# PILLOW: A UNIVERSAL SYSTEM FOR PILL DISPENSING

Team 28
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# 1. Introduction

## 1.1 Objective

According to Consumer Reports, more than half of Americans regularly take prescription drugs [1], which results in over 150 million Americans managing their health through medication. But relying on a patient to correctly adhere to their routine isn't perfect: Unexpected life events, accidents, and simple forgetfulness can cause a patient to under- or overdose their medication. This can create dangerous consequences: The CDC estimates that over 1 million Americans are hospitalized from adverse drug experiences, many of which are preventable[2]. Even over-the-counter medication can be harmful or even lethal at high doses[3], while underdosing on any drug limits its effectiveness and puts the patient's health at risk. Our project is meant to prevent under- and overdosing in an effective, yet easy to use and inexpensive way.

Our solution is to build a two-module system. Most critical to the system is a universal pad (the 'Pill Scale') that attaches to the bottom of an existing pill bottle and detects how much of the medication is removed once the bottle is accessed. This pad is powered by batteries and connected, by Bluetooth, to a second module, an outlet-powered hub (the 'Pill Hub'). This hub allows the system to be connected to Wi-Fi without increasing the size of the hub. This allows us to construct an application for the users, and their physicians, to update the system with relevant information such as pill weight, dosage, and scheduled times to medicate. Altogether, this system intends to be the assurance that even the most forgetful of users will get the exact amount of medication they need.

## 1.2 Background

Other attempts to solve this problem have been focused on replacing the actual pill bottles with some sort of automatic dispenser. Because of the (often) motorized components involved, these products can be much larger, more power-hungry, and more expensive than our solution. And the cost is the most pressing concern with these solutions - current dispensers on the market start at hundreds of dollars [4]. The components going into our system are inexpensive and will give the users access to an effective and affordable solution to over- or under-dosing.

Additionally, the data collected from these pill bottles can be integrated with healthcare metrics and at the same time be monitored by the patient's doctor either through a mobile app or website. It can also be used by pharmacies for automatic refills and scheduled delivery of the medicine. This software element works well with the system’s hardware, extending its functionality to solve this problem.

### 1.3 High-level requirements list

i. The ‘Pill Scale’ will count the number of times a medicine is taken and at what time, transmitting that data to the ‘Pill Hub’.
ii. Users will be reminded daily to stay on their schedule, and will receive alerts in the form of push notifications and alarms if they dispense the incorrect dosage. These notifications can be scheduled by the user, and can occur simultaneously on their phone or through the speakers and lights on the hub module. Additionally, doctors connected via the application will also be alerted for any deviation from the schedule.
iii. The user’s activity will be monitored and shared through an app (to both the user and doctor). These analytics will be quantified by charting usage, which can help both for regular routines or for medicines which don’t have fixed dosages (like lactose pills). Doing so will help inform doctors and their patients about the effectiveness of their current pill regimen.

## 2. Design and Functional Overview

We will be using a ‘Pill Hub’ which has Wi-Fi and Bluetooth modules. The hub will be connected via Bluetooth to multiple small ‘Pill Scale’(s). The ‘Pill Scale’ will have a universal design such that it can be attached to the base of any regular bottle or dispenser available. The ‘Pill Scale’ will have a weight sensor and Bluetooth module which gives regular feedback to the ‘Pill Hub’. The hub will be connected to the home Wi-Fi to easily communicate with the mobile app for the product and provide valuable metrics and reminders to patients, doctors and pharmacies.

