ECE 445: Senior Design Lab
Laboratory
Fall 2017

# Automatic Pill Dispenser

## Design Document

Matthew Colletti
Iskandar Aripov

Instructor:
Prof. Arne Fliflet

TA:
Rebecca Chen

# 1. Introduction

## 1.1. Objective

Our product will help those who have medications and vitamins that they need to take on a daily basis. It can be quite difficult to remember what pills to take when and how much the correct dosage is. To overcome this difficulty, the pill sorter will be able to take in a full month's worth of several pills, sort them into the correct dosage, and dispense them at the correct interval. This takes the potential for error each day and moves it upstream to a single task: correctly inputting the prescription information into the pill sorter. Now instead of 30 or 31 opportunities for a mistake to be made, there is one. This method decreases the opportunity for error and makes it easier for the end user because all they have to do is open their hand and the correct medication will be dispensed.

This problem has been tackled in the past. However, the solution that others have come up with tends to resemble an alarmed box, still requiring manual sorting by the user, or a bulky countertop box without a direct user interface, requiring a somewhat high technical knowledge to operate. Our solution will overcome both of these common pitfalls with an intuitive user interface so even those with limited computer and technical knowledge can fully utilize the system and a simple design that avoids oversized motors, actuators, and containers. The end product will be a low-cost solution to an everyday problem [1].

## 1.2. Background

According to a study by NPR, 119 million Americans take prescription drugs. In addition to that group, our target population includes any person who takes over the counter allergy medication, pain relievers, and vitamins routinely [1]. As Figures 1 and 2 show below, there is a significant population between the ages of 0-18 and 65+ years old that take both prescription and over the counter medicines routinely. The Kaiser Family Foundation found that on average those who are 0-18 years old purchase medication 4.3 times each year and for those who are over 65 years old, that number jumps to 23.9 times per year in the United States [2]. People between the ages of 19 and 64 purchase 12.7 medications annually. We are gearing towards helping those between 0 and 18 and over 65 because these are the age groups that typically require extra help whether it be from parents, guardians, or caretakers. Removing the task of counting out and alerting these groups to take their medication could preserve the autonomy of aging users and give children a sense of autonomy as they are able to take their medication without having a parent watching over them once the dispenser is programmed [2].

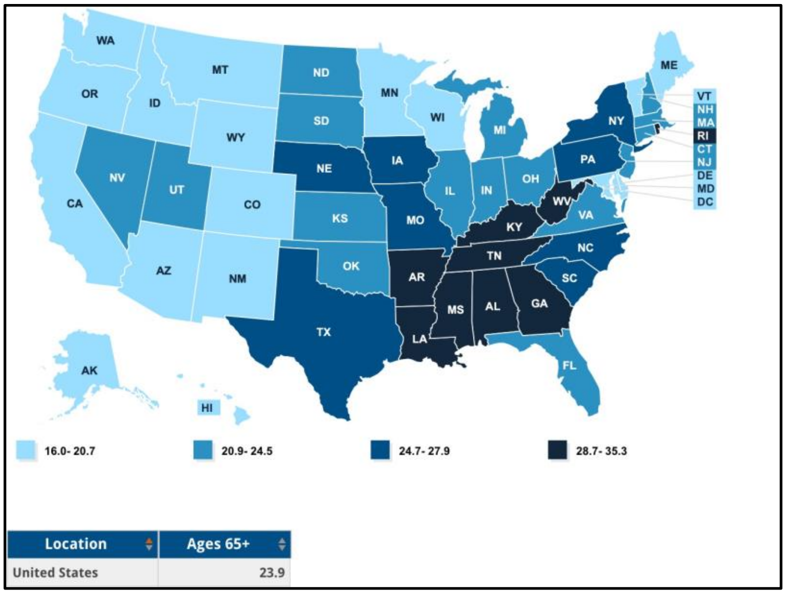



**Figure 1**: Retail Prescription Drugs Filled at Pharmacies (Annual per Capita Ages 65 and Up) [2]

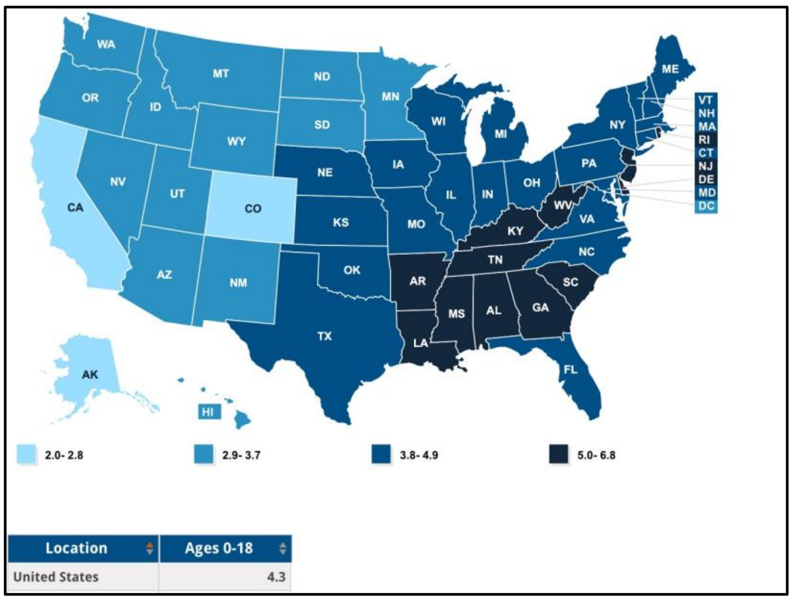



**Figure 2**: Retail Prescription Drugs Filled at Pharmacies (Annual per Capita ages 0-18) [2]

### 1.3. High-level Requirements

1. The machine will sort and properly dispense one pill at a time for any given pill.
2. The machine will be able to dispense medication at specified times.
3. The machine will audibly alert the user that it is time to take medication.

## 2. Design

## 2.1. Block Diagram

Our dispenser will require five separate sections: a power supply which will turn the 120 VAC 60 Hz to 5 VDC; a control unit featuring a microcontroller and sensors to properly alert and dispense medication; a user interface to program the proper dosage; three motors (one per type of medication) to dispense a single pill; and most importantly, a system of alerts so the user knows that it is time to take their medication. The block requirements are laid out below.

- Power Supply - convert an incoming 120 VAC signal into a 5 VDC supply. Pass the incoming 5 VDC supply to each component.

- IR Break Beam Sensing and Control - Detect when a single pill has been dispensed . Alert user if the wrong dosage has been passed. Turn motors on and off individually.

- User Alerts - Turn on LED and speaker when medication is dispensed. Turn off LED and speaker when medicine is removed from the machine.

- User Interface - Display which pill the user is setting a dispensing schedule for. Allow the user to change days that the pill will be dispensed. Allow the user to change the time that the pill will be dispensed.

- Dispensing Motors - Dispense indicated quantity of pills at programmed time. Rotate 90 degrees forwards and 90 degrees backwards to starting position.

