for power saving purposes.

### 2.2.8 Force Sensors

The core of the “Helmet Detection Circuit”, force sensors will be placed strategically around the inside of workers’ helmets, to detect the presence of the workers’ heads. We have identified this as the most effective way to check if a helmet is being worn, and think that the contrast between wearing a helmet and setting it on a table will be clear in the readings.

The helmet detection circuit as a whole also requires an MCU to interpret, then store the data on the SD card. It also requires a WiFi chip to broadcast data at the end of each work day. Finally, it will be powered by a 3.7V Li-Ion battery, which has an estimated lifespan of slightly longer than a workday at 10 hours.
Requirement: The detection circuit must be able to communicate with the MCU over I2C and take no more than 150 ma at 3.3V for power saving purposes.

### 2.2.9 Ambient Data Block

The purpose of this block is to track ambient working conditions to ensure the health and safety of the worker. Conditions measured include temperature, luminosity, humidity, as well as IMU data to track sudden impacts, or falls on the part of workers. This data can also be analyzed to ensure that working conditions are healthy and safe, and gives management the insight to see if things need to be changed.

The sensor array will be sewn into a wearable vest, and powered by the battery pack -- a larger battery than the 3.7V batteries used in the detection circuit. It will also store data on an SD card, and transmit it to the server at the end of the day.

Requirement: The sensor circuit must be able to measure temperature, humidity, and luminosity accurately with a 5% tolerance.

Requirement: Each sensor component must take no more than 50ma of current at 3.3V

### 2.2.10 Data and Analysis Blocks

These blocks will warehouse the data gathered by the wearables. Clearly, the SD card on each wearable does not have enough memory for months of worker data, so these will be stored on a cloud based server. The data will be discretized, and various timeslices will be analyzed to determine whether or not the worker is wearing their PPE. Analytics will be provided by IBM BlueMix, or another machine learning platform, and since the task is just binary classification, algorithms to do this already exist. A major challenge to using this approach is the feature selection that will need to happen on the sensor data, but we feel confident that there will be significant differences in readings when PPE is being worn, and when it is not.

The software will also be responsible for tabulating how often employees are wearing their PPE appropriately, and identifying “at-risk” employees whom managers should pay special attention to, along with providing a human-readable interface for the data. This block depends on the readings taken from other blocks, as well as the successful data storage (on SD cards) of these readings, and the successful broadcast, using the wifi chip of the data.

Requirement: When classifying the wearables' data, the machine learning algorithm must be at least 90% accurate, to ensure that the output is sufficient.

Requirement: The analytics provided by the server must be human-readable, and offer actionable insights

Requirement: The total time to run an analysis should never exceed 30 minutes.

### 2.3 Risk Analysis

The most obvious point of failure in this entire system is the power block. The first risk condition is the conversion from 120V to 5V -- because of the large change in voltage, the charging circuitry has the potential to overhead. The PCB that is used to design this charging apparatus will need to be designed with heat dissipation in mind.

The use of Lithium Ion batteries to power the wearables is also a risk condition, depending on the working environment. Lithium batteries are prone to thermal runaway, so the thermal and voltage regulators that are used will have to ensure that there is no chance of the batteries overheating. We plan to use industry standard regulators, to ensure the safety of these batteries. In addition, if the sensor packages are not built to be low-power, then they will drain their batteries before the end of the workday, rendering the products unusable. Rigorous analysis of power consumption, and choosing very low-power sensors will be key to ensuring that the batteries last long enough.

## 3. Ethics and Safety

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.

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.