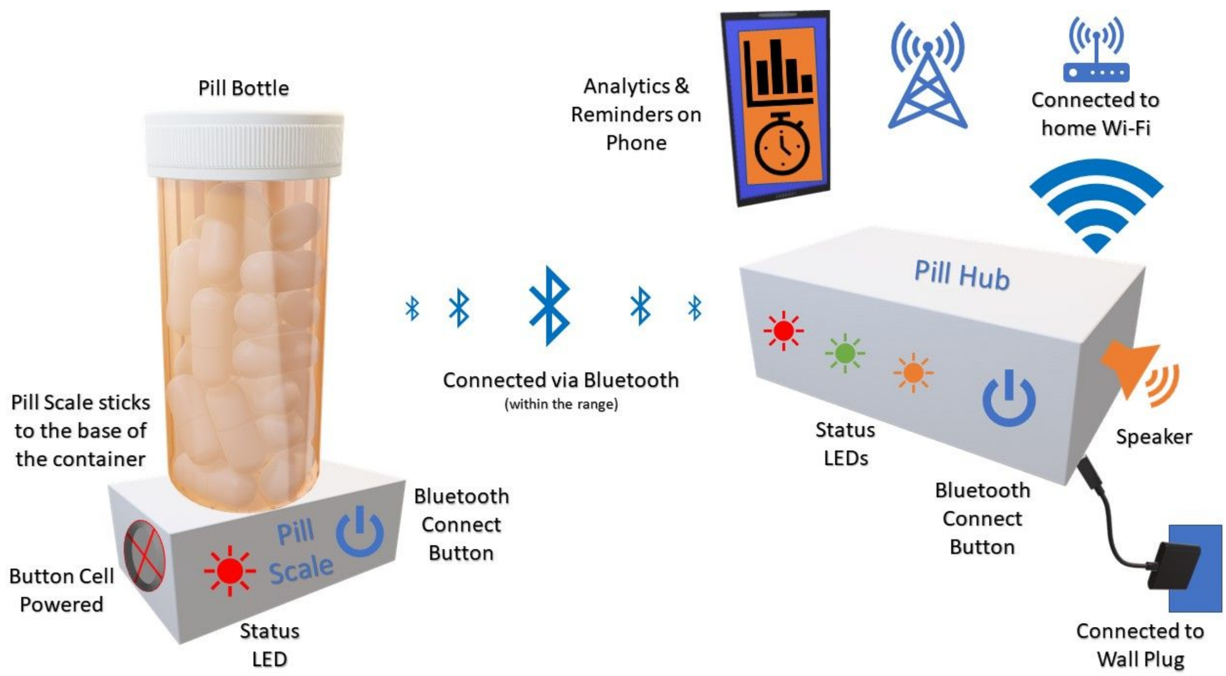


Figure 1. Physical Mockup of Pill Scale and Hub

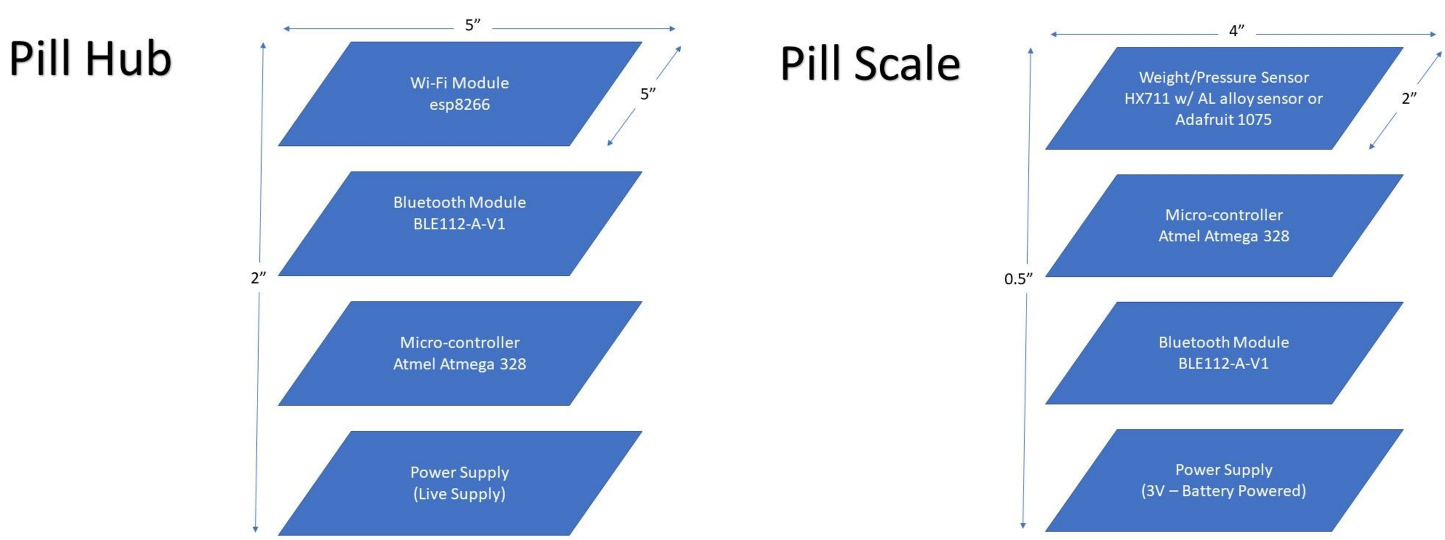


Figure 2. Physical Design of Pill Hub and Scale

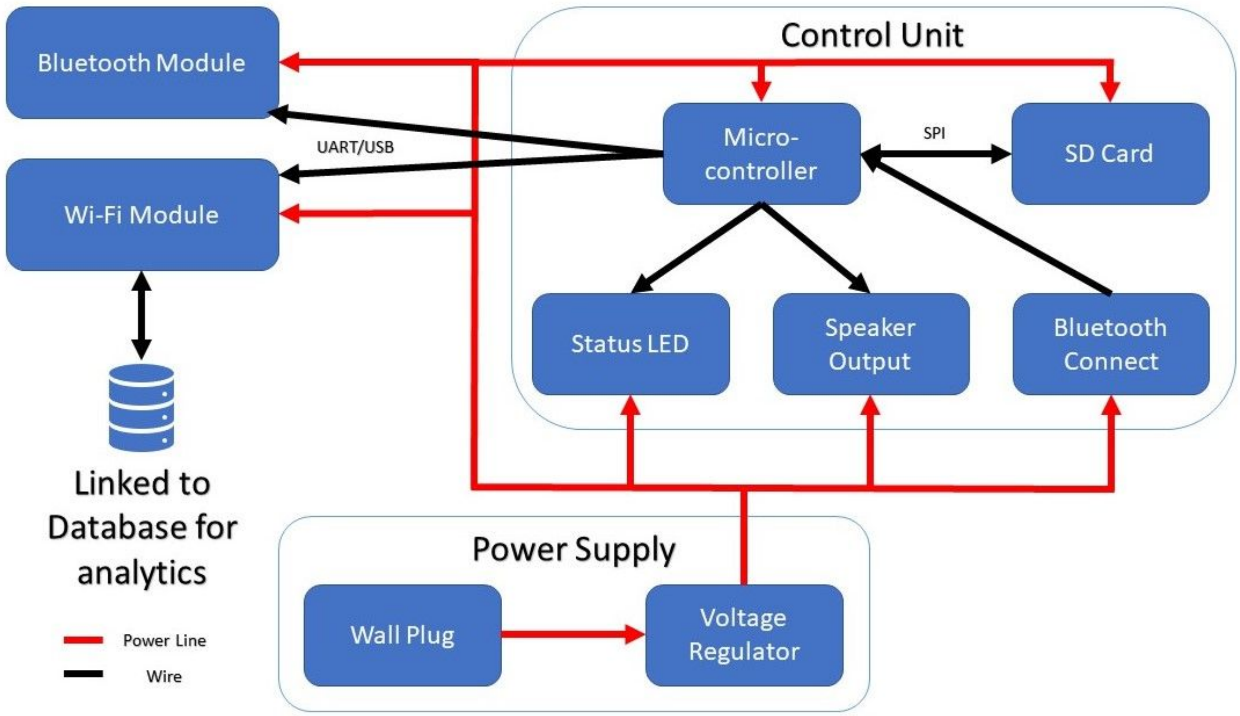