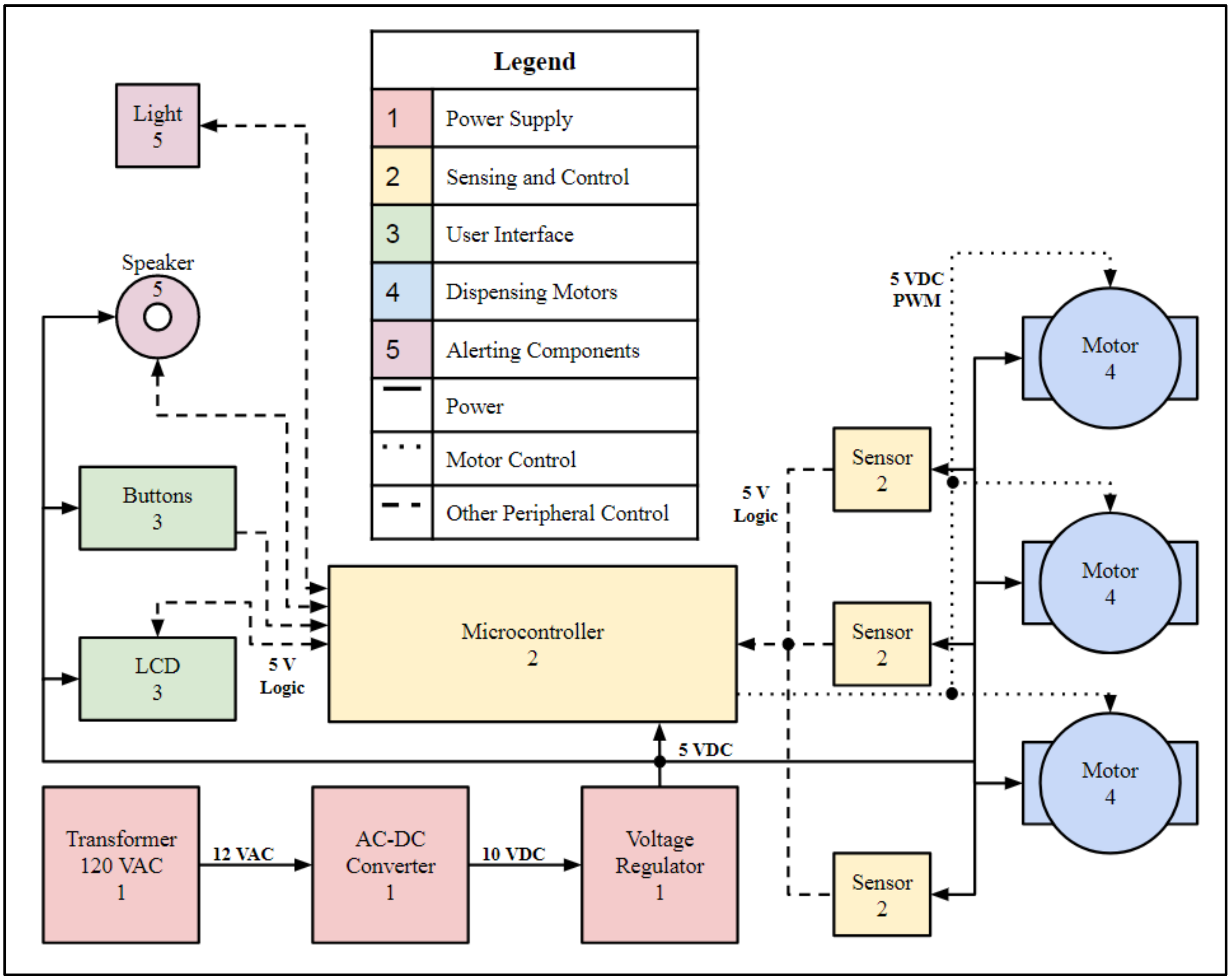



**Figure 3:** Block Diagram

## 2.2. Functional Overview

The part numbers, vendors, part details, datasheet links, and purchasing links are all summarized in a separate document. A complete parts list can be seen below in Table 10.

### 2.2.1. Transformer

A transformer is the first of the three power supply components. Our board needs a reliable DC voltage supply to power the dispenser's circuit components, however, we desire this device to plug into the wall for accessibility. As a result, our circuit requires a transformer to step down the wall voltage of 120 VAC to 12 VAC.

**Table 1:** Transformer Requirements and Planned Verifications

| Requirements | Verifications |
|---|---|
| 1. Steps down 120 VAC to 12+-1 VAC | 1. Oscilloscope measurements taken to verify that output voltage is within 1 V. |

## 2.2.2. AC-DC Converter

The second piece of the power supply is a bridge rectifier for full wave rectification of the incoming 12 VAC coming in from the transformer. This full-wave rectified signal will be smoothed out with a capacitor and then passed to two parallel voltage regulators.

**Table 2:** AC-DC Converter Requirements and Planned Verifications

| Requirements | Verifications |
|---|---|
| 1. Fully rectifies incoming 12 VAC<br>2. Capacitor effectively smooths AC signal so voltage stays within 12+-1 V | 1. Oscilloscope measurements taken verify rectification occurs.<br>2. Oscilloscope measurements taken verify voltage stays within 1 V. |

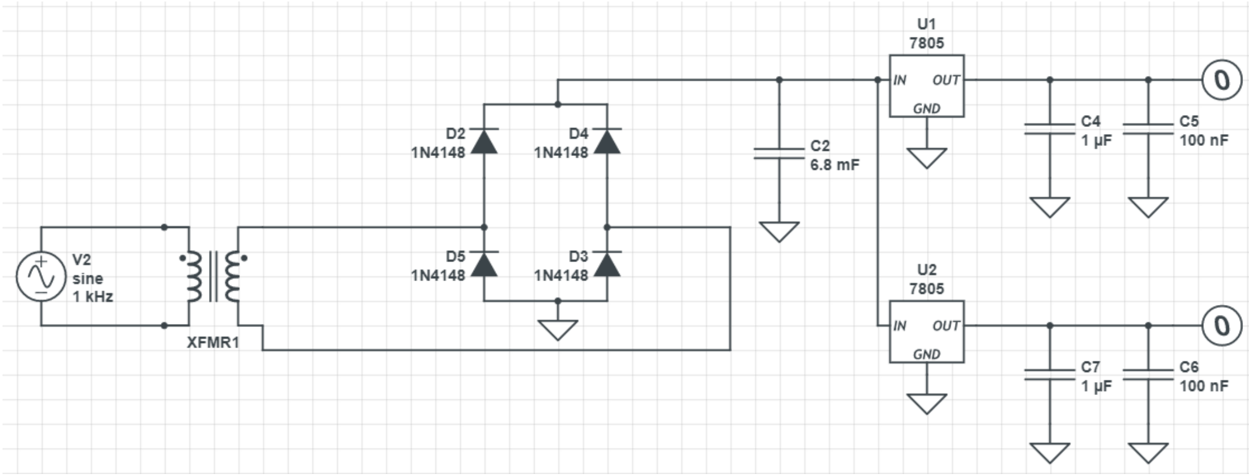



**Figure 4:** Power Supply Circuit

## 2.2.3. Voltage Regulator

The final part of the power supply is the voltage regulator. Our voltage regulator will buck the 12 VDC input to a steady 5 VDC input; this constant direct current is critical to supplying the digital components the power they need.

