Package Anti-Theft System

ECE 445 Design Document

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1 Introduction

1.1 High-Level Concept

The emergence and subsequent boom in online shopping has changed the way consumers shop and buy goods. According to a recent survey conducted by the Pew Research Center, 79% of Americans shop online, and 15% buy online on a weekly basis [1]. Now more than ever before, consumers have access to thousands of products with a tremendous degree of selection, all at the convenience of a few clicks and a standard shipping and handling fee. However, the convenience of online shopping is offset by a lack of security in the delivery process. UPS Ground packages are generally delivered Monday through Friday between 9:00 a.m. and 7:00 p.m., which overlaps heavily with the standard 9:00 a.m. to 5:00 p.m. work day. Hence, most people are not at home during UPS shipping hours, leaving their packages completely unattended. This increase in package delivery coupled with lax protection has led to a surge in package theft. According to a survey done by Xfinity Home, Comcast's home security service, more than 50% of people across the United States know someone who has had a package stolen, and about 30% of people have had it happen themselves [2]. Clearly, this is a pervasive problem.

Our goal is to design and construct a device that stymies package theft through a weight, alarm, motion, and camera-based security system. We use load cells to precisely measure the weight of a package, and an alarm system that is triggered when the weight of the package decreases past a certain threshold. If a potential thief gets within a certain radius of the package, a PIR motion sensor is triggered, causing a verbal warning to sound and a camera to take a temporary picture of the person. If the alarm is triggered, the picture is sent via Wi-Fi to an Android application on the user's cell phone. The user can disable the alarm via the app over Wi-Fi or through an RFID tag. We believe that these measures will provide both deterrence and protection of the user's package.

1.2 Background

Several approaches have been attempted to solve the widespread package theft problem across the country. The most common approach is to use a package lock-box that holds packages until a user opens it up with a traditional lock-and-key mechanism. Although simple and seemingly effective, the lock-box solution is costly [3] and ineffective at handling large and oddly-shaped packages. Another common approach is to deliver your package to an Amazon drop location, which is an Amazon-run store where people can ship and pick up their packages. This is an effective security measure, but it is not as convenient as delivery to one's home. Also, these Amazon drop locations are usually only found in urban areas, and according to a study conducted by the video security company Blink, package theft is much more common in rural and suburban areas than urban areas [4]. Another option includes "smart locks" that allow delivery people to enter the home to deposit the package. These systems, while very simple and effective at first glance, cost around $200, require coordination with delivery companies, and necessitate strangers entering the customer home, something many may feel uncomfortable with [5].

Our design provides security and convenience without being overly expensive. We intend to make two products, the first being the basic core device which consists of the sensor unit, control unit, power unit, and the alarm module. The main goal of the core product is to provide security while staying inexpensive. We calculate that this core device will cost about $30[1], as opposed to a similar commercial unit costing $80. The second device that we will design and build is the deluxe product. The deluxe product has all of the features of the core device, plus a Wi-Fi and camera system for added protection, and will cost about $100 while giving more features than the competition. The goal of this device is to compete with other products on the market in terms of cost, while adding the option of further functionality.

1.3 High-Level Requirements

- The device must be capable of holding loads ranging from 1lb to 80lbs and differentiate between loads with a resolution of 0.2 lbs up to 10lbs and a resolution of 0.5lbs above 10lbs.
- The alarm must be at between 75 and 85 dB as measured 1 meter from the unit.
- The system should be fully solar powered, requiring no recharging and capable of running for at least 3 days without sunlight

2 Design

The high-level design of the core device consists of four main modules: a power unit, control unit, sensor unit, and the alarm module. In addition to the four core modules, the deluxe device includes the camera module and the Wi-Fi module. The power unit supplies necessary power at various voltages to our entire system. The sensor unit consists of four different sensors which send signals to the control unit, which in turn activates the alarm module and the camera module.

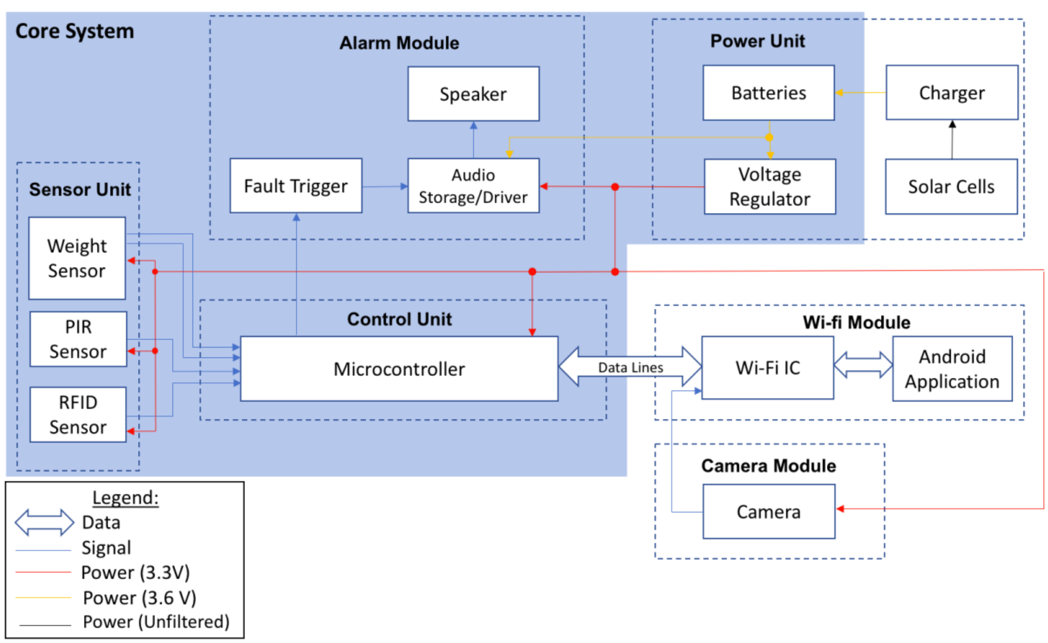

Figure 2.1: High-Level Block Diagram

[1] An in-depth calculation of the cost of building the core system can be found in section 2.3.2

2.1 Power Unit

Our power unit consists of solar cells for power generation, rechargeable Ni-MH batteries for energy storage, and a voltage regulator to ensure stable voltage to the loads in the rest of our device. A block diagram of the power module is shown in Figure 2.1 below.

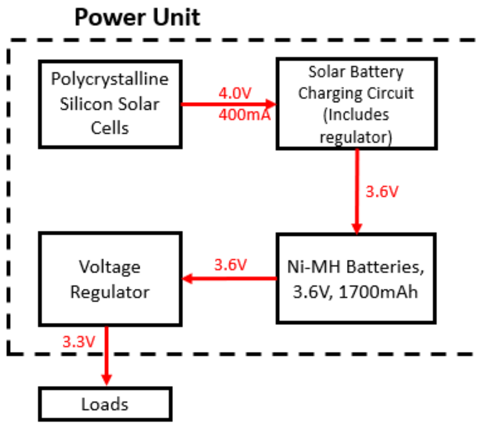

Figure 2.1: High-Level Block Diagram of the Power Unit

We calculate the likely power consumption of all of the loads in our device in Table 2.1 below. It takes into account that all of our components will not be active one hundred percent of the time. For example, we use the built-in sleep mode for the ESP8266-12E Wi-Fi microcontroller and we turn off the camera when it is not in use.

