CAPSULE CORP

Dr. Andrew Rawicz
School of Engineering Science
8888 University Drive
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440, Design Specification for a medical dispensary and reminder device

Dear Dr. Rawicz

The attached document is the Design Specification for the for the PillPal medical dispenser. The following document highlights and justifies the implementation of all priority one functions listed in the Functional Specification document. Our design targets the senior audience, who often are required to adhere to complex medical regimens, and is primarily intended for a home environment. The goal is have the PillPal become a common product in all homes and to be used by patients of all ages.

The Design Specification shall demonstrate the low level design of the PillPal medical dispenser. An in depth analysis explains and justifies our choice in component selection and implementation techniques. To thoroughly justify our design, the specifications are divided into hardware and software implementation. The hardware section will explain the overall design and integration of each module followed by an in depth analysis of each component. By doing so, the reasoning for each component is defined and justified. Similarly, the Software section is explained thoroughly by breaking down the code into different modules. Each module will explain and demonstrate the necessary functions required for the PillPal to function as a coherent and safe medical dispenser.

Our diverse team of 4 senior computing and electronics engineers are dedicated to the development of this device. Please feel free to contact us at *igl@sfu.ca* or *440-cc@sfu.ca* with questions or comments regarding our enclosed documentation or our product.

Sincerely,

Izaak Lee
CEO
Capsule Corp

Design Specification for PillPal

Medical Dispenser

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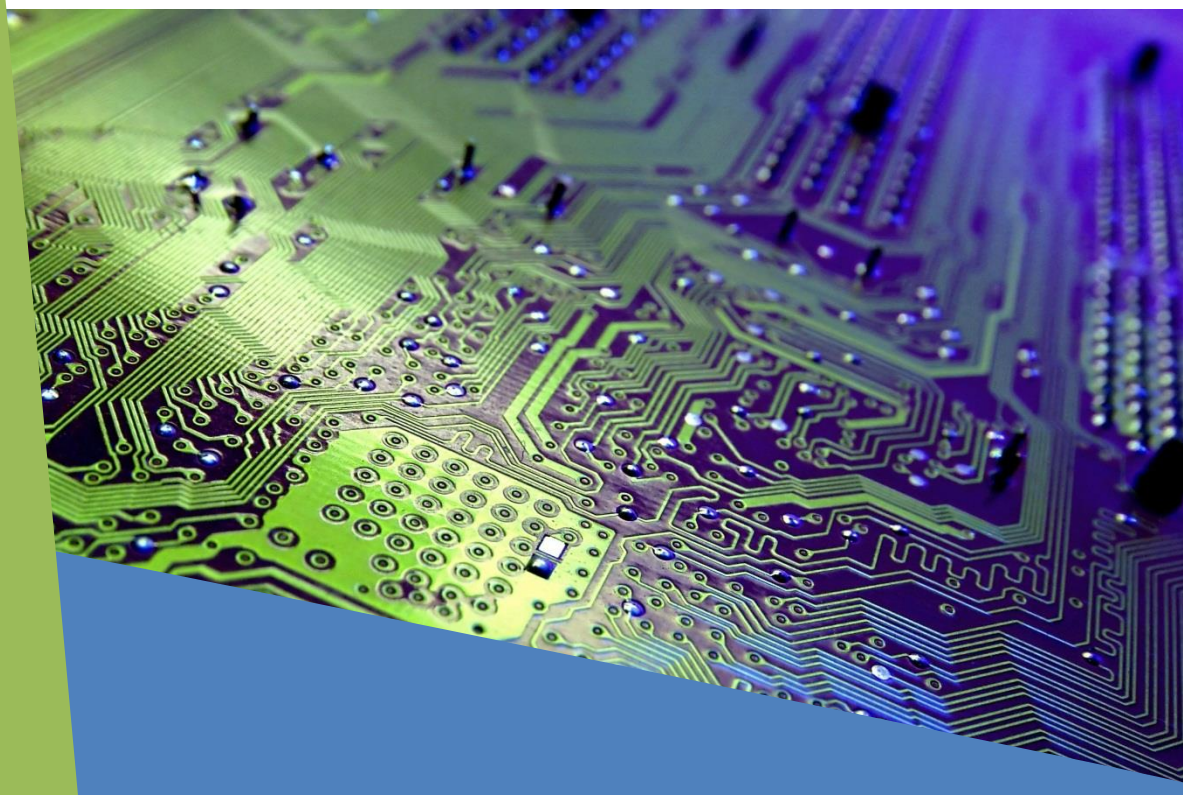
March 14, 2013