Figure 3. Block diagram for Pill Hub

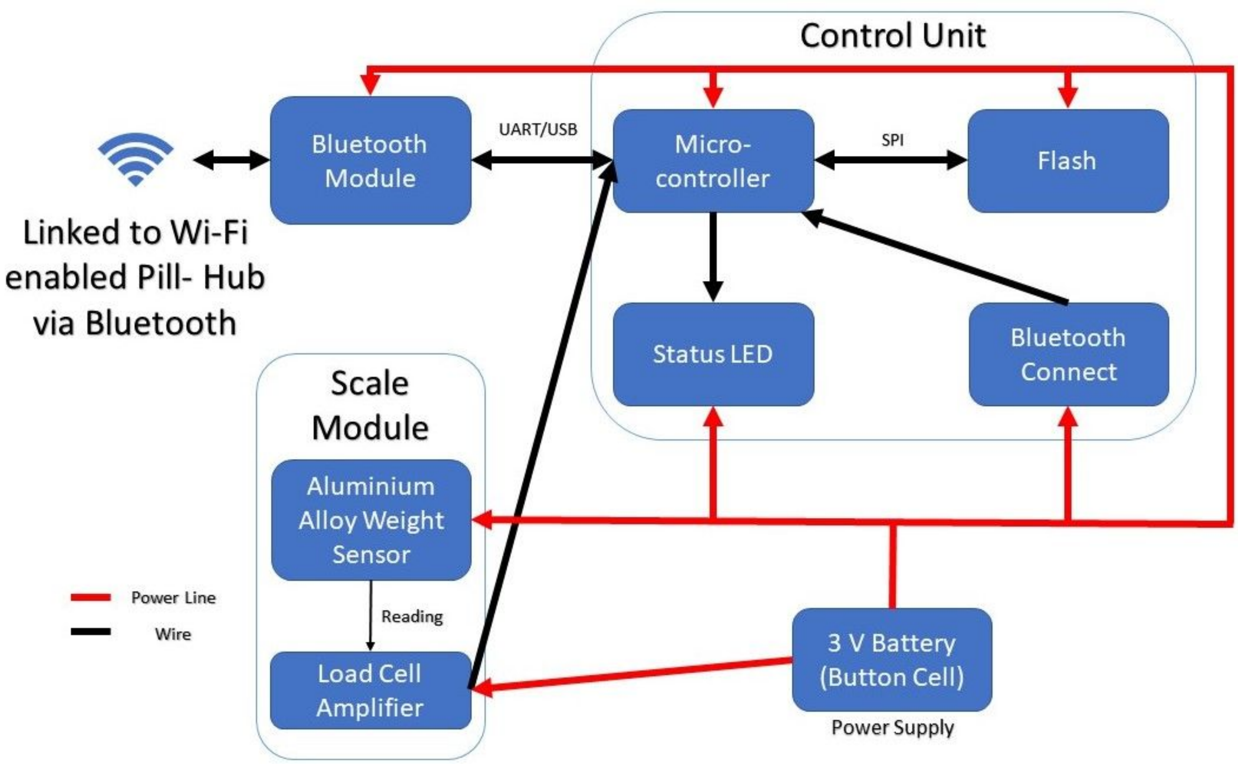


Figure 4. Block diagram for Pill Scale

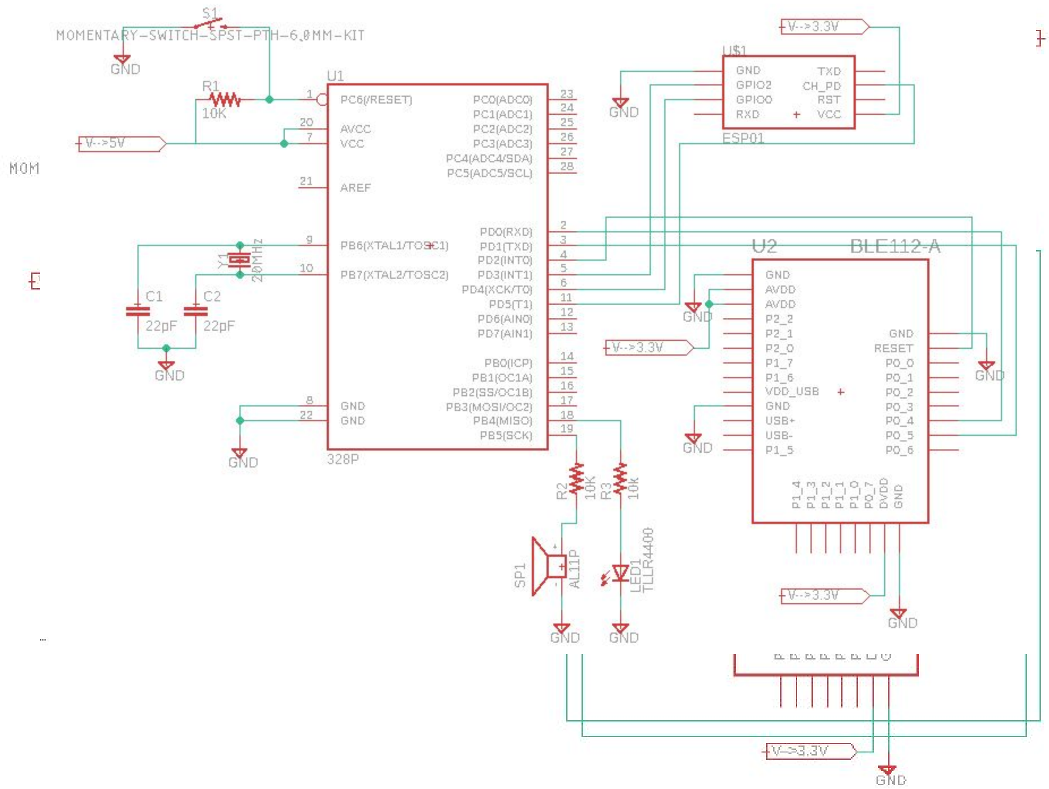

Figure 5. Schematics for Pill Scale

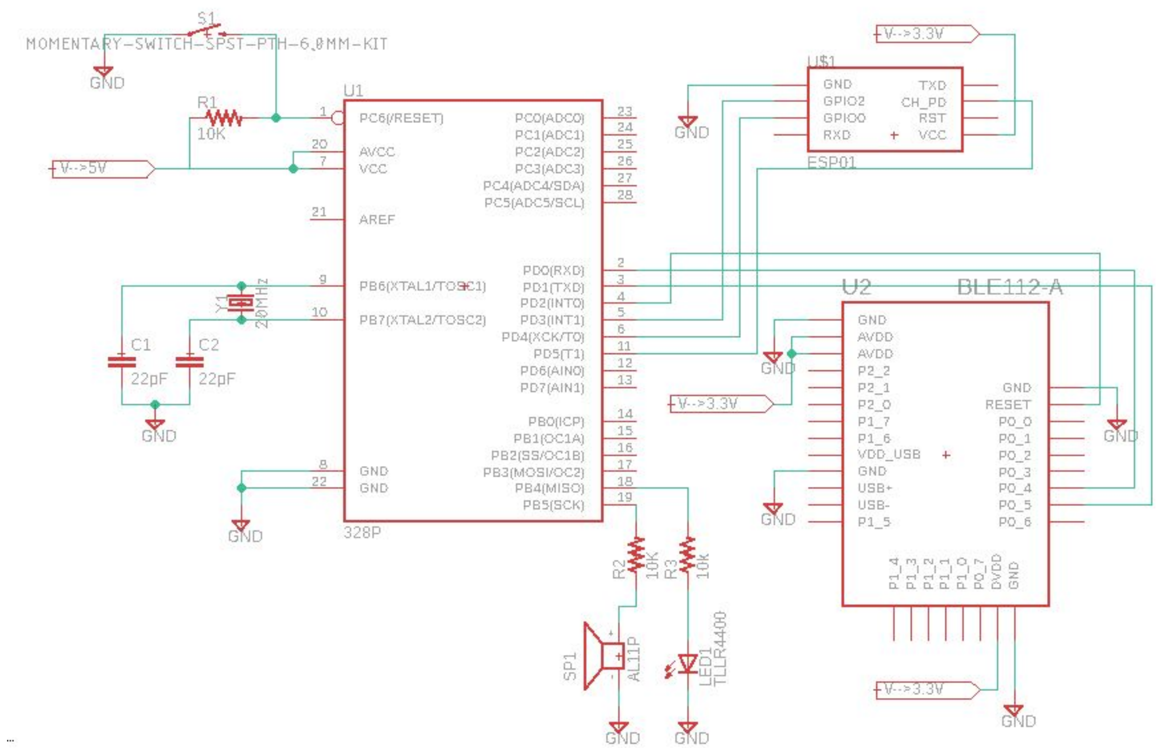

Figure 6. Schematics for Pill Hub

## 2.1 Power Supply

A power supply is required to keep the Pill Scale communicating with the Pill Hub. Power from a wall plug will keep the Pill Hub connected to the database for analytics.