Load	Current (mA)	Time Use Per day (hrs default)	Energy (mAh) Consumed / day	Comments[2]
Polycrystalline Si Solar Cells	-400	1	-400	Assume 1 hour of "peak Sun hours"[3], a very harsh assessment
Camera (On)	70	15 minutes	17.5	Assume camera is on for 15 min/day
Camera (Sleep)	20	4	80	Camera idles when PIR triggered
Camera (Off)	1	20	20	When no package, "Deep Sleep"
ESP8266 Wi-Fi IC (Active)	70	20 minutes	2.33	Assume Wi-Fi chip is "on" for 20 minutes per day
ESP8266 (Sleep)	1.8	24	43.2	
Alarm Module (Active)	300	5 minutes	25	Assume the alarm is "active" for 5 minutes a day (worse case)

[2] Module consumption estimates are from datasheets, cited in their respective sections for simplicity

[3] Peak Sun hours refers to the number of hours in a day that the intensity of the Sun is 1000W/m^2. 4 hours is the commonly accepted average across the world, we decided to divide that by 4 to be even harsher on ourselves. [6]

Load sensor	0.5	24	12	Only one active op amp circuit
PIR sensor	0.5	24	12	Worst-case scenario, not sure yet
RFID sensor (Sensing)	0.01	24	.24	While actively sitting around
RFID (Triggering)	60	3 minute	3	When senses card to check
Atmel (Active)	5	8	40	Exits sleep mode 8 hours a day, when actually has any package
TOTAL	444.5mA	-	255.27+ -400 = -144.73mA	The solar cells, even under the most harsh consumption and generation conditions, still provide enough power to operate

Table 2.1: Overestimated power consumption of our System in one day

2.1.1 Batteries

In order for our device to run off its own power, we need to include an energy storage component. We analyzed several different types of rechargeable batteries with respect to their chemistry, nominal voltage, energy capacity, discharge rate, and cost. We decided that Nickel-Metal Hydride batteries are the most aptly suited for the needs of our device, given their high charge capacity. They are also relatively cheaper and less dangerous than some of the alternative rechargeable battery types (Lithium-Ion, Lithium Polymer) [7].

Given every element of our circuit runs on 3.3V, we will use three Ni-MH batteries for a total voltage of 3.6V. We will then use a voltage regulator to regulate output a steady voltage of 3.3V to the rest of the circuit.

Requirements	Verification
1) When the alarm is triggered and all parts of the circuit are loaded, the batteries must successfully unload enough power for all functions to operate	1) Fully charge batteries. Given open circuit voltage measured using a voltmeter, calculate the needed resistive load to source a current of 400 mA. Discharge the batteries through this load for 1 minute, measuring the current with a DMM, and ensuring that the current stays greater than 400mA for the entire duration.

2.1.2 Solar Cells

We want our device to be self-sufficient and operate independently of any external power supply or wall outlet. Thus, we have decided to implement a solar-based power generation system that charges our rechargeable Ni-MH batteries. It consists of eight 17% efficient polycrystalline Silicon solar cells, each with an active area of $10cm^2$. The voltage output of a single solar cell is 0.5V, and the average current produced under full illumination is 400mA [8]. In order to achieve at least 3.6V, the battery pack voltage, eight solar cells will be connected in series, so the voltage output should be 4.0V.

Requirements	Verification
1) In optimal conditions (sunny day), the solar cells in series must have a voltage > 3.6V 2) In optimal conditions, eight solar cells in series must generate a current of greater than 300mA	1) On a sunny day, measure voltage of series-connected solar cells with a multimeter 2) On a sunny day, measure voltage of series-connected solar cells with a multimeter

2.1.3 Solar Cell Battery Charging Unit

We need to have some way of recharging the Nickel-Metal Hydride batteries through the solar cells. This is the purpose of the solar cell battery charging unit. The charging circuit consists of a network of resistors, capacitors, diodes, and a 2N2222 npn BJT. The operation of the transistor and the Zener diode are crucial for regulation and overcharge prevention of the battery. Normally, the 2N2222 BJT is off, but when the battery voltage exceeds 3.6V, the Zener diode conducts and provides base current to the BJT. This in turn grounds the top node of the circuit, thus cutting off power from the solar cells and stopping charging of the battery. The full schematic for the battery charging unit is shown as part of the power schematic in Section 2.6.

Requirements	Verification
1) Safely charges three Ni-MH batteries to full charge 2) Does not overcharge the batteries	1) Run the battery with a known load to ensure estimated charge capacity, check voltage of battery using a voltmeter 2) Connect a 4.0V DC Power Supply to the input where the solar cells connect, and connect fully charged (>3.6V) batteries, measure voltage and current with multimeter. Next, connect solar cells and repeat verification.

2.1.4 Voltage Regulator

A voltage regulator will be used to accurately power each component in the device. We will use a Texas Instruments LM1117 800-mA Low-Dropout Linear Regulator as an intermediate between the 3.6V battery voltage and the 3.3V for the rest of our circuit. We chose this regulator for its wide input and output voltage range, built-in overcurrent and thermal protection, and 800mA maximum output current, which is more than enough to provide for all of our loads. The circuit schematic is shown below, inspired by the LM1117 datasheet [9].

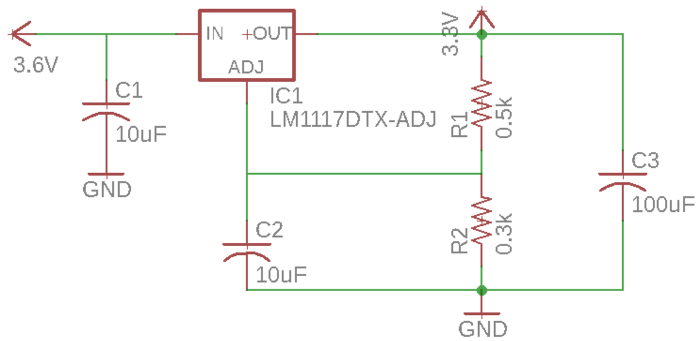

Figure 2.1.4: 3.6V to 3.3V Voltage Regulator from Batteries to Rest of Circuit

We programmed the output voltage to 3.3V by setting the values of R1 and R2. According to the LM1117 datasheet [9],

$$V_{OUT} = 1.25(1+\frac{R_1}{R_2})$$

$$\frac{R_1}{R_2} = 1.64$$

So we can set R1 = 15kΩ and R2 = 9kΩ in order to achieve a steady 3.3V output.

Requirements	Verification
1) Provide the regulator's desired voltage: LM1117: 3.3V, +/-5% under maximum 800mA load	1) Use DMM with a resistor network to ensure proper, stable voltage regulation under desired loads (test both our circuit's predicted load--617mA and maximum load conditions--800mA)

2.2 Weight Sensor Module

The weight sensor is the crux of this project's design. In order for our product to be successful, the weight sensor must be robust, inexpensive, and accurate. In order to accomplish these goals, we will use 10kg full bridge micro load cells. We considered using force sensors, but found that their minimal improvement in precision was offset heavily by their cost and fragility [10]. Almost all commercial electronic scales use load cells, which led us to finding very inexpensive modules.

The weight sensor will take in 3.3V regulated power, and output an analog power signal rated from 0-3.3V, with a one-to-one correspondence to the weight of the package, as well as a digital output telling the user whether or not there is a package on the device. This digital output turns off the other modules in our system when there is no load, resulting in much lower idle power consumption the majority of the time. The high level diagram of this module is shown below in Figure 2.2, and the schematic is included in Section 2.9. This high level design was inspired by a SparkFun "Introduction to Load Sensors" article that we found [11].

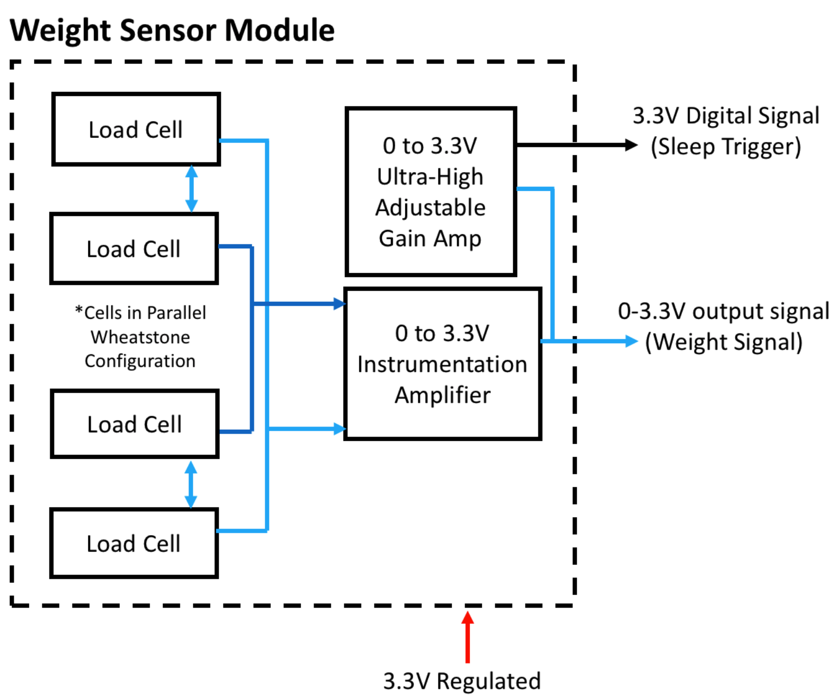

Figure 2.2.1: High-Level Weight Sensing Module Design

Because this module has so much overlap with the physical design, we have decided to merge the requirements both this unit and that, seen in section 2.8. We also included two bonus functionalities that are protection from misuse by the user or delivery person and will be included in our final product, but possibly not our demonstration.