**Table 3:** Voltage Regulator Requirements and Planned Verifications

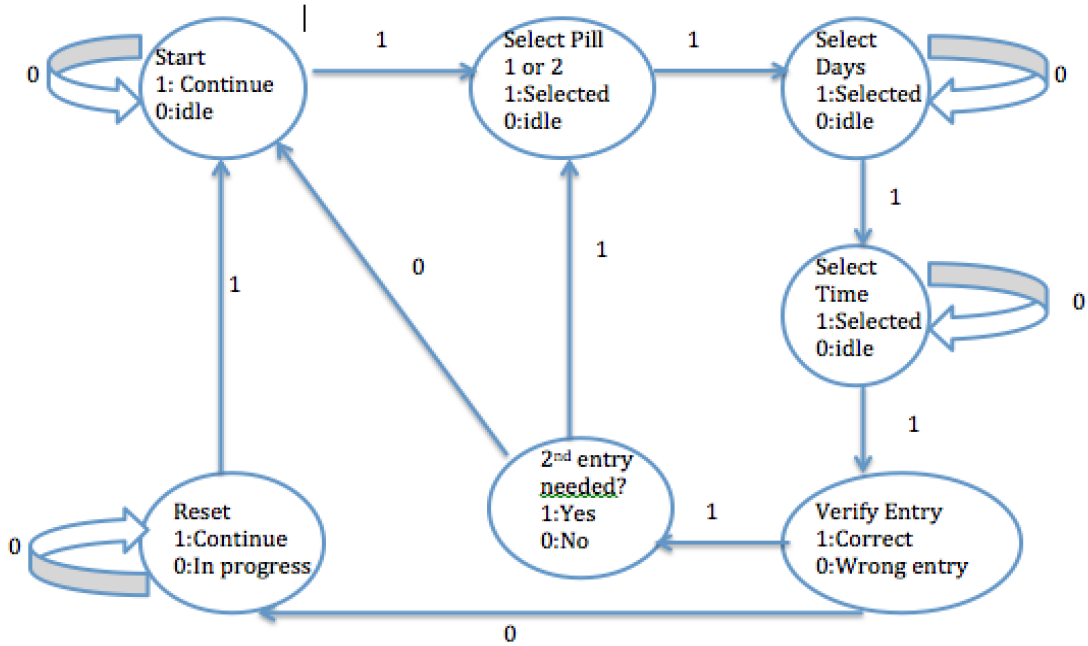
| Requirements | Verifications |
|---|---|
| 1. Voltage output stays 5+-0.5 V | 1. Oscilloscope measurements taken to verify voltage is between 4.5 V and 5.5 V. |

### 2.2.4. Microcontroller

A microcontroller (MCU) is necessary for our circuit to function, for we have multiple control input and output peripherals. This MCU will have to accept the user's designated medication time while properly keeping track of the current time. That way, the controller can then control the motors to dispense the pills while sensing whether one came out. We will be using the ATmega328P MCU to control our board. This microcontroller operates around the 5 V level and has a CPU which runs at 16 MHz.

**Table 4:** Microcontroller Requirements and Planned Verifications

| Requirements | Verifications |
|---|---|
| Operating Voltage: 1.8 - 5.5V<br>Temperature: -40C - 85C | 1. Verifying Voltage Regulator should ensure incoming Microcontroller Voltage |




**FSM 1:** Microcontroller Pill Selection

Microcontroller starts when the Vcc Voltage applied to it. It asks user to select the pill type of 2 possible. User presses enter for pill type 1, or presses right and then enter to select pill type 2. Then after user hits enter it asks user to select what days of the week should it dispense pill. User selects days by moving right and left, whether to select a day by moving up or down on selected day and enter to go to the next state. Then user selects time. After time is set the LCD shows to "save settings", user selects yes/no to verify the selections. If it needs to reset

then microcontroller enters reset state and start the whole cycle again. If user selects yes to save settings then user chooses to set up 2nd pill. If user needs to take another pill then user referred to select pill state. Otherwise the selection steps are over and it enters into idle state. Further steps with all parts integrated can be found in pseudocode.