Revision 1.0



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Executive Summary

In this day and age, it has become a common routine for many to take pills or tablets for various reasons. Many will take pills to boost immune systems and some will require pills in a fight against diseases. Whatever it may be, Capsule Corp is determined to create and design a product which will adhere to various pill regimens. The design specifications of this document provides an in depth analysis on the PillPal's design. We first begin with a high level overview of the actual system. Then we will break it down into its individual modules. The section after the individual modules discuss more detail about each individual component and hardware chosen and their related design decisions.

The designs presented in this document focus mainly on completing the requirements to create a proof-of-concept with core functionality as outlined as priority 1 in the functional specifications. As such, some design concepts may be subject to change for the prototype and production models depending on further testing and User Acceptance Tests.

To assist everyday medication consumers, the PillPal is designed to provide autonomous pill dispensing, scheduling and notifying. The pill dispenser is a mechanical device with an intuitive GUI for users to customize personalized schedules and remind settings. Thus, this document will highlight on the following designs:

Hardware:

- Label Reader: The mechanical mechanism which rotates pill bottles as a camera captures images. The image is captured with a webcam through a Raspberry Pi which controls an Arduino microcontroller.
- Pill Allocator: The electrical DC motor that selects the correct container by rotating the pill containers to store the pills. The motors are controlled via the Arduino microcontroller which follows the commands provided by the Raspberry Pi.
- Pill Dispenser: The linear motor is capable of picking up individual pills and dispensing them into the correct bin given user inputs. The technique of picking up pills is done through a vacuum. The Arduino is responsible for switching a relay to power the vacuum.

Software:

- GUI: An interactive touch screen display allowing users to customize their scheduling and emergency contacts. It also allows users to manually select settings such as WiFi, brightness, and alarms.
- Arduino: The microcontroller which governs the movement of all motors. It is also responsible for reading inputs from sensors to ensure all items are aligned and medication is dispensed.

This document will further elaborate on the functional specifications and provides justification to our method of choice.

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Glossary of Terms

ADC - Analog to Digital Converter
ARM -Acorn RISC Machine (Now referred to as ARM)
ATX - Advanced Technology eXtended
BJT - Bipolar Junction Transistor
C-MOS - Complementary Metal Oxide Semiconductor
DC - Direct Current
DIP - Dual Inline Package
DSP - Digital Signal Processing
EEPROM - Electrically Erasable Programmable Read-Only Memory
EMF - Electro-Magnetic Field
FET - Field effect Transistor
FPS - Frames Per Second
GPU - Graphic Processing Unit
GUI - Graphic User Interface
HD - High Definition
HDMI - High Definition Multimedia Interface
HP - Hewlett Packard
I/O - Input/Output
IC - Integrated Circuit
J-FET - Junction gate Field Effect Transistor
JPEG - Joint Photographic Experts Group
LCD - Liquid Crystal Display
LED - Light Emitted Diode
LED - Light Emitting Diode
Li-ion - Lithium ion
LK (register clock), and the SER
LVDS - Low-voltage differential signaling
MCU - Microcontroller Unit
MP - Megapixels
NC - Normally Closed
NO - Normally Open
OC - outer diameter of gear bore if flanged
OCR - Optical Character Recognition
OD - Outer diameter of the whole gear
Op-Amp - Operational Amplifier
PC - Personal Computer
PD - Pitch diameter of the gear
PWM - Pulse Width Modulation
RAM - Random Access Memory
RGB - Red, Green, Blue
RISC - Reduced Instruction set Computing
SATA - Serial ATA
SMTP - Simple Mail Transfer Protocol
SoC - System on Chip
SPC - Smart pill container

SPI - Serial Peripheral Interface
SRAM - Static Random-Access Memory
SRCLK - Shift Register clock
SSID - Service Set Identifier
TCP - Transmission Control Protocol
TFT - Thin Film Transistor
TTL - Transistor Transistor Logic
UCV - USB Video Class
UK - United Kingdom
UPS - Uninterruptable Power Supply
USART - Universal Synchronous/Asynchronous Receiver/ Transmitter
USB - Universal Serial Bus
V4L - Video4Linux
VAM - Vacuum Arm Manipulator
VDC - Direct Current Voltage
WiFi - Wireless Fidelity (802.11 IEEE standard)
XML - Extensible Markup Language