Requirement	Verification
1) The weight sensor is capable of sensing a weight change of less than 0.5lb.[4]	1) Gently apply a 0.5lb weight to the module, then remove and the alarm should be triggered
2) The sensor is capable of sensing over 45 lbs of force without error	2) Load apparatus to 45lb, then add another 5 lb which we then will remove to trigger the alarm
3) A package weight of 0.5lb[5] is capable of waking the apparatus from sleep mode	3) Apply 0.5lb weight to apparatus, then check if motion sensor triggers a vocal warning
4) A person walking nearby the unit will not trigger the alarm	4) We will test this by placing the apparatus on a commercially available folding table we bring, then dropping a 5lb mass one foot away from the apparatus from a 3 inch height, to cause vibration, and seeing if the alarm goes off.
Bonus Requirements	
5) A package carelessly dropped on this unit will not set off the alarm	5) A 5 lb package dropped from 3 inches above the module inside a cardboard box must not trigger the alarm
6) Protection from someone stepping on the unit	6) A 150 pound person should be able to step on the unit, and afterwards the module still should function properly

[4] For the final product, we will use a more sensitive sensor that is the same price, but requires a minimum order of 100 units and has a lead time of two months [12]. Given that the only difference between the parts is the full-scale weight (the part dimensions, resistance, and error are the same), we are confident that by simply replacing the cell we will achieve precision down to 0.125lb with the exact same circuitry

[5] See footnote above

2.3 Audio Output Module

The alarm module is the core protective measure we implement in this project. Its features include a loud speaker capable of producing a voice to warn people of its protection and a siren of the owner's choice. This module is also built to be self-sufficient and highly durable, still going off even if the entire apparatus is smashed. For prototyping purposes, we also designed the amplifier to have adjustable gain to get a desired output volume. The exact features are quantified in the requirements and verification table.

The high-level implementation of this module is shown in Figure 2.3 below, with a detailed Eagle schematic and board layout shown in Section 2.8. This module has five inputs and one output. Four of the inputs are control signals from our microcontroller. The first is a trigger to make the voice-recording module play its pre-recorded message. The second and third signals set off the alarm and allow the user to choose the specific alarm they would like (such as a fire truck siren, police siren, and security alarm). The final control signal is used to route the correct signal to the speaker. The default setting of this signal is routed to the fault trigger. Both of these circuit designs were highly inspired by example circuits given in their datasheets [13-14]. The required instrumentation amplifier designed was acquired from a Wikipedia article [15].

The final input is unfiltered power from the batteries, which is used to drive the amplifier/speaker at the maximum power available, and is put into a 3.3v regulator circuit. The output of this module is the 3.3V regulated power. Thus, in effect we implement the power system for the whole circuit inside of the alarm module. This was done in order to power the alarm module even in the case of damage from a thief, to prevent them from simply smashing our apparatus to silence the alarm and fleeing. By combining these modules very closely, we reduce the chances of this occurring substantially.

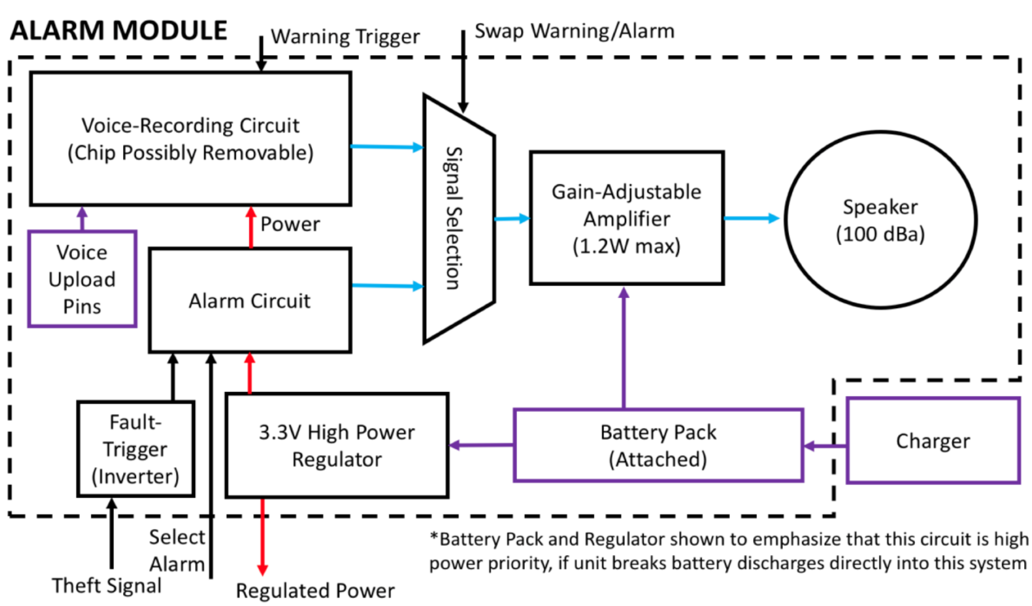

Figure 2.3.1: A high-level schematic of our alarm module

The requirements and verification table for the alarm module is shown below. We separated the requirements and verification table into two sections, first the internal “test” requirements we won’t show in demo but are needed for the module to operate successfully, and second the standard requirements and verifications.

Internal Testing/Requirements	Verification
1) The alarm circuit is fully powered by our inverter’s output current (In the case of failure, we will use a reed switch)	1) The circuit successfully outputs perceptible noise before amplification using an 8W, 0.5W test speaker
2) Low-power testing of the audio channel switching apparatus	2) Switch between perceptible noise before amplification using an 8 Ohm, 0.5W test speaker

Requirements	Verification
1) The alarm circuit is capable of choosing between at minimum a police siren noise and security alarm noise, either manually or through an application	1) Demonstration of triggering the alarm under both settings
2) The module plays a warning message when under load and the motion sensor is triggered	2) Place a 5lb weight onto the apparatus,
3) The alarm produces a noise of 75dB to 85dB as measured 1 meter away from the device	3) Using a decibel meter application on the Google Play app store, we measure at least 75dB on a phone at a 1m distance and verify it is in our desired range
4) The alarm is capable for playing at least 1 minute continuously	4) After triggering the alarm by removing weight, time the alarm to 1 minute using a phone timer

2.4 Core Microcontroller with Assorted Sensors

2.4.1 Atmel Core with Pinouts and RFID Sensor

The core Atmel Processor, RFID sensor, and motion sensor are combined into one module for simplicity, since both the RFID Sensor and PIR sensor are separate boards that we purchase, and their only importance in design is how we interface them with the Atmel chip. The verification for these two modules comes in the form of producing the correct functionality in our overall circuit.

The our core microcontroller is based heavily on the Atmega328p datasheet [16] and Arduino Mini design [17]. The only modifications come in the form of reducing the power consumption by setting the input power to 3.3V, halving the clock speed from 16MHz to 8MHz, and removing the programmer chip. These concepts were largely inspired by a SparkFun article [18]. To reduce costs, we directly place the circuit on the main PCB board. The module, with all of the required inputs and outputs, is shown below in Figure 2.4.1.

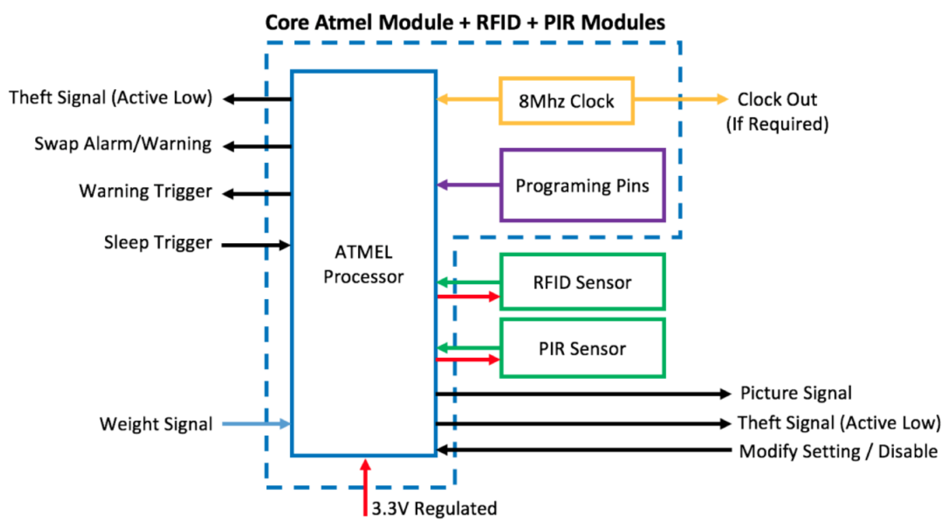

Figure 2.4.1: The primary microprocessor driving the core functionality of our device

The most original aspect of this module is the code that controls the microprocessor, shown as a high-level flowchart in Figure 2.4.2. This code includes actions for disabling the alarms, detecting and warning potential thieves, and sensing if a package has been taken. We significantly reduce power consumption through our code by disabling features such as extra counters and brownout detection, and enable the device to enter sleep mode when there is no package on the system.