### 2.1.1 Wall Plug

Connected to an AC power supply or outlet at home.

| Requirement | Verification |
|---|---|
| 1. Input Voltage = 100-240V<br>2. Input Current = 500mA, 50~60Hz | 1. Place a digital multimeter in parallel with the output of the wall outlet adapter to measure the voltage<br>2. Place a digital multimeter in series with the output of the wall outlet adapter to measure the current |

### 2.1.2 Voltage Regulator

The integrated circuit provides the required 3V to the Bluetooth and Wi-Fi module. This chip must also be able to handle the maximum input from the battery.

| Requirement | Verification |
|---|---|
| 1. Provides 3 V ± 0.5 V source from a 100V to 240V source<br>2. Can operate at currents of 50/60Hz 500mA<br>3. Maintains thermal stability below 125°C | 1. Measure using a digital multimeter in parallel with the output voltage, ensuring that the output stays within 5% of 3V<br>2. Use an IR thermometer to ensure the temperature stays below 125°C |

### 2.1.3 3V Battery

The Lithium Ion battery must be able to keep the Pill Scale circuit continuously powered especially in the morning and evening when the device will primarily be in use.

| Requirement | Verification |
|---|---|
| 1. Nominal Capacity: 210 mAh (on continuous discharge at 20℃ under 15kΩ load to 2.0V end-voltage)<br><br>2. Service Life: 900 Hrs | 1. Measure the stress conditions using a multimeter<br><br>2. Temperature variations tests should take place to ensure small changes aren't impactful, administered by cooling/heating elements and documented with an IR thermometer |

## 2.2 Control Unit

A control unit prepares data to be sent over UART to the Wi-Fi, Bluetooth, and Scale module and it manages the flash storage. The microcontroller controls the SD card and provides a simple user interface with a status LED and speaker. The microcontroller we chose is the Atmel ATMega328.

### 2.2.1 Microcontroller

The microcontroller communicates with the Wi-Fi, Bluetooth, and Scale chip via UART and reads the SD card cache via SPI.

| Requirement | Verification |
|---|---|
| 1. Successfully enters sleep mode when no user input is detected (i.e. when no module is actively transmitting data)<br><br>2. Must have enough I/O ports to accommodate Bluetooth and Weight module or Bluetooth and Wi-Fi module | 1. Using an oscilloscope, check if any signal is being transferred when on sleep mode.<br><br>2. Must have enough I/O ports to accommodate Bluetooth and Weight module or Bluetooth and Wi-Fi module |

### 2.2.2 SD Card

The microSD card will serve as cache and save data in case of losing connectivity with home Wi-Fi.

| Requirement | Verification |
|---|---|
| 1. Must be able to read and write at speeds above 4.5Mbps | 1. Check the end-point of data received and then average the bits transferred per second |

### 2.2.3 Bluetooth Connect

The Bluetooth connection will allow users to connect to their Pill Hub and pair with the device for setup. Bluetooth connect is a physical button, which informs the microcontroller to switch on to the pair mode.

| Requirement | Verification |
|---|---|
| 1. Must require little force, 150 ± 50 gf (roughly 1.5 N), to activate/hold (easily pressable) | 1. Using a force sensitive resistor we will measure the amount of force it takes to activate and pair with a device via Bluetooth |

### 2.2.4 Status LED

The status LED will display to the user whether the Pill Hub and Pill Scale are connected to the Wi-Fi and Scale modules respectively.

| Requirement | Verification |
|---|---|
| 1. Clearly visible from over 1m away with a drive current of 10 mA ± 5mA | 1. Measure current through LED with digital multimeter. Ensure current is within the required range (10 mA ± 5mA)<br><br>2. When left in a room, with no obstructions of view, measure the distance where the LED is no longer visible (unable to determine what color it is or what color it switches to). |

### 2.2.5 Speaker Output

Speaker will be able to give a scheduled reminder to the user about his or her medicine.

| Requirement | Verification |
|---|---|
| 1. Clearly audible at 60 dB (normal conversation level) from over 1m away | 1. When left in a room, with no obstructions, measure the distance where the decibel level drops below 60 dB using a decibel meter application found in the App Store |

## 2.3 Bluetooth Module

Data from the control module is sent via UART to be accessed on a Bluetooth network. The Bluetooth IC, the BLE112-A-V1, allows for low energy features which makes it ideal for the Pill Scale and Hub as the chip only consumes 400nA in its lowest sleep mode and will wake up in a few hundred microseconds. The Flash holds the program memory for the Bluetooth IC. Currently, we do not know our programs size for the microcontroller, but we will prototype a size less than 1MB.

| Requirement | Verification |
|---|---|
| 1. Bluetooth Range: greater than 10 meters<br>2. Very low current consumption during sleep mode: ~400nA<br>3. Wake-up time in few hundred microseconds | 1. Move the Hub and Scale apart in 1 meter increments until data transmission fails.<br>2. Using a multimeter in series, measure the current during the sleep mode.<br>3. Verify the time it takes to wake-up (check the difference in current) using an oscilloscope. |

## 2.4 Scale Module

### 2.4.1 Aluminum Alloy Weight Sensor & Load Cell Amplifier

We will use 0-100 grams electronic scale aluminium alloy weight sensor. The signal sent from the weight sensor needs to be amplified in order to be processed by the microcontroller. SparkFun load cell amplifier (HX711 - https://bit.ly/2nOrBYq ) can be used for this purpose. This will give a mg precision.

| Requirement | Verification |
|---|---|
| 1. Capable of sensing a weight change of less than 0.5 grams | 1. Apply a weight greater than 0.5 grams to the module, then remove at least 0.5 grams (one pill, for example). The status LED will flash when a weight of 0.5 grams or less has been removed (indicating that a “pill” was removed from the weight) |

## 2.5 Wi-Fi Module

Data from the control module is sent via UART to be accessed on a Wi-Fi network. The Wi-Fi IC, the ESP8266, is a self-contained SOC with integrated TCP/IP that gives our microcontroller access to the users Wi-Fi network. The Flash holds the program memory for the Wi-Fi IC. Currently, we do not know our programs size for the microcontroller, but we will prototype a size less than 1MB.