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1 Introduction

The PillPal is a pill dispensing machine capable of generating schedules for multiple patients, dispense drugs automatically, and have multiple techniques to remind users that it is time for their medication. By using this product, patients are now reminded periodically by the machine through the technology available around them. Reminders such as emails, online calendars, text messages, and phone calls are available through this product. Of course, the simple alarm is still available. The design of the PillPal is divided into the hardware and software sections, this document is written to justify our design choices.

1.1 Scope

Based on the functional specification document, this design specification highlights and details the implementation of functions related to the PillPal. The information provided will justify the design techniques implemented and will further provide detailed information regarding mechanical parts and software interface. It should be noted that the design specification will not fulfill all functions highlighted in the functional specification document.

1.2 Intended Audience

The design specification document is created to guide and provide detailed information for Capsule Corp engineers. This document will detail all components and modules to demonstrate how each feature is implemented.

The document will also highlight the features on each component to further justify our component choices.

2 Hardware Overview

This section shall provide the list of components used and highlight all relevant technical details about each component. Breaking the hardware into modular sections we can describe the project as

1. Label Reader
2. Pill Allocator
3. Pill Dispenser

These individual modules above together work in unity to deliver medications to patients in a safe and timely manner. The goal of the PillPal is to be a device that is as simple and intuitive as possible while performing all the necessary actions flawlessly. As such, the label reader is designed to automatically read and record the medical labels on pill bottles. Utilizing a 12V, 2 phase stepper motor to rotate the pill bottle and a 5.7 megapixel HP camera to capture images the label reader is capable of producing a flat image from a curved surface. The images are stitched together using our own personal code. Once

stitched, PillPal will create a schedule based on the image created. Using optical character recognition (OCR) technology, we can determine and pinpoint key words which will create a schedule for our patients. To do the image processing and scheduling a Raspberry Pi computer is used. The Raspberry Pi is a credit card size computer using an ARM processor. Released last year in the UK, the Raspberry Pi is a low cost**,** powerful computer. Complete with audio and full 1080p HD video outputs, the Raspberry Pi is the heart of our device.

Connected to the Raspberry Pi is a touch screen for user interaction. The stitched image is displayed on a 10.1" touch screen. The Raspberry Pi interfaces with the touch screen using a special connector for the Raspberry Pi designed by Chalk Electronics. The touch screen is connected through the LVDS cable into the LVDS-HDMI assembled converter which outputs HDMI and USB into the Raspberry Pi. The specially designed assembly kit allows us to install the device through plug-n-play method, treating touching the screen as mouse clicks, thus no driver development is required. The screen prompts users to make changes or customize the generated medication schedule. Once the schedule and medications are confirmed, the pills are automatically stored into a designated container designed by Capsule Corps. A total of 8 different pills may be stored in the PillPal, each container sits on an angle to ensure all medications are able to be picked up by the VAM. The size of each container is designed to fit the largest over the counter pill containers available. From research, Capsule Corp understands that largest pill bottles reach up to 60 Drams. [1] The overall system is rotated by a servo motor capable of producing 13kg/cm of torque. The Metal Gear Digital Servo Motor will provide the power and precision required to ensure the correct pills are delivered. To further ensure the correct pills are taken, photomicrosensors are placed to detect container numbers. A series of 4 sensors are used to provide a binary code to the Arduino Uno. The pills are stored until a patient requires the medication.

Once the patients acquire pills, he or she must verify his or her identity using the fingerprint reader. The servo then rotates the designated container to the VAM (Vacuum Arm Manipulator) and the pills are picked out individually by using a DC vacuum. The vacuum arm is operated by a linear motor. The motor moves a hose in a linear motion**,** picking up pills in the container as it enters. Once retracted, the pill is dropped into the dispensing mechanism. The dispensing mechanism is used to ensure that the correct number of pills are dispensed to prevent overdosing and underdosing. The switch for the dispensing mechanism is another simple servo motor which toggles to release the pill. The PillPal is designed to have redundant checks and reminders to ensure the pills are delivered to the correct patients in the most efficient manners.