As mentioned before, for our final Cozad competition proposal, we plan on offering two products. The first is an expensive version implementing all of the features mentioned in this proposal, such as WiFi, a camera, and application for around $100. The second version is a “basic” module that includes only the weight sensor, alarm, and RFID unit with the core processor shown below. Because of this intended difference between the final products, we decided two separate microcontrollers would be optimal for streamlining the entire design process.

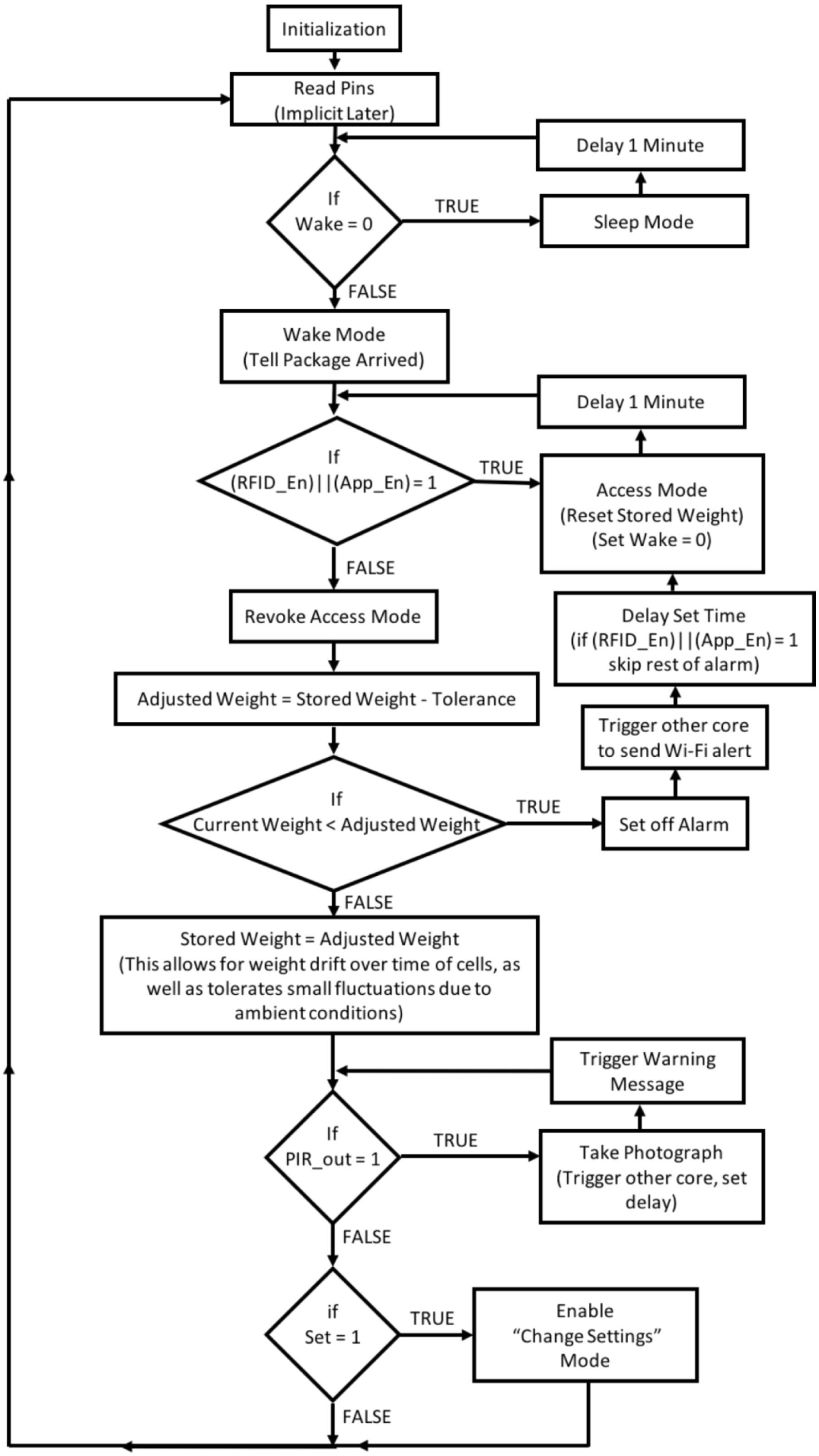

Figure 2.4.2: Core Atmel code Process Flow

Requirements	Verification
1) The core microprocessor successfully enters sleep mode when no package is applied 2) When the RFID tag is triggered, the system becomes enabled 3) The module sets off the alarm even when the microprocessor stops sending signals 4) The Atmel processor consumes <5mA in active mode and <2mA when in sleep mode	1) Placing low voltage on the “sleep” input results in the PIR sensor not giving a verbal warning 2) After flashing the RFID tag, the indicator LED turns on to show it is disarmed, and the package is removed without the alarm triggering 3) Demonstration of warning message under loading conditions 4) Test current draw into Atmel processor in both modes using an ammeter placed between the regulation and Atmel Vdd pins

2.4.2 PIR Motion Sensors

Passive infrared (PIR) sensors detect motion with infrared light and output a digital high value when triggered [19]. We use a PIR sensor in conjunction with the camera as an additional security measure in our device. When significant motion (large objects, not just tree leaves blowing) is detected within 3 meters +/- 0.5m from the sensor, the camera will be triggered to take a photo. This allows us to have some surveillance functionality on our device as well as play an optional warning message. The reason that we do not just have the camera take a picture when the alarm is set off is because it would be easy for the thief to cover the camera or position themselves in such a way where the camera would not get a picture of their face. The Field of Vision (FOV) of the sensor is a cone sensor of <100 °, so we need the sensor to be at some distance (~3m) from the target in order to get a good image from the camera. The PIR sensor keeps the camera in a low power mode and directs the Wi-Fi board to come out of sleep mode. This allows us to use much less power when nothing notable is happening near our device. The exact current draw our device will use before and after the PIR will be triggered can be seen above in the Power Unit Section; in Table 2.1. We chose to use the HC-SR501 [20], because of its adjustable sensitivity, its price and its shipping convenience [20].

Requirements	Verification
1) Outputs digital high signal of >3V to the microcontroller when triggered	1) Walk towards PIR sensor at different speeds and see if the sensor picks up movement
2) Sensitivity is adjusted so that the device is only triggered when significant movement is detected 3 meters +/- 0.5 in front of sensor	2) Connect PIR sensor to DMM for power. Connect LED to PIR sensor. Use a tape measure to have subject stand and walk by sensor at predetermined distances in increments of 1 ft. Record when PIR sensor is triggered by observing LED.

2.5 Camera Module

2.5.1 Camera

For added security, we have included a camera module in our device. The purpose of the camera module is to take a picture of the potential thief as they approach the device. We will have the camera capture images of significant movements at a distance of about 3 meters away from our device. The camera board we are using is the Arducam-M-2MP. We chose this camera for its high image quality, its JPEG output, and its software compatibility with Arduino.

The internal block diagram for the camera module, which is from the ArduCAM mini camera user guide, can be seen in Figure 2.5.1. The main components consist of an image sensor, an ArduChip, and a lens. The image sensor is a 2 Megapixel CMOS OV2640 from Omnivision. The ArduChip handles the camera, memory, and hardware timing, providing a user-friendly SPI interface [21].