| Requirement | Verification |
|---|---|
| 1. Must be able to communicate over IEEE 802.11/b/g/n at greater than 100kbps<br><br>2. Must be able to communicate over both UART and SPI | 1. Detect and connect to this Wi-Fi Network from phone and other Wi-Fi enabled devices. If Wi-Fi microchip is IEEE 802.11b/g/n- compatible, it should be connected successfully<br><br>2. Check on the receiving side, whether any data was received or not |

## 2.6 Tolerance Analysis

In order for this system to work appropriately, the most important element of tolerance comes down to the scale and the modules that end up sending that input into the microcontroller. To start, we need to define the desired tolerance for the scale itself. For this design to work, the scale needs to have enough resolution to accurately measure when even a single pill is removed from the bottle. Finding the actual weight of a singular pill is difficult, especially since the quoted weights for most medication is the strength of the active ingredient, not the weight of the pill itself (for instance [5]). "Weights" can therefore differ by several orders of magnitude. The pills themselves tend to come in around 200-400 mg each (although sizes vary wildly). And even though the pills are made by a mechanized process, it's inevitable that there are some irregularities. Finding the actual expected difference between pill weights will require extensive testing, but for now we can estimate that the difference will be around 1-5mg. So when selecting a tolerance, we need to choose a value that's bigger than this expected difference so as to not trigger alerts of over or underdosing. For this estimation, we'll select ±10mg as our desired tolerance.

**Micro Load Cell**: We first need to determine if the load sensor we have chosen already can fulfill this role and output within the desired tolerance. According to the specifications [6], our micro load cell has a capacity of 100g, which is enough to weigh dozens of pills (if need be we can zero out the weight to read just the difference). But also noted is the "Cell Repeatability Max". At ±50mg, this is much too high for the resolution we desire. If we tie the output of this load cell directly to the microcontroller, we could incorrectly measure the dosage, especially if it is several pills at once. We need to amplify the signal from the load cell in order to ensure better resolution.

**HX711 Load Cell Amplifier**: This module is used to actually increase the resolution of the load cell. By feeding the output from the load cell into the Channel A of the amplifier, we realize a gain of 64, resulting in a differential input voltage of ±40mV. This newly amplified signal is passed out of the amplifier as a 24-bit 2's complement number. This output is passed directly into the microcontroller.

**ATMega 328p**: The final step in extending the tolerance of the load cell is in the programmable microcontroller itself. At the software level, the scale system needs to be calibrated further. The scale correction can be calculated from the following equation, derived from here[7].

$$Correction = (outputRating * gain * ADCRange)/maxRange$$

"outputRating" is the output from the load cell, gain comes from the amplifier (64), ADCRange is the range of values for the ADC output (2^24 -1), and the maxRange is maximum rating for the load cell (100g). This equation allows us to constantly calibrate the processor, accounting for the minute changes in temperature and placement that can affect the results

Overall, these three modules use hardware and software to correctly define the tolerance of the scale, and ensure that it is operating correctly.

### 2.7 High-Level Software Flowchart

The high-level software flowchart can be found in Figure 7.

The software cycle starts first by connecting the Pill Scale and Pill Hub via Bluetooth. Then a pill container is attached to Pill Scale. Its initial weight is recorded and sent to the Hub. Also, the “pill weight” and “pill count” are requested by the phone app for the user to input. The weight is recorded and compared with the previous/initial weight. If the difference between the weights is equal to the “pill weight”, then it means a pill has been taken. The time of taking the pill is recorded at the hub and then sent to database for analytics.