To further highlight the PillPal design, in depth examination of each module followed by specifications of hardware components are listed below.

2.1 Pill Bottle Label Reader

This section will outline our design choices for the pill bottle reader and will reference sections in this documentation for more detailed look into the components we have chosen. Figure 1 is a CAD drawing of the label reader highlighting the placement of the camera and the dimension of the enclosure.

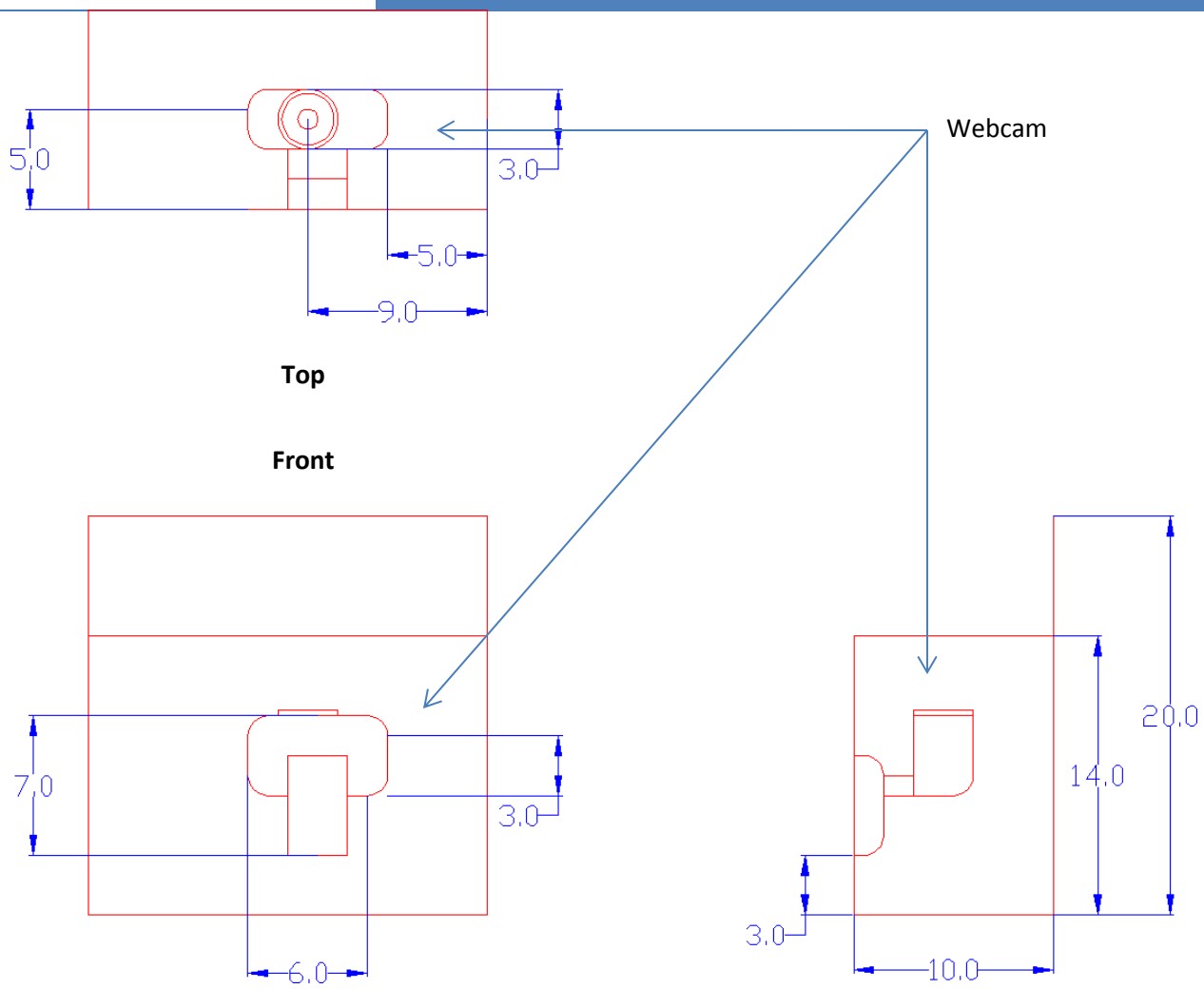


Figure 1 - Orthographic view of label reader design and camera placement

The main function of the bottle label reader is to automate the process of which to read the data from the prescriptions labels themselves. The pill bottle reader is made up of rollers, a motor, gears, and the physical compartment to hold everything together. Figure 2 provides an orthographic view of the bottle rolling module. To rotate the pill bottles, a stepper motor and gears are used.