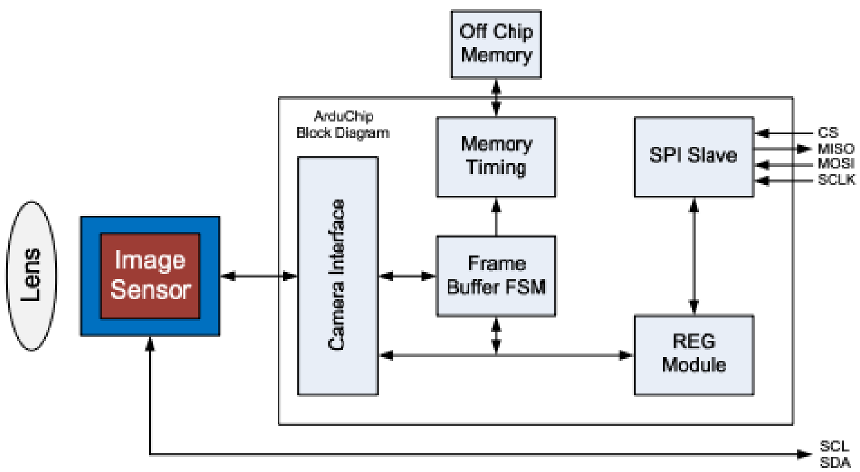

Figure 2.5.1: ArduCAM Mini Internal Block Diagram [21]

Requirements	Verification
1) Must take a photo after a capture command via SPI port. Picture is stored on off-chip memory in <30 seconds time.	1) Send a command to camera to take a picture. Check if picture was stored on off chip memory.
2) Resolution of photo must be >= 1280x960, and we must be able to make out facial features from photos of people standing 3 +/- 0.5 meters away (in high light conditions).	2) Hook up camera to DMM for power. Use a tape measure to have subject stand predetermined distances (3+ separate distances) from camera. Send capture command from SPI interface. Analyze results of each image, record results, making sure to state if subject is recognizable.

2.6 Wi-Fi Module

2.6.1 Wi-Fi IC and Related Infrastructure

The chip we are using in the Wi-Fi module is the ESP8266-12E microcontroller with built-in Wi-Fi functionality. Specifically, we are using a development board called the NodeMCU-devkit. This development board is designed to work with the open source NodeMCU firmware, which is Lua-based firmware for the ESP8266 Wifi SOC [22]. This firmware communicates with a PC through a serial USB link that provides an interactive programming language for programming and debugging. We chose to buy this part because of its affordable price without sacrificing any of the functionality needed for this project. We extend this functionality by allowing the Wi-Fi chip to send data to an Android application on a user's cell phone. Therefore, the ESP8266 must be capable of sending and receiving data from the user's cell phone when it is connected to the same Wi-Fi network.

2.6.2 Android Application

The user will be able to control the alarm from their cell phone via an Android application designed specifically for this project. There are three main functions of the app. First, it will allow the user to disable the alarm before they pick up their package when the user is connected to the same Wi-Fi network as the anti-theft device. Second, the user will receive a picture of the thief on their app if the alarm gets triggered. This functionality is included so the user can alert neighbors that a package thief is lurking. Third, we will give the customer alerts for when packages have arrived, so that neighbors or friends can grab especially valuable packages for them and just to know.

Requirements[6]	Verification
1) Wi-fi IC must be able to control the alarm via the developed application	1) Connect the Wi-Fi module to a laptop or cell phone sharing its Wi-Fi connection. Turn on the developed Android application and ensure internet connectivity. While the alarm is triggered, click the "disable" button to shut it off within 15s as measured by a stopwatch.
2) Wi-fi IC must be able to give a alert the package has arrived via the developed application	2) Connect the Wi-Fi module to a laptop or cell phone sharing its Wi-Fi connection. Turn on the Android developed application, and ensure internet connectivity. When a package is placed on the module, within 30 seconds warning should arrive via the application as measured by a stopwatch.

3) Wi-fi IC must be able to upload the photo of the thief within 1 minute	3) Connect the WiFi module to a laptop or phone "router" sharing its connection. Turn on the Android developed application, and ensure internet connectivity. When a package is taken from the module, within 1 minute a photo should arrive as measured by a stopwatch.
Bonus Requirement 4) User can pick what kind of sound plays out of the alarm	4) Program different types of sounds (e.g. police siren, gunshot noise), ensure that the user can control the type of the sound by selecting it on the app and then triggering the alarm to see if the sound changes.

The Wi-Fi board will also communicate with the Atmel chip so that the Wi-Fi board knows when the alarm has been triggered. This will tell our Wi-Fi board to upload the most recent pictures.

2.7 Physical Design

In order to successfully commercialize our product, we need to design a robust physical enclosure. The chassis must be protective, cheap, and aesthetically pleasing. In order to accurately obtain these goals, we will create 3D printable CAD designs. The original prototype of our physical design is shown in Figures 2.8.1 and 2.8.2 below. Once we receive parts and finish our PCB design, we will refine these CAD designs.

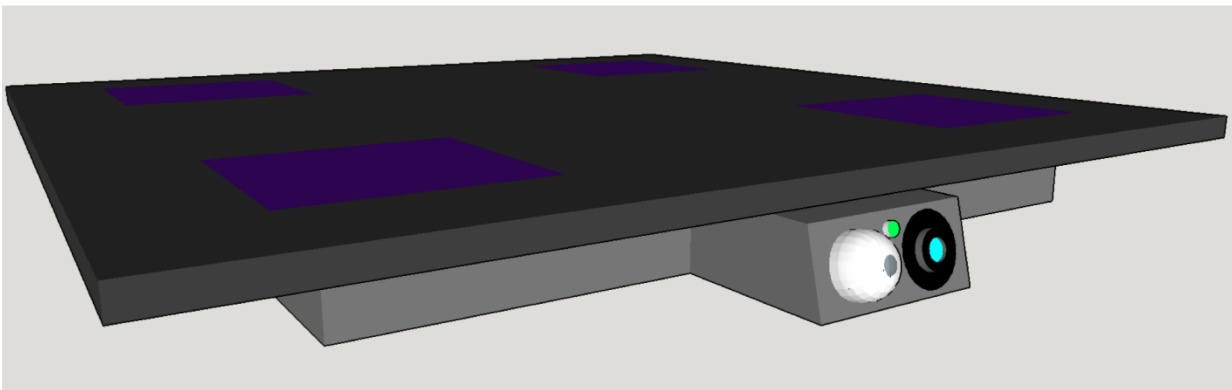

Figure 2.7.1: Front top view of our device, showing the camera, PIR sensor, indicator LED, and solar cells

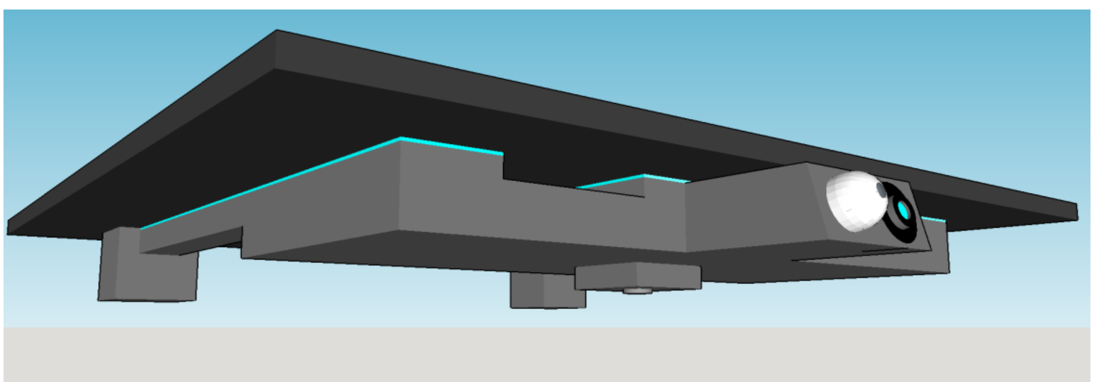

Figure 2.7.2: Bottom view, showing the speaker port and weight sensors

The requirements of this design are explored in Section 2.2, in the weight sensing module, due to the strong overlap. A “bonus requirement” is below, which we do not guarantee for demoing but hope to have eventually.