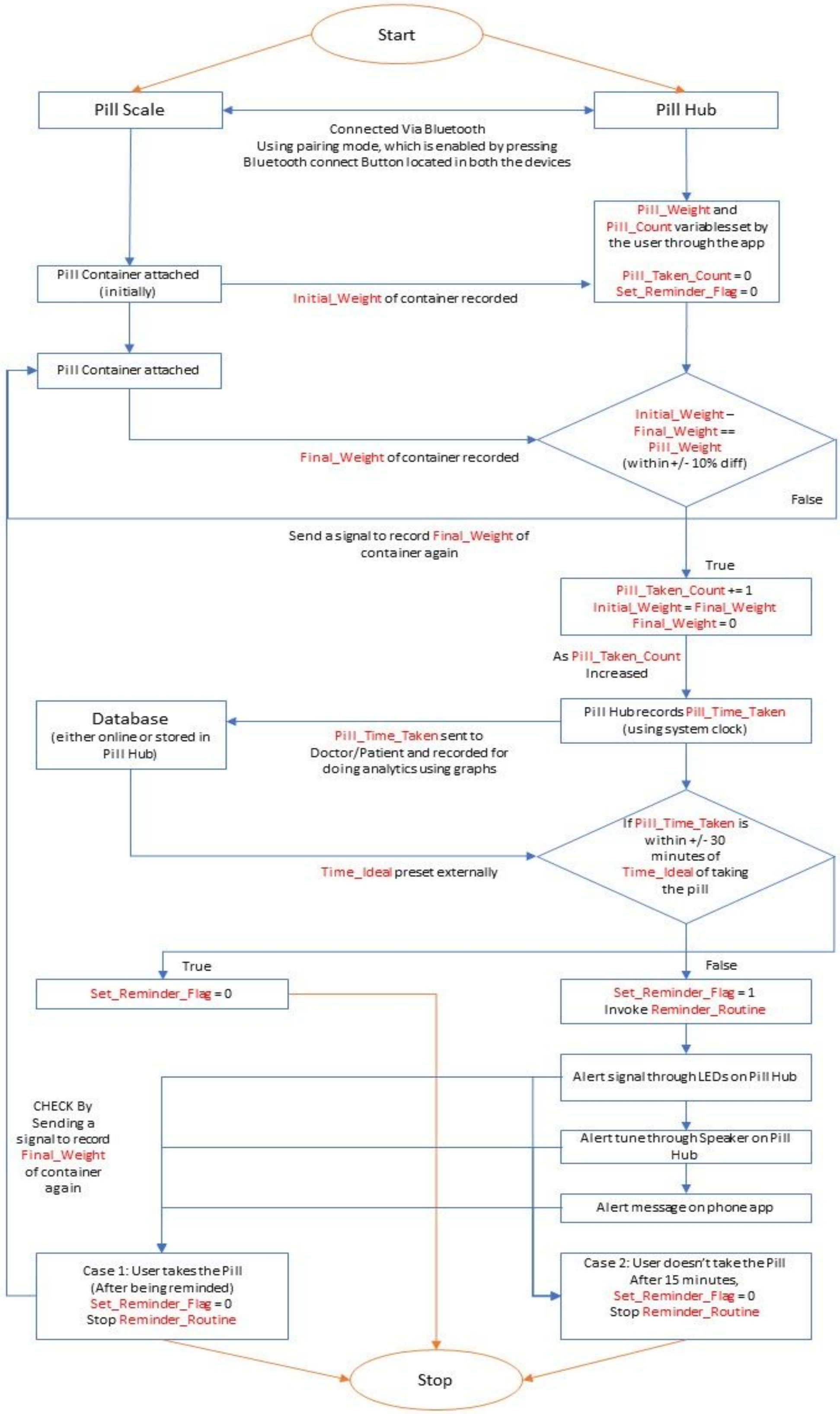


Figure 7: High-Level Software Flowchart

## 3. Cost and Schedule

### 3.1 Labor

We assume a labor cost of $35 per hour. With three partners working approximately 10 hours per week for the next 10 weeks left in the semester, we come out to the following equation:

$$3 * \$35/hr \ * \ 2.5 \ * \ 10 \ hrs/week \ * \ 10 \ weeks \ = \ \$26,250$$

### 3.2 Parts

We are only factoring in the cost of building a single prototype. Buying these parts in bulk and introducing some form of production line would greatly reduce the costs associated.

| Part | Unit Price | Quantity |
|---|---|---|
| Microcontroller (ATMega 328p) | $2.14 | 2 |
| Wi-Fi Module (ESP8266) | $6.95 | 1 |
| Bluetooth Module (BLE 112-A-V1) | $11.89 | 2 |
| Load Cell | $8.48 | 1 |
| Load Cell Amplifier (HX711) | $9.95 | 1 |
| 3V Lithium Ion Battery | $1.60 | 1 |
| **Total** | **$55.04** | |

Altogether, most of the cost of this prototype will be realized in labor, for a total cost of $26,305.40.

### 3.3 Schedule

| Week | Jack | Robert | Lohitaksh |
|---|---|---|---|
| 10/7 | Design document | Design document | Design document |
| 10/14 | Work on PCB design for scale | Work on PCB design for hub | Purchase components, help with schematics |
| 10/21 | Finish PCB and submit for first order | Finish PCB and submit for first order | Begin verifying components |
| 10/28 | Debug PCB, make changes to design | Write user interface files for both PCBs, continue verifying components | Write code for skeleton of application, just for warnings |
| 11/4 | Submit changed PCB design for second order | Work out security for Bluetooth and wireless modules | Extend application support to cover more functions like doctor integration |
| 11/11 | Debug prototype, test each component | Run full tests of integrated parts, help with debugging | Finish debugging application and test functionality |
| 11/18 (Fall Break) | Prepare for mock demo | Prepare for mock demo, 3D print housing | Prepare for mock demo |
| 11/25 | Finish last minute debugging, integration | Complete full tests of prototype | Finalize demonstration procedure |
| 12/2 | Complete demo, work on report and presentation | Complete demo, work on report and presentation | Complete demo, work on report and presentation |
| 12/9 | Prepare final report and presentation | Prepare final report and presentation | Prepare final report and presentation |

## 4. Ethics and Safety

The most important safety concern with this project is the fact that its use is directly tied to the health of our users. The most glaring hazard revolves around a malfunction somewhere in the circuit that results in an incorrect output. The main concern here is the resolution of the scale, as determined by the load amplifier and its connection to the microprocessor. If the tolerance is too high, the system may insist the user take another dose in order to even out the scale, leading to an accidental overdose. If the tolerance is too low, then the user is at risk of taking too small of a dosage, resulting in an underdose. Both of these outcomes are not just dangers to the users of the system, but they also directly negate the initial purpose of this entire design. Combating this possible catastrophe requires us to focus on three areas: During wiring, we will follow the datasheet of the load amplifier[8] to ensure that the connections between the load sensor, the amplifier, and the microcontroller are tuned to our desired resolution (around 1mg). During the programming of the integrated chip, we need to set a reasonable tolerance to avoid both under- and overdosing. And both hardware and software need to be rigorously tested with known weights to verify our implementation.
The most directly dangerous part of our circuit is in the Scale part of the project, since it contains a Lithium-ion battery. The main danger here is making a mistake when connecting the wiring which could lead to runaway current, flammable temperatures, or even explosions[9]. To avoid this, we will rigorously verify our charging circuit along with following the guidelines set up by the ECE445 “General Battery Safety” document [10]. Specifically, we will simulate our design before having it signed off by our TA and an additional power-centric TA before we actually attempt to attach the battery.