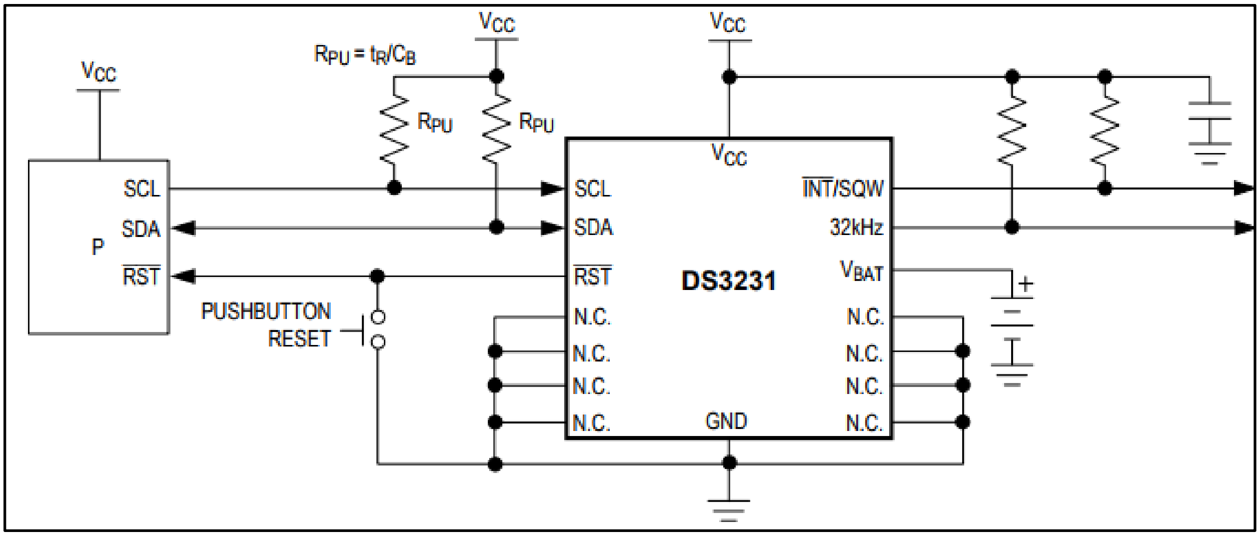



**Figure 5:** Real Time Clock Circuit [6]

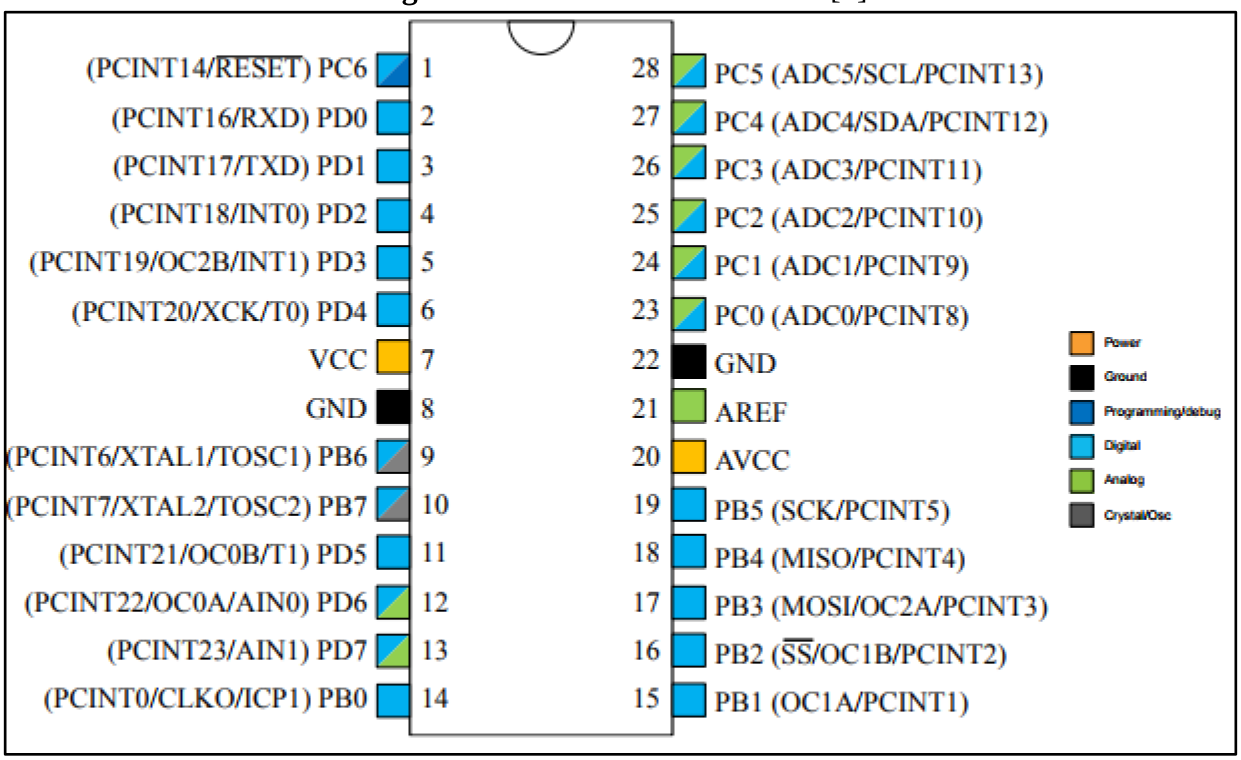



**Figure 5:** Microcontroller Pinout [7]

### 2.2.5. Sensors

These sensors will work in tandem with the microcontroller to sense the proper dispensing of the pills; meaning, only the desired number of pills are administered. We will be using IR break-beam sensors. This will allow detection of whether or not a pill has passed through the sorting mechanism. The response time is less than 2 ms so these are able to take in data fast enough to be able to detect if more than one pill has been passed through with the intended dosage.

Our IR sensor consist of transmitter and receiver. The transmitter have two terminals: Vcc and Ground which will be appended to the Vcc and Ground on the microcontroller. The IR receiver also has Vcc, Ground, as well as Out terminal which needs to be appended to Vcc. The IR required Vcc and microcontroller Vcc are both 5 V so they are compatible.

**Table 5:** Sensors Requirements and Planned Verifications

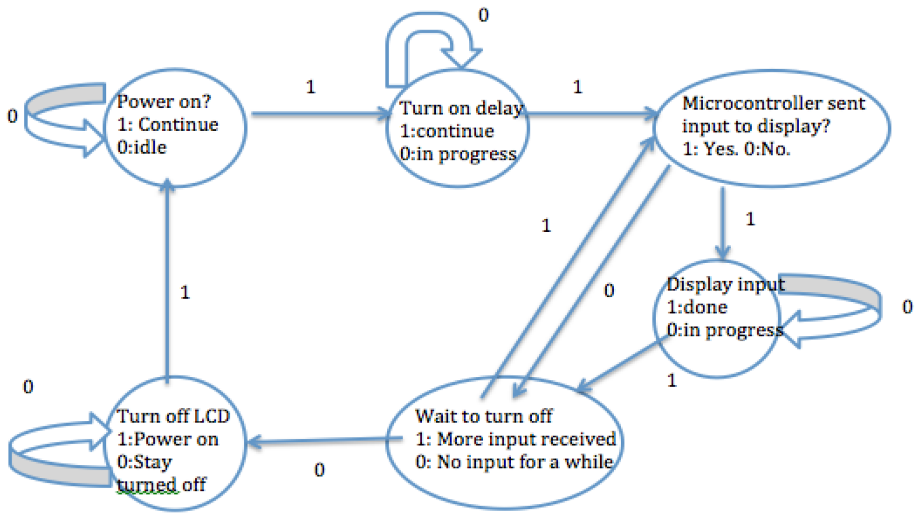
| Requirements | Verifications |
|---|---|
| 1. Sensors turn on between 4.5 V and 5.5 V<br>2. Sensors send signal out when beam is broken<br>3. Broken beam signals are distinguishable | 1. Voltage applied to sensors measured with multimeter<br>2. Sensor output signal measured with multimeter<br>3. Successive output signals shown and measured with oscilloscope |

## 2.2.6. LCD

The LCD chosen can display two 8-character lines. This was chosen so that the user can see which of the three tubes they are setting a time for on the top line with the second line showing the desired days to have the medicine dispensed. After the days are selected, the top line will remain the same while the second line will show the time for the medicine to be dispensed so that the user can set it. With pressing appropriate buttons microcontroller should be able to change state as per its FSM and feed the signals into the LCD inputs, and LCD should be able to display the changes. We have Vss and Vcd on LCD go into GND and Vcc on Transformer and LCD pins Enable, R/W, DB0:7 pins to Read/Write information from/into Microcontroller. The figure 6 shows all of the LCD pins. Figure 7 has more detailed LCD to Microcontroller Interface.

**Table 6:** LCD Requirements and Planned Verifications

| Requirements | Verifications |
|---|---|
| 1. LCD turns on with voltage between 4.5 V and 5.5 V<br>2. LCD displays text input from microcontroller | 1. Voltage applied to LCD measured with multimeter<br>2. Test text input is shown |




**FSM 2:** LCD

Once LCD receives Vcc it turns on and waits for any input to display. Once it receives input stream from microcontroller it outputs appropriate symbols. This happens everytime we touch a button. For example if we touch right button it moves the highlighter one cell to the right. If user presses the enter button then it clears the screen and displays new bitstream. Once it has been idle for a while without receiving any input it turns off.