Bonus Requirements	Verification
1) Waterproofing	1) Pour a bucket of water over the top of the unit and ensure that it still works for a testing time of five minutes

2.8 Schematics

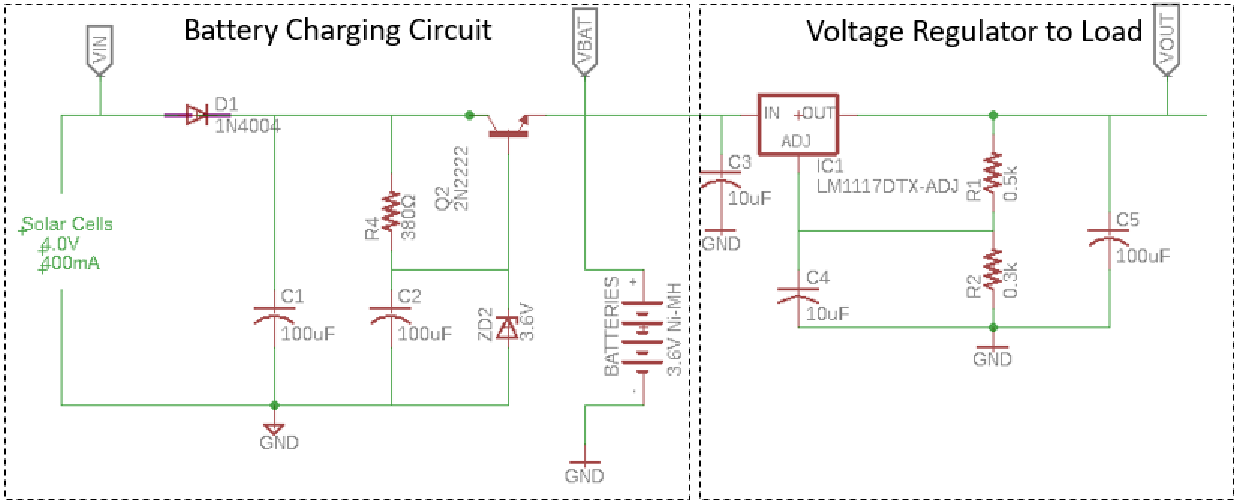

Figure 2.8.1: Power Module Schematic [7-9]

In Figure 2.8.2 below, we show our audio circuit schematic. Things to note in this design are the powering of the UM3561 chip via an inverter (which is possible due to its small, <0.5 mA current consumption), the unspecified, adjustable amplifier gain, and the external programmer for the ISD1820 chip. These schematics were all inspired by circuits on their respective datasheets [13, 14, 23].

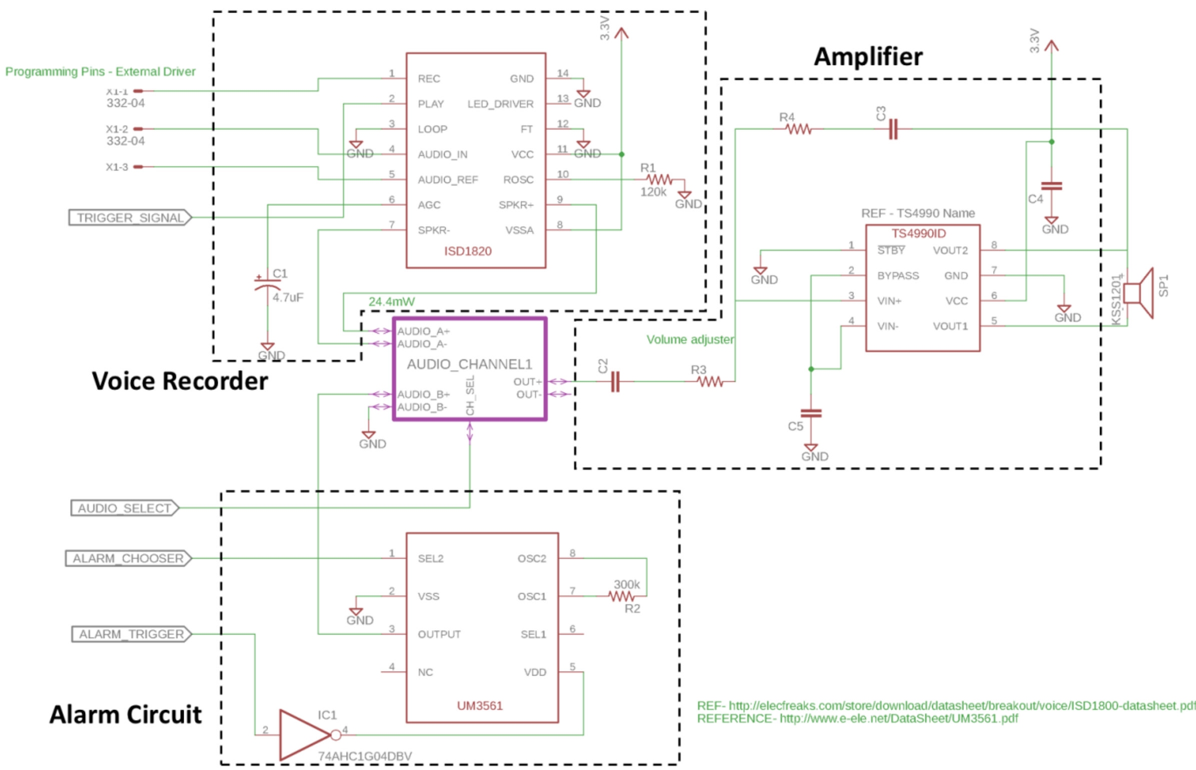

Figure 2.8.2: Audio circuit schematic

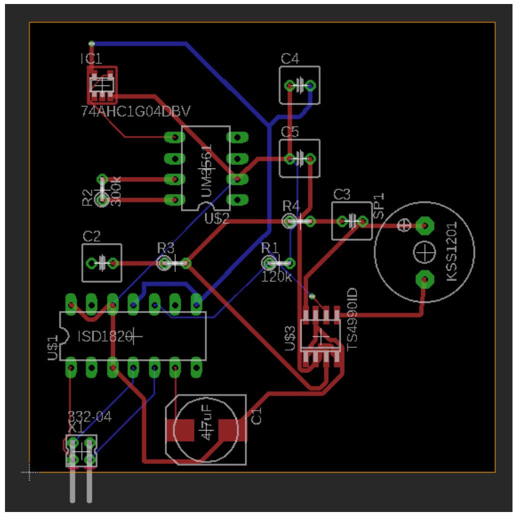

Figure 2.8.3: First PCB design for Audio Circuit, used to give us an estimate of the final physical dimensions. Power and output traces are thicker than the smaller signal traces, and the on-chip power regulator is not shown yet. Before making the circuit PCBs, we plan to do breadboard testing.

Shown in Figure 2.8.4 below is our weight module schematic. Several aspects to note in this design are the load cells put in a parallel Wheatstone configuration, to reduce noise and temperature variability [11], the implementation of an instrumentation amplifier manually, using three of four OP Amps we have available, and a "Clipping Sleep Trigger". The clipping trigger takes advantage of the extra Op Amp we have available and is designed to "wake" the Atmel processor by amplifying the small package signal to a 3.3V signal that causes the Atmel chip to exit sleep mode. The instrumentation amplifier may be replaced by a more expensive commercial unit if not accurate enough.