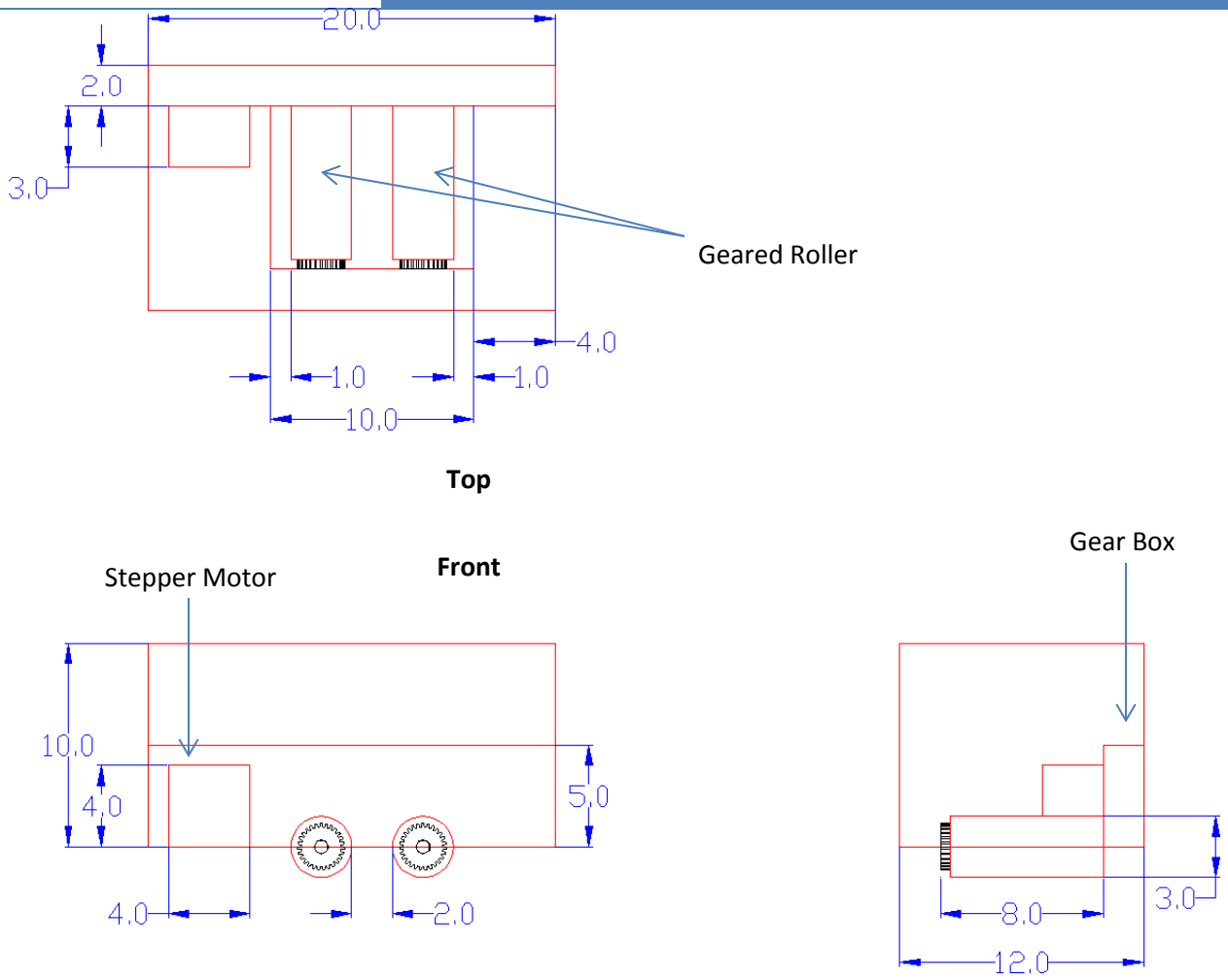


Figure 2 - Orthographic view of label reader pill bottle rotating mechanism

We chose the particular gear ratio with consideration to three constraints.