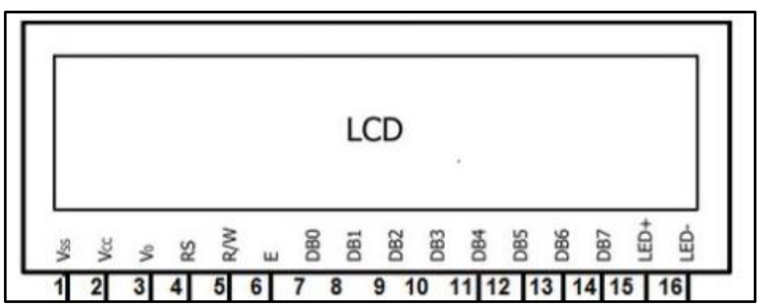



**Figure 6:** LCD Pinout

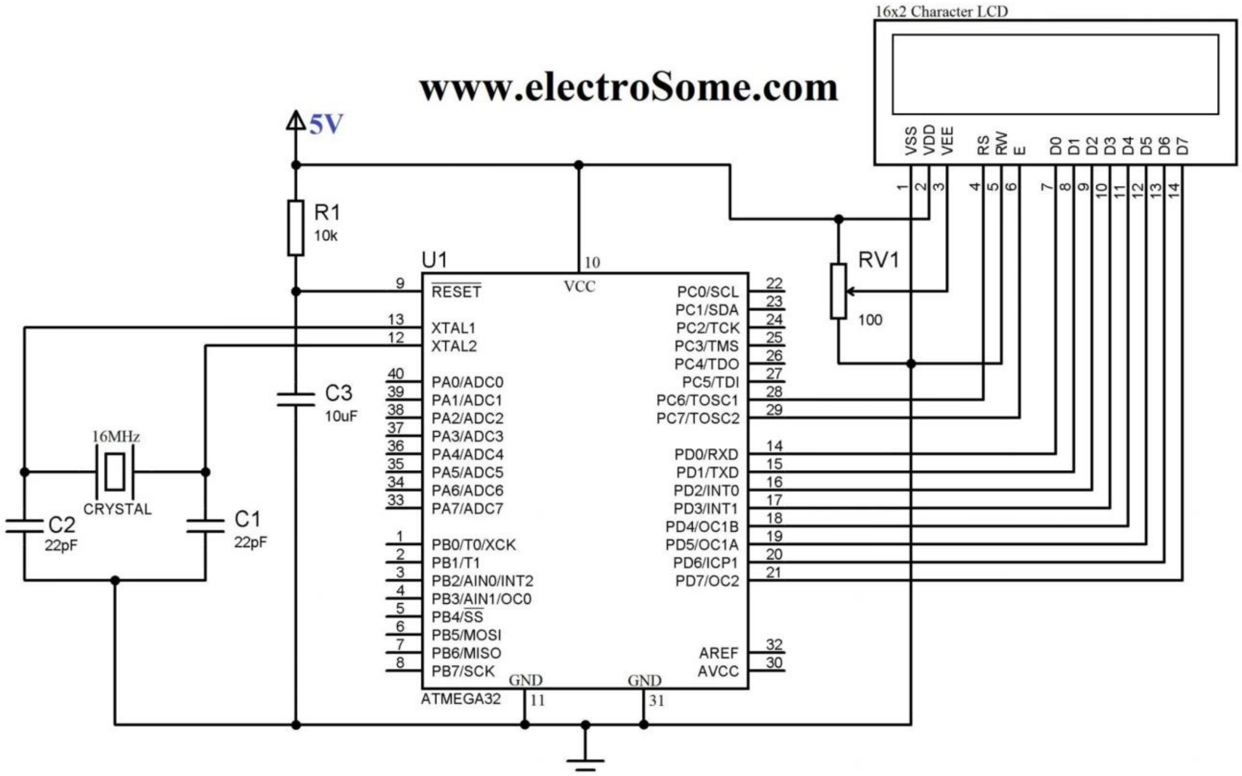



Figure 7: LCD to Microcontroller Interface [3]

### 2.2.7. Buttons

These buttons will allow the user to enter information. There will be four directional buttons and an enter button. Allowing the user to fully program the machine without any need for a computer. The user will select their schedule by first navigating and then clicking enter button into the corresponding parameters which are described in 2.2.4 and 2.2.10. The navigation is pretty intuitive for all age groups since it is used in many other common appliances such as TV remote.

**Table 7:** Button Requirements and Planned Verifications

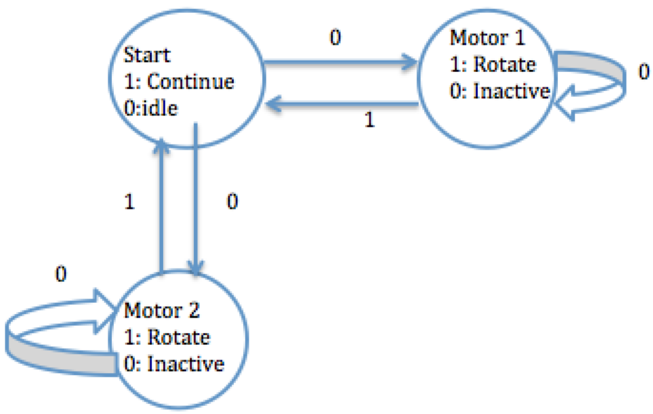
| Requirements | Verifications |
|---|---|
| 1. Buttons are on with voltage between 4.5 V and 5.5 V<br>2. Buttons send signal out when pressed | 1. Voltage applied to buttons measured with multimeter<br>2. Buttons output signal measured with multimeter |

### 2.2.8. Dispensing Motors

We will be using compact stepper motors to precisely turn the pill dispensing tumbler. The motors will have 64 steps per revolution allowing for precise rotation of the two discs so that the correct dosage of medication is dispensed. The motors will be powered by their own voltage regulator out of the power supply and will accept incoming commands from the software through the microcontroller.

**Table 8:** Motor Requirements and Planned Verifications

| Requirements | Verifications |
|---|---|
| 1. Proper dosage dispensing<br>2. Has 64 steps per revolution | 1. Multiple different sized pills placed into dispenser<br>2. Will be counted with controlled input signals. |




**FSM 3:** Motor

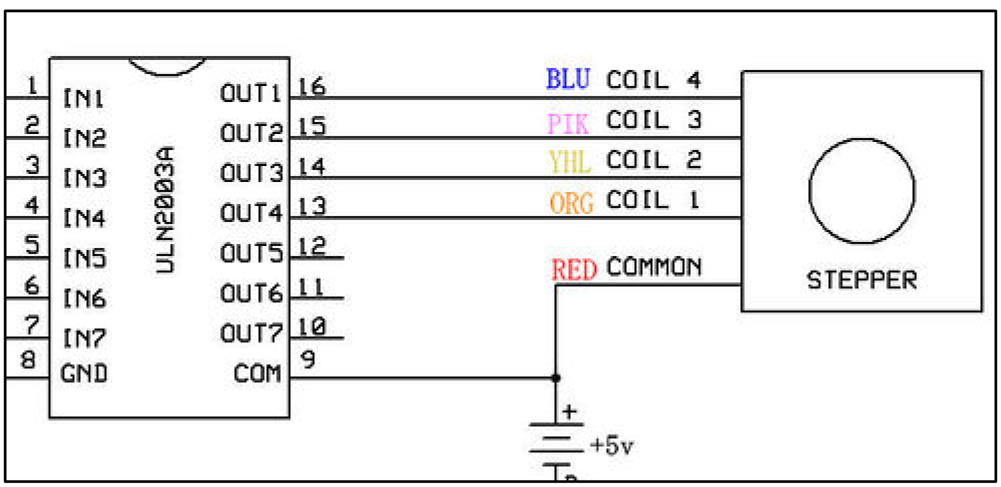



**Figure 7:** Stepper Motor Connections and Pinout

### 2.2.9. Alerting Components (Audio/Visual)

An LED light and a small speaker will be used to alert the user when to take their medication. The light will flash and the speaker will emit a sound starting at the time the medication is dispensed and ending after 15 seconds. These will be powered through the microcontroller and will be turned on and off as told by the software through commands sent from the microcontroller.

**Table 9:** Alerting Component Requirements and Planned Verifications

| Requirements | Verifications |
|---|---|
| 1. LED turns on between 4.5 V and 5.5 V<br>2. Speaker turns on between 4.5 V and 5.5 V<br>3. Speaker emits sound when turned on | 1. Voltage applied to LED measured with multimeter<br>2. Voltage applied to speaker measured with multimeter<br>3. Sound is audible to human ear must be at least 30 dB |