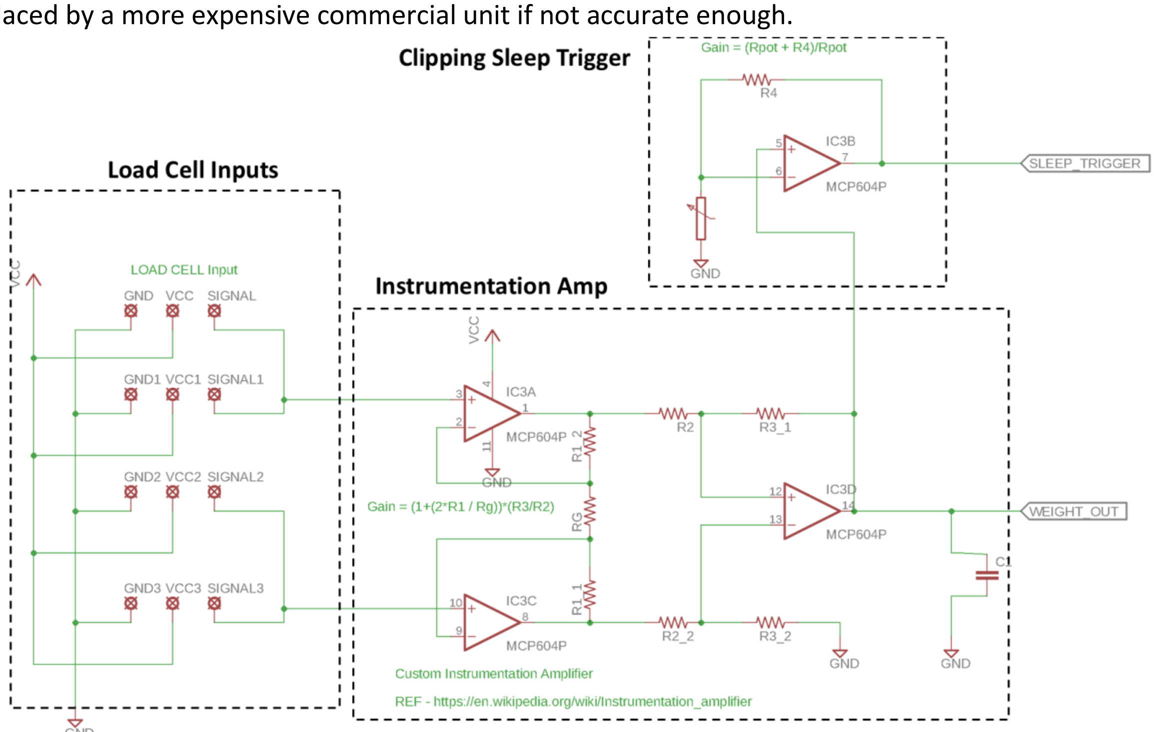

Figure 2.8.4: Weight Module Full Schematic

Below in Figure 2.8.5 is a circuit schematic of our camera board connected to our Wifi board. The SPI Master Output Slave Input (MOSI) and the SPI Master Input Slave Output (MISO) pins on the ArduCAM are connected designated General Purpose I/O pins (GPIO) [30]. The other SPI pins include a Chip Select, and a SPI clock. Lastly, the power, serial clock (SCL), and serial interface data pins (SDA) are connected between the boards. GPIO pins 6-11 are not available for use, and are used to address on chip flash memory [31]. We use two more GPIO pins to communicate with the Atmel microcontroller in the core system. These connections will allow the Camera/Wifi module to know when the PIR sensor has been triggered so our camera can take a picture.

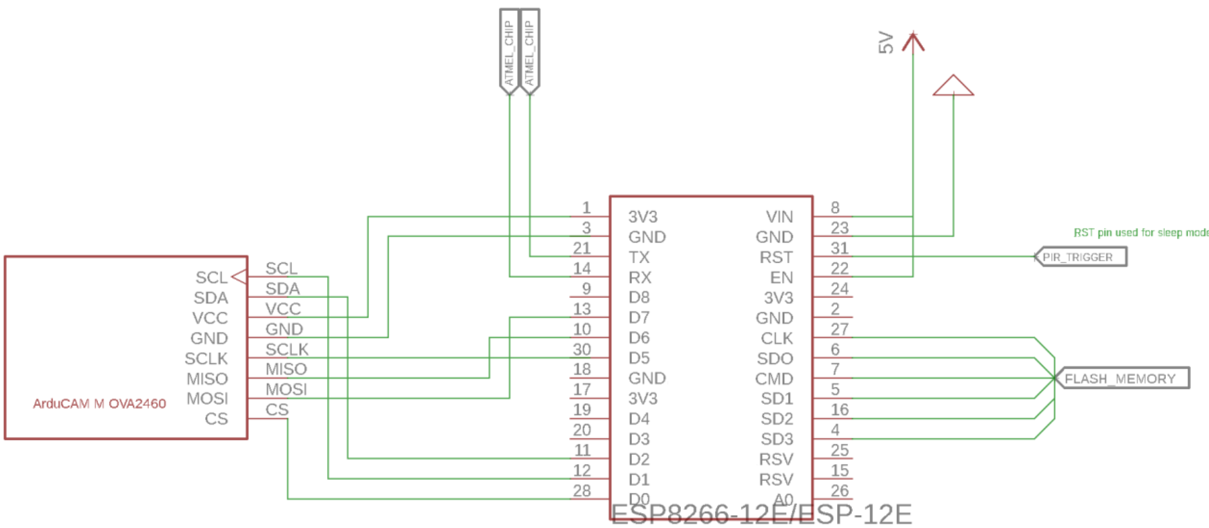

Figure 2.8.5: Wi-Fi and Camera Module Connections

2.9 Tolerance Analysis

2.9.1 Power Tolerance Analysis

Several components in our power unit supply or regulate voltage within a certain tolerance. Our solar cells are rated at 0.5V and 400mA each, so eight solar cells in parallel should supply 4.0V and 400mA. However, we must account for both losses and imprecision of the datasheet. Power losses occur in series-connected photovoltaic modules via resistance through the cells, which can mean significantly less current is delivered than expected. Precision wise, the voltages on the product description [8] were reported with only one significant figure, so we can't be too certain how accurate the voltage rating is. Therefore, we decided to keep the voltage requirement of the solar cells in optimal conditions to above 3.6V. The current produced from the solar cells is reported as 400mA in the product description, but again, this might be a slight over-exaggeration by the manufacturer or vendor. Therefore, to account for any "rounding up", we say our solar cells produce more than 300mA under ideal lighting, to be safe with our power requirements with a 25% error margin.

Secondly, the LM117 voltage regulator must provide a steady voltage within a certain tolerance. According to the datasheet [9], the regulator includes a Zener trimmed band-gap reference to ensure an output voltage accuracy +/-1%. In order to account for the internal resistance and precision of the instrument (likely DMM) used to measure the output voltage, we have increased the tolerance to +/-5%.

2.9.2 Load Cell Calculations

One of the most crucial aspects of our project is being able to precisely measure differences package weights. The option we decided on for doing this is the use of load cells. In order to estimate the possible accuracy, and thus minimum package weight, we use equation (1), where ε is the total error, ε_C is the combined error, $\varepsilon_z/\varepsilon_s$ the temperature effects on zero and span, L the rated load capacity, N the number of load cells, W the maximum load and t the operating temperature range. This equation is from an article on load cell accuracy effects [25].

$$\varepsilon > \sqrt{\varepsilon_C^2 + \left(\frac{\varepsilon_Z \times L \times N}{W_1} \times t\right)^2 + (\varepsilon_S \times t)^2} \tag{1}$$

From this, we can estimate that given a scale using four common 10kg load cells [11], operating at maximum load of 40kg at a worst-case temperature variation from -20°C to 40°C (-13°F to 104°F), we can expect a load cell error of less than 50 grams (~0.1 pounds), which is reasonable.

In our design, however, we will be using 50kg load cells to start, given that the lead time is about 2 months for the proper low cost cells of identical dimensions. Thus, for early prototyping we will use these instead, and given that the all of the error scales proportional to the full-scale, we can reasonably say we will have less than 0.5lb of error early on. Of course, we should expect much better performance in real operation, but this is the upper bound of it, which is still reasonable for our applications, given packages lighter than 1lb are generally put in mail boxes rather than in plain sight.

2.9.3 Custom Instrumentation Amplifier Gain Calculation

In order to read off the weight of a package precisely, we must amplify the voltage swing of the load cells to swing between a full 0-3.3V during operation. During operation, the load cells swing have a swing factor output of about 1.6 mV/V, meaning that at 3.3V operation the voltage will vary by only 5.28 volts from minimum to maximum load. Thus, to get our system to the full analog input range, we need a gain of 625, which is perfectly reasonable for our application.

$$\frac{V_{\text{out}}}{V_2 - V_1} = \left(1 + \frac{2R_1}{R_{\text{gain}}}\right)\frac{R_3}{R_2} \tag{2}$$

The gain of our amplifier is calculated using equation 2 above, and we set it to 625 by using precision resistor values of R_2 = 10k, R_3 = 100k, R_1 = 33k, and R_{Gain} = 10k. For early testing we will not be set on these values, but they are excellent starting points. Equation 2 was taken from Wikipedia [15].

2.9.4 Audio Amp Filter and Gain Calculations

The output of both the voice recording and siren circuits is around 25mW for an 8 ohm speaker load. In order to reach the required noise levels for our circuit however, we need a speaker power output of 1W. If we use an 85dBa speaker, this would correspond to a 85dB noise at 1 meter, far greater than our core requirements. Since we only need 80dB to fulfill our requirements, this would mean we only need a signal ~1/4th the strength, or about 250mW. This then would mean that we only need a power gain of about 10, assuming gain is low enough to avoid clipping.