As with any project involving electrical components, exposure to electricity is a safety concern. Luckily the modules we are working with require a relatively tiny voltage to operate, from 3.3 to 5 volts. Still, with the scale module being connected to a battery and the hub connected to the outlet, those power sources could potentially become dangerous with a wiring mishap. In order to ensure the safety of ourselves and the eventual end user, we will be following the guidelines given by the university for electrical safety [13].

And working in the lab brings upon its own dangers. As well as the general electrical concerns mentioned above, we will be operating soldering irons to construct our circuit. We have all passed our lab safety training, and will be following the rules set out in the University’s Lab Safety Guide[11].

Ethically, the most obvious concern with our system is that we are dealing with medical data from our users. We are therefore making ourselves responsible for the health of our users. Both the IEEE [14] and ACM [15] codes of ethics emphasize doing no harm (numbers 9 and 1.2, respectively). In addition, in order to remain compliant with the government’s HIPAA Privacy Rules [16] (and 1.6 “Respect Privacy” from ACM’s ethical code), we need to ensure that the medical information connected to our users is kept confidential, while still allowing the user the ability to share their information with physicians, caregivers, or pharmacists. Making sure that a user's medical information is under complete control of the individual is tantamount to us making sure that this system follows ethical and legal rules. To do this, all medical data needs to be encrypted on our database, accessible only through the user entering their password. Physicians wishing to participate in this system need the express consent of the patient before being able to access the relevant data from their own, separate account.

An additional concern regarding medical information is what data we are transferring between the hub and scale modules. Since the two are connected via Bluetooth, any information is potentially at risk of being intercepted. In order to minimize the risk here, we will take two major precautions: First, when pairing the two devices, we will adopt the highest security level available[12]. Since the two modules are meant to remain paired, no other device should be able to connect to the system. But since we can't be certain, we have to adopt the second precaution: Sending the absolute minimum amount of information possible over Bluetooth. So instead of relaying the entire patient's information, we will only send the change of the weight over this protocol. Doing so limits the actual information available to a bad actor.

Overall, the whole point of this project is to be beneficial to the health of our users. Designing in a safe and ethical way, and following the codes and guidelines enumerated above, is absolutely key to ensuring that our users benefit from this system.

**References**

[1] Carr, Teresa. “Too Many Meds? America's Love Affair With Prescription Medication.” *Consumer Reports*, www.consumerreports.org/prescription-drugs/too-many-meds-americas-love-affair-with-prescription-medication/.

[2] “Medication Safety Program.” *Centers for Disease Control and Prevention*, Centers for Disease Control and Prevention, 7 June 2018, www.cdc.gov/medicationsafety/program_focus_activities.html.

[3] “What Over-the-Counter Medications Can You Overdose From?” *Desert Hope*, deserthopetreatment.com/drug-overdose/over-the-counter/.

[4] “Automatic Pill Dispensers.” *Automatic Pill Dispensers - Never Forget Medications Again*, www.epill.com/dispenser.html.

[5] “2632 V Pill Images (Yellow / Round).” *Drugs.com*, Drugs.com, www.drugs.com/imprints/2632-v-13546.html.

[6] “Micro Load Cell.” *Micro Load Cell (0-100g) - CZL639HD*, www.eztronics.nl/webshop2/catalog/index.php?route=product%2Fproduct&product_id=423.

[7] Bogde. “Calculating the Proper SCALE Value · Issue #20 · Bogde/HX711.” *GitHub*, github.com/bogde/HX711/issues/20.

[8] “24-Bit Analog-to-Digital Converter (ADC) for Weigh Scales.” *Avia Semiconductor,* PDF File, *r*https://cdn.sparkfun.com/datasheets/Sensors/ForceFlex/hx711_english.pdf

[9] “Lithium-Ion Safety Concerns.” *Lithium-Based Batteries Information – Battery University*, batteryuniversity.com/learn/archive/lithium_ion_safety_concerns.

[10] Spring 2016 Course Staff. “Safe Practice for Lead Acid and Lithium Batteries.” *ECE 445: Senior Design Project Laboratory,* https://courses.engr.illinois.edu/ece445/documents/GeneralBatterySafety.pdf

[11]”Laboratory Safety Guide University of Illinois at Urbana-Champaign.” *Division of Research Safety,* https://www.drs.illinois.edu/site-documents/LaboratorySafetyGuide.pdf

[12] “Understanding Bluetooth Security.” *Decipher*, duo.com/decipher/understanding-bluetooth-security.

[13] “Electrical Safety in the Laboratory.” *Bases Hydroxides - Safety Library | Division of Research Safety - Illinois*, www.drs.illinois.edu/SafetyLibrary/ElectricalSafetyInTheLaboratory.

[14] “IEEE Code of Ethics.” *IEEE - Advancing Technology for Humanity*, www.ieee.org/about/corporate/governance/p7-8.html.

[15] “The Code Affirms an Obligation of Computing Professionals to Use Their Skills for the Benefit of Society.” *Association for Computing Machinery*, www.acm.org/code-of-ethics.

[16] HHS Office of the Secretary, Office for Civil Rights, and OCR. “Privacy.” *HHS.gov*, US Department of Health and Human Services, 16 Apr. 2015, www.hhs.gov/hipaa/for-professionals/privacy/index.html.