**Table 10:** Parts List and Cost

| | Name | Details | Manufacturer/ Distributor | Part Number | Datasheet | Link | | Market | Price Per Unit | Quantity | Total Price |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Transformer | 120/240/480 to 24 V transformer | Mars Motors and Armitures | 50354 - 40Va | datasheet | purchase | | Amazon | 14.97 | 1.00 | 14.97 |
| 2 | 6800uF capacitor | 16V 6800uF | NTE electronics | VHT6800M16 | datasheet | purchase | | Amazon | 3.44 | 2.00 | 6.88 |
| 3 | 100nF capacitor | 100V .1uF | NTE electronics | CML104M50 | Datasheet | purchase | | NTE parts diect | 0.31 | 2.00 | 0.62 |
| 4 | 1uF capacitor | 100V 1uF | NTE electronics | NPR1M100 | datasheet | purchase | | Newark | 0.22 | 2.00 | 0.44 |
| 5 | Voltage Regulator | 5V Output | Bestsupplier | L7805 | Datasheet | | | Amazon | 0.30 | 2.00 | 0.60 |
| 6 | Full wave bridge rectifier | 200V and 50A max | NTE Electronics | NTE53016 | datasheet | purchase | | Amazon | 5.35 | 1.00 | 5.35 |
| 7 | Microcontroller | 8-Bit with Flash Memory | Atmel | ATmega328-PU | datasheet | | | Amazon | 4.83 | 1.00 | 4.83 |
| 8 | IR Break Beam Sensor | 3mm LEDS | Adafruit | 2167 | Datasheet | | | Amazon | 3.99 | 3.00 | 11.97 |
| 9 | Ocsillator | 16 MHz | Uxcell | HC-49S | datasheet | | | Amazon | 0.50 | 1.00 | 0.50 |
| 10 | 22 pF Cap | 50 V, 22 pF | Uxcell | | | | | Amazon | 0.11 | 2.00 | 0.22 |
| 11 | LCD | 20x4 | RioRand | | Datasheet | | | Amazon | 7.99 | 1.00 | 7.99 |
| 12 | Buttons | Tactile Push Button | Uctronics | B3F-4055 | datasheet | | | Amazon | 0.17 | 5.00 | 0.85 |
| 13 | Stepper Motor | DC 5 V | Uxcell | 28BYJ-48 | datasheet | | | Amazon | 3.31 | 3.00 | 9.93 |
| 14 | Motor Drive Board | Inverter driver | Uxcell | ULN2003 | datasheet | | | Amazon | 3.31 | 3.00 | 9.93 |
| 15 | Buzzer | 12 mm, 5 V | Uxcell | ux | none | purchase | | Sparkfun | 1.95 | 1.00 | 1.95 |
| 16 | Transistor | 200mA 40V | Digikey | 2N3904 | Datasheet | purchase | | Digikey | 0.40 | 1.00 | 0.40 |
| 17 | Resistor | 500 ohm | | | datasheet | purchase | | Digikey | 0.88 | 1.00 | 0.88 |
| 18 | LED | 3-6V Red LED | | | none | purchase | | Amazon | 1.00 | 7.09 | 7.09 |
| | | | | | | | | | Project Total Price | | 85.40 |

### 2.2.10 Pseudocode

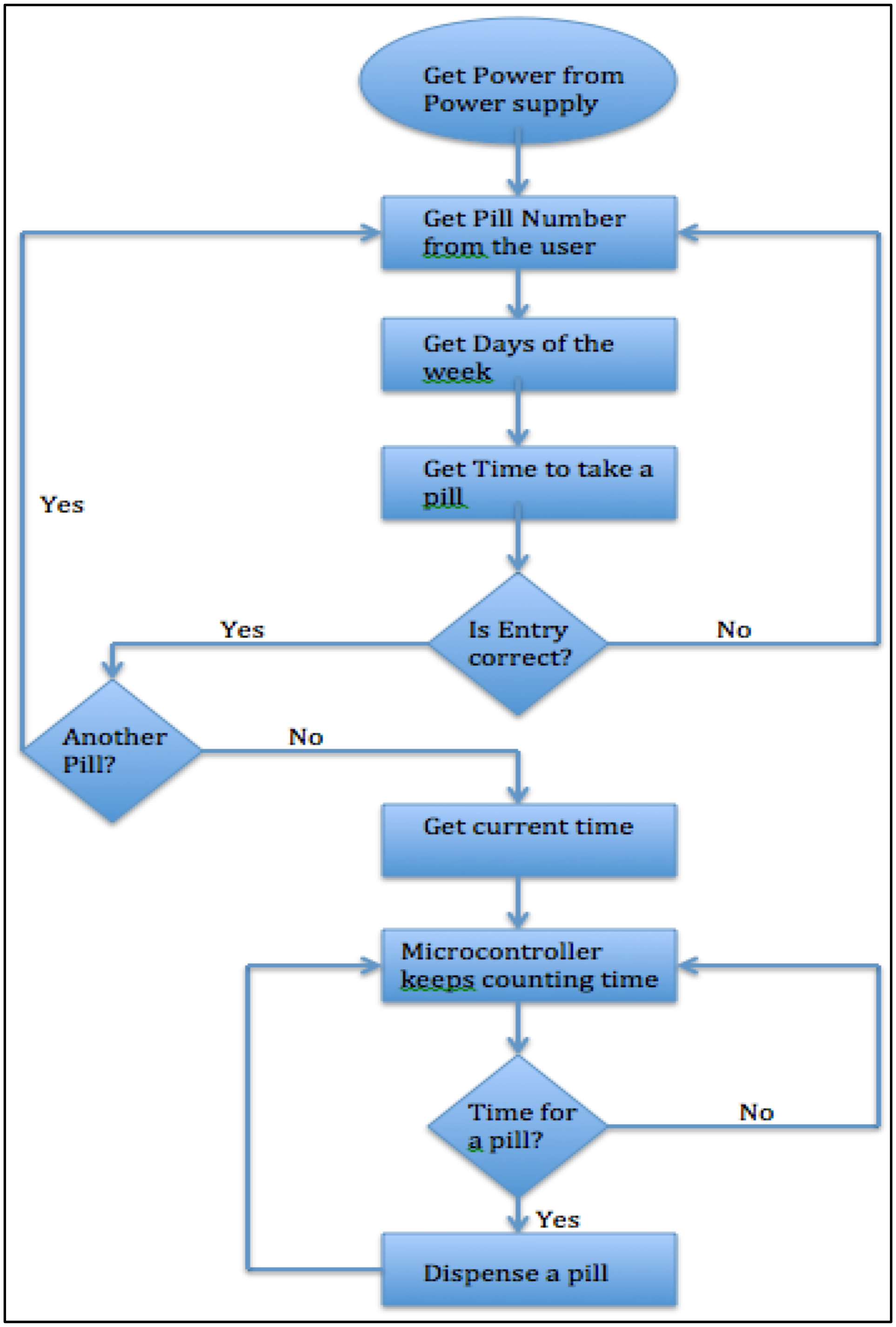



**Figure 8:** Microcontroller Pseudocode

## 2.3. Physical Design

Our device will use precisely controlled motors to spin a hopper. When desired, the pills will trickle down into a common tube and out to the medication cup. Figures 9 and 10 show a digital rendering of our projected final design. The two cylinders on top are where the user will pour their pill bottles into. The power supply, sorting mechanisms, microcontroller, break beam sensors, and motors will all be hidden from the user's line of sight within the enclosure. The LCD screen is on the left and buttons will be on the right of the enclosure. The pills will be available for the user to grab from the hole in the middle of the machine.