However, given amplifier we use, when determining gain we must also determine the 3dB cutoff frequency, which is F_c in equation 3 below before calculating the gain, shown in equation 4.

$$C_{in} = \frac{1}{2\pi F_C R_{in}}) \tag{3}$$

$$G = 2 \cdot (\frac{R_{feed}}{R_{in}}) \tag{4}$$

We have not yet determined what lower bound frequency cutoff will be acceptable, and plan to prototype different values and check the distortion on the output. Because of this we are not comfortable giving exact figures since we plan to play around with this circuit manually, but these equations will guide our intuition.

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor Cost

An ECE Illinois graduate can earn around $40 an hour working in the industry, so we assume that each of our three team members' time is valued at $40 an hour. Given that the first two-three weeks were spent going to lecture and getting a handle on the expectations of ECE 445, we estimate that it will take 13 weeks to deliver a working prototype. We also assume that each of us works 15 hours per week. This leads us to a final labor cost calculated by:

$$3[\text{people}] \times \frac{15[hrs]}{[week]} \times 13[weeks] \times \frac{40[\$]}{1[hour]} \times 2.5 = \ \$58{,}500$$

3.1.2 Parts Cost

Part	Manufacturer	Part Number	Quantity	Cost (single)	Cost (bulk)
Camera	ArduCAM	ArduCAM M-2MP	1	$25.99	$20.99
Wi-Fi Board	Espressif Systems	ESP8266-12E	1	$8.99	$6.97
PIR sensor	DIYmall	HC-SR501	1	$1.80	$1.19
Alarm Module*	Assorted	N/A	1	$7.87	$2.08
Weight Sensor*	Assorted	N/A	1	$12.23	$6.60
Microcontroller	Microchip/Atmel	ATmega 328p	1	$2.50	$1.80
Passive Elements	Various	Various	N/A	<$5	<$1
Poly-Si solar cells	Aoshike	N/A	8	$0.25	$0.10
LM317 Regulator	Texas Instruments	LM317DCYR	1	$0.78	$0.33
LM1117 Voltage	Texas Instruments	LM1117T	1	$0.99	$0.40
NIMH Batteries	Panasonic	HHR150AA	3	$2.00	$1.50
TOTAL	-	-	-	$70.20	$42.96

Below is a more detailed look at the audio and weight modules, which contain several different parts.

Part	Part Number	Bulk Price	Single Price	Units	Total Bulk Cost	Total Single Cost
Load Cells	GML670	$1.50	$2.50	4	$6.00	$10.00
Op Amps (4)	MCP6004	$0.47	$0.30	1	$0.47	$0.30
Comparator	LM393ST	$0.13	$0.43	1	$0.13	$0.43
Potentiometer (Debug)	3306F-1-204	$0.00	$0.50	3	$0.00	$1.50
WEIGHT TOTAL	-	-	-	-	$6.60	$12.23
Speaker	CSS-1021028N	$0.40	$5.51	1	$0.40	$5.51
Audio Op Amp	TS4990	$0.33	$0.77	1	$0.33	$0.77
Voice Chip	ISD1820	$0.60	$0.60	1	$0.60	$0.60
Alarm Chip	UM3561	$0.75	$0.99	1	$0.75	$0.99
AUDIO TOTAL	-	-	-	-	$2.08	$7.87

Note the coloring schemes. Red means that this will not be in the final module, but is useful for debugging and design. Orange corresponds to features likely to be removed for the cheapest product, and yellow is in every module.

3.1.3 Total Cost

The total cost of building our first prototype is the sum of our labor costs and the total individual parts cost. $58,000 + $70.20 = $58,070.20.

3.2 Schedule

Week	John S.	John G.	Joe B.
2/5	Design the audio, weight sensing, and core Atmel module at a high level	Refine overall design, figure out key functionalities we want to implement in "Deluxe" version	Research camera boards with memory units. Research PIR sensors.
2/12	Determine the best RFID reader, Atmel chip, and parts for purchase	Look into energy storage and recharging options, investigate Android app development	Research Wifi module. Start finding compatible parts to purchase for camera, PIR, and Wifi.
2/19	Create full, first round circuit schematics for audio, weight, and core Atmel systems. Place parts order for IC's/passives	Calculate max and normal current draw, design power module schematics. Purchase power components	Design camera unit and wifi unit. Design prototype schematic. Purchase all necessary parts.
2/26	Begin breadboarding weight measurement circuit, voice circuit, and alarm module, running off of Arduino Uno	Learn Android studio, work on developing a simple Android app. Look into ways to minimize power consumption on board	Design and set up experiments to test requirements of parts. Start working on and researching the software to implement Wifi board--Camera communication
3/5	Test first iteration of audio and weight circuits on ArduinoUno with first version code. Begin amplifier construction on breadboard	Continue Android studio training, test and debug simple app Test battery recharging circuit by building it on a breadboard, help make PCB	Estimated time of arrival for parts. Start using parts on breadboard. Conduct experiments. Optimize design.
3/12	Finish debugging code, alarm, and weight modules. Finish final PCB design for these modules, as well as custom Atmel chip, before spring break	Test and verify the remainder of the power circuit as described in the R and V section of the power unit, including solar cells	Optimize design. Write high level code. Finish code to communicate between boards if possible. Debugging of any hardware components if still necessary.
3/19	**Spring Break** Catchup, all PCB orders in	**Spring Break**	**Spring Break**

3/26	PCB should arrive, build core processor first and debug. PCB design should account for testing parts	Debug any issues with the power circuit. Complete Android studio training, begin working on developing our application	Finish up all software involved in camera and Wifi units.
4/2	Finish final CAD design, fit all electronics inside. Finish soldering all weight and sound modules with microcontroller triggering. 3D Print first design	Continue developing application, work with John and Joe to ensure application is integrated with hardware, integrate solar cell top with physical design	Work on configuring my Wifi-Camera module with John's application. Establish communication that is consistent.
4/9	Board testing, as detailed elsewhere. Optimize audio gain and load sensitivities	Test and debug application	Work with partners to put our work together in optimal design
4/16	Test, debug with full integrated package. Begin Report	Test and debug application, possibly add bonus features	Test, debug groups design Add any additional. features if time permits.
4/23	Test, debug with full integrated package	Prepare final presentation and final report	Test and retest multiple times to make sure the finished product works flawlessly for demo.
4/30	Present project and finalize report for submission		

4 Safety & Ethics

We must be cognizant of several potential safety hazards while constructing this device. First, and perhaps most obviously, we must ensure that our alarm system and speaker does not exceed the limit of a safe noise level exposure for the public. Hearing loss has become more prevalent in the United States, having increased from 13.2 million (6.3% of the US population) in 1971 to 48 million (15.3%) in 2011 [3]. We do not want our device to contribute to that statistic, so we will keep our alarm under 85 dB. This device will be displayed outdoors, and outdoor electronics present a risk, especially in wet conditions. We intend to waterproof the protective layer for the electronics by adhering to IP68 guidelines [26], which keeps the equipment suitable for continuous immersion in water before making this a real product, though for our prototype we do not guarantee this.

From an ethical standpoint, we must design our device to deter crime in such a way to scare away criminals from stealing packages, but not make people fear for their lives. An alarm system that is so loud that is causes permanent hearing loss, or so jarring that it causes heart palpitations is not in accordance with IEEE Code of Ethics #1, "to hold paramount the safety, health, and welfare of the public" [5]. Furthermore, we must consider the health and safety of the neighbors and of people passing by. Especially in urban neighborhoods where houses are clustered close together, a loud and jarring alarm system could be detrimental to the health of the public. Another ethical consideration is to test and figure out the limits of our device, and avoid making claims that exceed the limits. We will quote realistic and accurate claims, in accordance with IEEE Code of Ethics #3, "to be honest and realistic in stating claims or estimates based on available data" [27] Also, by designing and building this device, we will gain a better understanding of the principles of electrical engineering we have learned in the last four years as ECE students at Illinois. Therefore, IEEE Code of Ethics #5 is central to the nature of this project: "to improve the understanding of technology; its appropriate application, and potential consequences" (IEEE Code of Ethics #5).

Finally, in doing market research for this product, we found a very similar product idea to ours, a device called the "PackageGuard" [29]. In doing this work, we must make sure to adequately cite any influences from their ideas, and inform the ECE445 staff of this product, which we have done in previous reports.

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