1) availability and pricing
2) Physical dimensions of the compartment of which it will be placed
3) relative size between the different gears

Due to the physical constraints of our label reader's compartment's design, 4-8 centimeter of space is available to place our gears. We chose to transfer motion via an intermediary gear because of the size constraint of the motor itself and the ability to support a bigger diameter gear based on the dimensions of the enclosure. We chose the simple design of the spur gear type due to the simplicity and the abundant availability of it. For compactness, other designs for gear configuration can be considered to minimize the physical footprint, increase rigidity, and precision.

The rollers are placed 20 mm (0.787402 inches) apart to allow enough room for the camera to capture images but enough to hold the pill bottles back and allow for rotation. Standard pill bottles and vials range from 0.875 inch to 1.8125 inch diameter.

The camera placement is 4 cm below the location of the pill bottle. This location gives us flexibility for adjustable focus as well as sufficient distance for lighting to avoid blooming in our pictures. We will be controlling the motors and with the Arduino Uno and the camera with the Raspberry Pi. For quick prototyping purposes, items will be bread boarded first before spending vast amount of time working and cost with custom designed boards with our microcontrollers. Figure 3 demonstrates the gearing to be used in the proof of concept design.

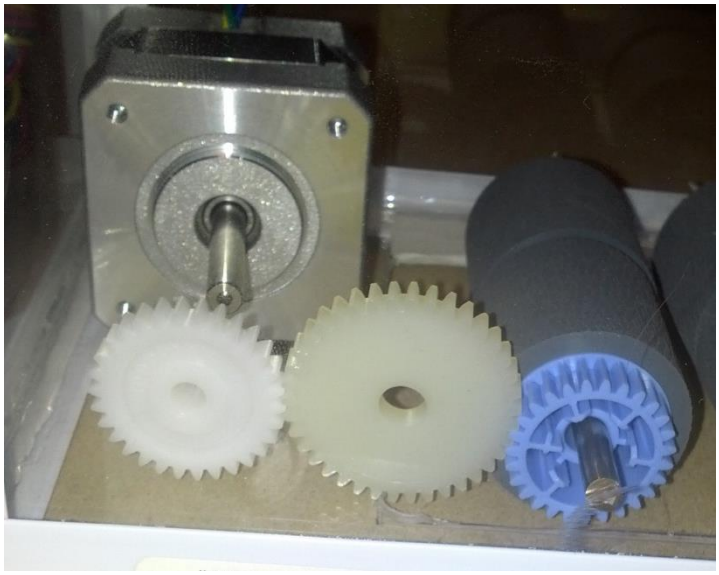


Figure 3 - Label reader pill roller gearing

2.2 Pill Allocator

The pill allocator contains two modules, one is the dispensing arm, we call, and VAM (vacuum arm manipulator) and the other are the storage compartments called the SPC (smart pill container).