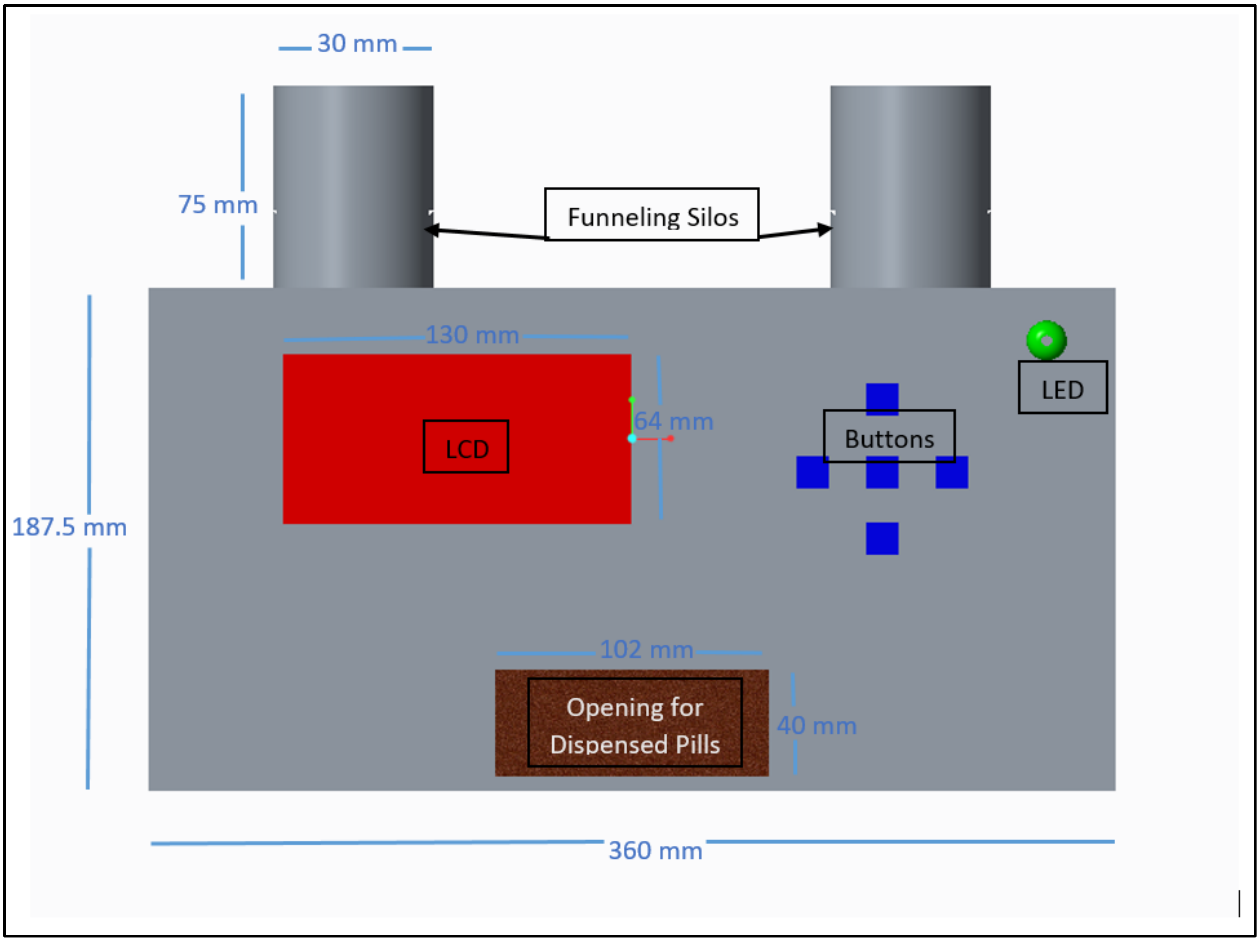



**Figure 9:** Front View of Physical Design

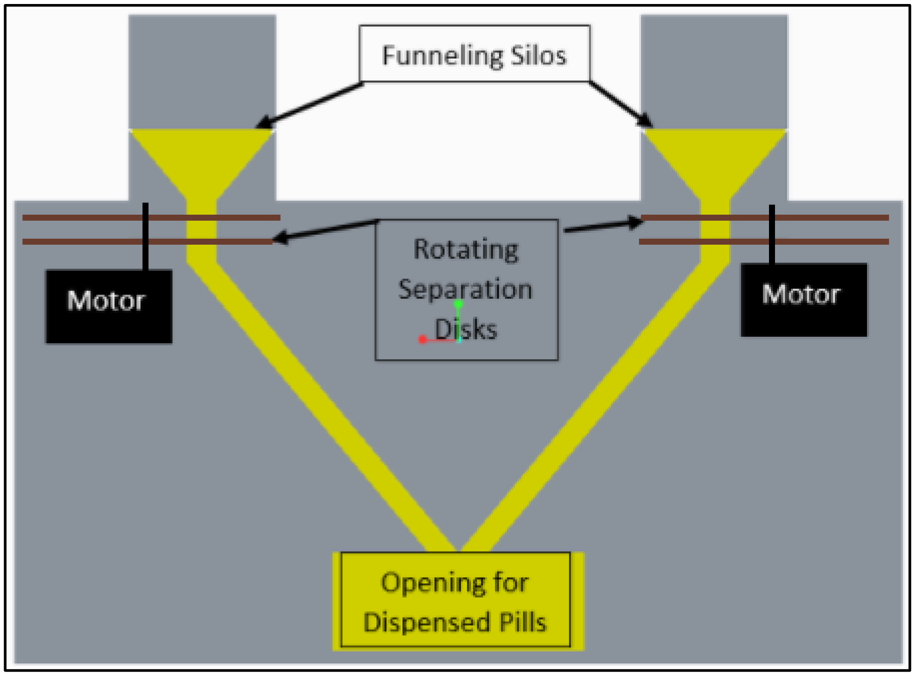



**Figure 10:** Cutaway View of Physical Design

## 2.4. Safety and Risk Analysis

The main concern we have while thinking about and designing this circuit is the improper dispensing of medication by the machine. We must assure that only the proper dosage will be administered. Additionally, we assure that our machine will alert and dispense the medication at the correct time. Currently, we have one faux pas; we cannot assure who takes the medication. In our design, we only have one user.

When building a circuit to be in the center of someone's home, one needs to make sure the circuit is safe and stable. A faulty circuit risks starting on fire. We must ensure that our circuit and housing come together to create a reliably safe device.

The two components that pose the greatest risk to successful completion of the project are the microcontroller and the software. These two things pose the greatest risk because they are the pieces that we as a group have the least familiarity with. The proper selection of a microcontroller that can perform the tasks we need is a crucial and time heavy task. As a group of electrical engineering majors, the software provides another obstacle similar to those that we have faced in previous computer engineering focused classes.

## 2.5. Tolerance Stack Analysis

One of the most critical components of our design is to ensure that only one pill is sliding at a time. To do that we implement two stage check by having motor rotate two disks with apertures (of diameter of the size of one pill) which are out of phase with each other (meaning when one is open the other is closed and vise versa). Between the apertures we have a very thin container that can hold only 1 pill at a time. Initially all the pills are above the upper disk. When time to take a pill reaches, the upper disk's aperture opens and lower aperture is closed. 1 pill falls into the thin container. Once the pill has fallen into the container it obstructs our IR transmitter, and IR receiver receives no signal. Then IR receiver sends that signal to the controller which makes our motor to run disks again. The upper aperture closes to make sure no other pill falls and the lower aperture opens so that the pill is dispensed to the customer.

We need to make sure that pill fully obstructs our IR signal. To do so we need:

- To install our IR transmitter and receiver within 10 deg max out of phase. This translates into 10deg * 3mm / 180deg = 0.17 mm. So width or height of the edge of Receiver shouldn't deviate more than 0.17mm from the width or height of the transmitter.
- We intentionally select our IR sensor with smaller diameter to allow for larger range of pill sizes. Our diameter is 3mm. So the pill needs to be at least 3mm in all 3 dimensions to effectively obstruct our IR sensor.
- Our container needs to have dimensions, height: minimum = pill height, maximum = 1.5pill height - disk thickness. Our maximum value is due to the fact that we need 2nd pill that might get attached to be wiped by our upper disk. Width: minimum = pill width, maximum = pill width + pill(minimum dimension). The width maximum is because our 2nd pill shouldn't vertically get attached. Our length uses similar formulas to our width.

Ensuring above requirements minimizes our chances of accidental 2nd pill getting stuck in container. If we decide to completely eliminate the possibility of 2nd pill stuck in our container we would need to significantly complicate our design which would make it out of scope of a semester project. Ideally we would need to make our discs asynchronous to ensure that no second pill would fall into the container before 1st pill dispensed. But with our design the user should never get more than one pill.

# 3. Cost and Schedule

## 3.1. Cost

Our projected cost for parts is $95.40. We came to this number by finding sources for all of the electrical parts and components we will be buying. The itemized list can be seen above in Table 10. Our projected labor cost is $13,500. We have allotted 180 hours at a rate of $30 per hour which translates to a salary of $62,400. The total labor cost is calculated with the following equation:

□□□□□ □□□□□ □□□□ = □□□□□□ □□□□ ∗ *2.5* ∗ □□□□□ □□□□□□ {1}

The total project cost is the summation of parts and labor. This comes out to $13585.40. Itemized Costs list can be found in Table 10.

## 3.2. Schedule

Table 11 lays out the individual responsibilities of each team member for each week. This will be used to drive successful and on-time completion of tasks. Priorities have been given to long lead time aspects of the project and to items that will hold up to the rest of the project until they are finished. In addition to this table, there is a google calendar that holds all important dates and deadlines.

**Table 11:** Schedule and Individual Responsibilities

| | **Project Goals** | **Matt C.** | **Iskandar A.** |
|---|---|---|---|
| **9/10 - 9/16** | Obtain Approval | Project Approval | |
| **9/17 - 9/23** | Have Idea of Parts | Brainstorm Project Parts | |
| **9/24 - 9/30** | Completed Parts Lists | Research Individual Components | |
| **10/1 - 10/7** | Parts Purchased and Delivered | | |
| **10/8 - 10/14** | Recalibration After Losing Partner and Rescoping Project | | |
| **10/15 - 10/21** | Parts Tested and Validated | Order Parts, Full Create Circuit Schematic | Familiarize with microcontroller; write FSMs for LCD, sensors, and motors; and write pseudocode |

| | | | |
|---|---|---|---|
| | | | for microcontroller |
| **10/22 - 10/28** | Hardware Build Completed | Test Individual Circuit Components to Verify that they are within tolerance | Complete programming for motors and sensors |
| **10/29 - 11/4** | Software Build Started | Build circuit bringing together all individual components and verifying that they are sending correct signals | Complete programming for LED, Buttons, and LCD |
| **11/5 - 11/11** | Software Debugging Completed | Build housing: silos, dispensing tooling, full enclosure, mounting for circuitry | Complete programming if needed for power supply and Merge software modules |
| **11/12 - 11/18** | Software Merged with Hardware | Troubleshoot any problems with hardware-software communication | Debug and software-hardware communication problems |
| **11/19 - 11/25 (Break)** | Mock Demo Preparations | Prep project for demo, work on any needed documentation with regards to software and microcontroller | Prep project for demo, work on any needed documentation with regards to software and microcontroller |
| **11/26 - 12/2** | Mock Demo Bugs Fixed and Final Paper Underway | Begin work on final paper and final presentation with regards to hardware components | Begin work on final paper and final presentation with regards to software and microcontroller |
| **12/3 - 12/9** | Mock Demo Bugs Fixed and All Design Documents Finalized | Complete all work for final documentation with regards to hardware components | Complete all documentation with regards to software and microcontroller |
| **12/10 - 12/16** | Project Completed | Presentation, Final Paper, Lab Checkout, and Lab Notebook Due | |

# 4. Ethics and Safety

The potential costs of delivering incorrect doses or medications from the dispenser are extremely high. It would not be outlandish for this error to result in a hospital visit or death. Therefore, we take responsibility in “in making decisions consistent with the safety, health, and welfare of the public” [4] as per IEEE Code of Ethics, #1. With the correct automation and double checking, these mistakes could be avoided with our system. As spoken about above, if used correctly this product takes 30 potential opportunities for error each month and shrinks it into one step. Also, our multi layer design of power supply is a standard practice intended to minimize any chance of fire hazards [5].

When making design decisions we take responsibility into making our design implementation of all components and peripherals user-friendly for different demographics of users, as per requirements of the IEEE Code of Ethics, #5: “To improve the understanding of technology; its appropriate application, and potential consequences” [4]. While there is more importance put on the programming of the machine, it is much easier for a parent, guardian, or caretaker to set aside the proper amount of time once to set the correct dosage and timing information than it is for them to set daily reminders to set up, count out, and provide medication to the patient. As a whole, the proper use of this system does not cross any IEEE and/or ACM ethics codes as its intended use will streamline the lives of those taking multiple medications each day.

When we first took on this project we researched many previous attempts at delivering a similar item. What will set us apart from the others is our project’s ability to take in full bottles of pills without manual sorting. The other projects have been closer to alarmed safety boxes than automated pill dispenser. This is because they still require the user to manually sort the days pills into a silo; so each silo is only good for one day. Then the machine rotates or makes the pills available to the user at the right time and alerts the user in some fashion. This does not reduce the risk for error and is no better than using a plastic monthly sorter in combination with a cell phone alarm or alarm clock. While our project has a similar goal to these others, there is a large improvement in user interface, simplicity, and error minimization that only comes with ours.

High importance has been set for the handling of all electrical components that will be included in our design. We have sourced from reputable businesses, clearly defined the parameters we need each part to meet, verified through testing that our requirements have been met, set up failure detection for the dispensers, and will verify that all components are functioning as intended. Performing our due diligence to ensure that parts are not damaged, are within tolerance, and working together will ensure the delivery of a quality product.

# References


[1] R. Harris, "Federal Survey Finds 119 Million Americans Use Prescription Drugs", *NPR.org*, 2017. [Online]. Available: http://www.npr.org/2016/09/08/493157917/federal-survey-finds-119-million-americans-use-prescription-drugs. [Accessed: 22- Sep- 2017].

[2] "Retail Prescription Drugs Filled at Pharmacies (Annual per Capita by Age)", *The Henry J. Kaiser Family Foundation*, 2017. [Online]. Available: http://www.kff.org/other/state-indicator/retail-rx-drugs-by-age/?activeTab=map&currentTimeframe=. [Accessed: 22- Sep- 2017].

[3] Ligo, George. "Interfacing LCD with Atmega32 Microcontroller Using Atmel Studio." ElectroSome, 20 May 2013, electrosome.com/interfacing-lcd-atmega32-microcontroller-atmel-studio/.

[4] Ieee.org, "IEEE IEEE Code of Ethics", 2016. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 02-Oct-2017].

[5] Bob Mammano and Lal Bahra, "Safety Considerations in Power Supply Design," TI Literature No. SLUP227. Available: https://www.ieee.li/pdf/essay/safety_considerations_in_power_supply_design.pdf. [Accessed: 02-Oct-2017].

[6] Maxim Integrated, "Extremely Accurate I2C-Integrated RTC/TXCO/Crystal," DS3231 datasheet, October 2015 [Revised March 2016].

[7] Atmel, "8-bit AVR Microcontrollers," ATmega328/P datasheet, November 2016.