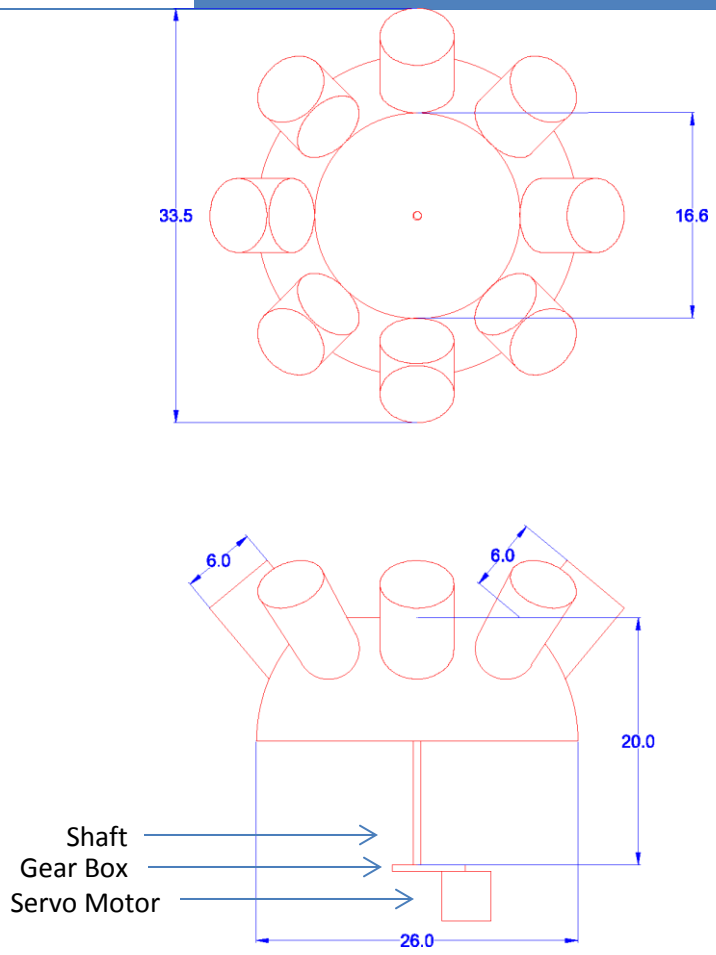


Figure 4 - Top view and side view of the Smart Pill Container (SPC)

The SPC compartments are built from plastic tubes measuring 6cm in height with a diameter of 6cm. These containers are situated on a dome shaped elevation; this designed angle is 30 degrees and is implemented such that the pills will always fall to the lower portion of the SPC. This ensures that pills are not stuck and that the VAM is able to pick pills from the same location every time. Beneath the dome is a 3 ⅛" metal rod connected to the servo motor through a couple of gears. The gears are chosen to allow the servo motor to deliver maximum torque and precision to the SPC. The ratio from the end effect is small due to the low ratio between gears from the servo motor to the metal shaft. Because of the gears, the motor is displaced 26mm away from the metal shaft.

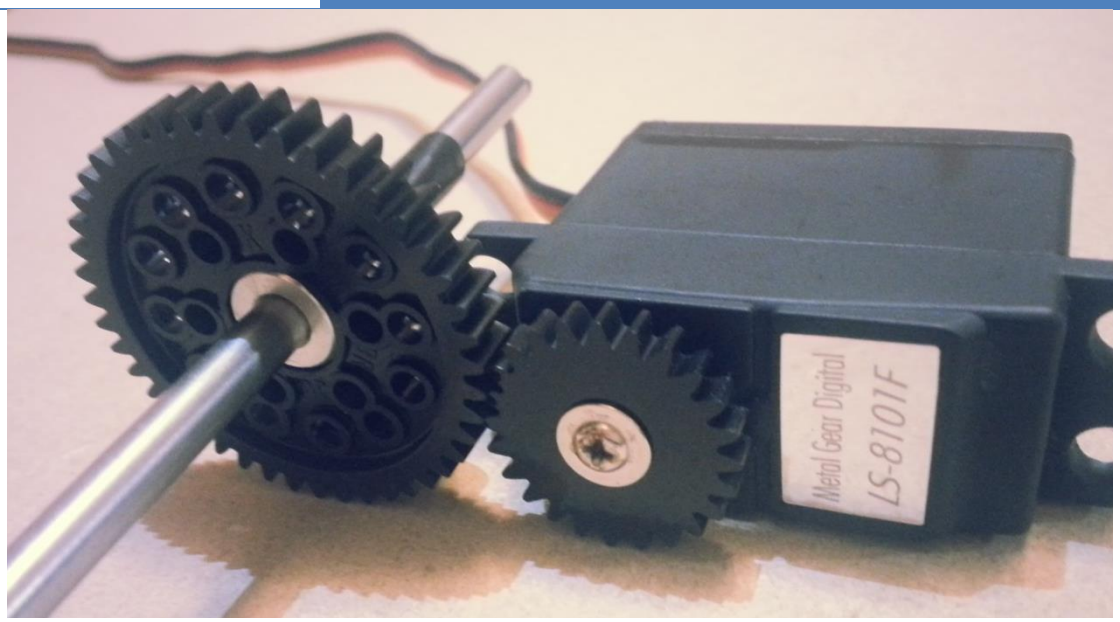


Figure 5 - Servo to main shaft of SPC gearing

To determine the position of each pill container, each container is fitted with sensor tripping wires to trip 4 photomicrosensor. By placing specific number of wires, a binary code is used to determine which container is in line with the VAM.

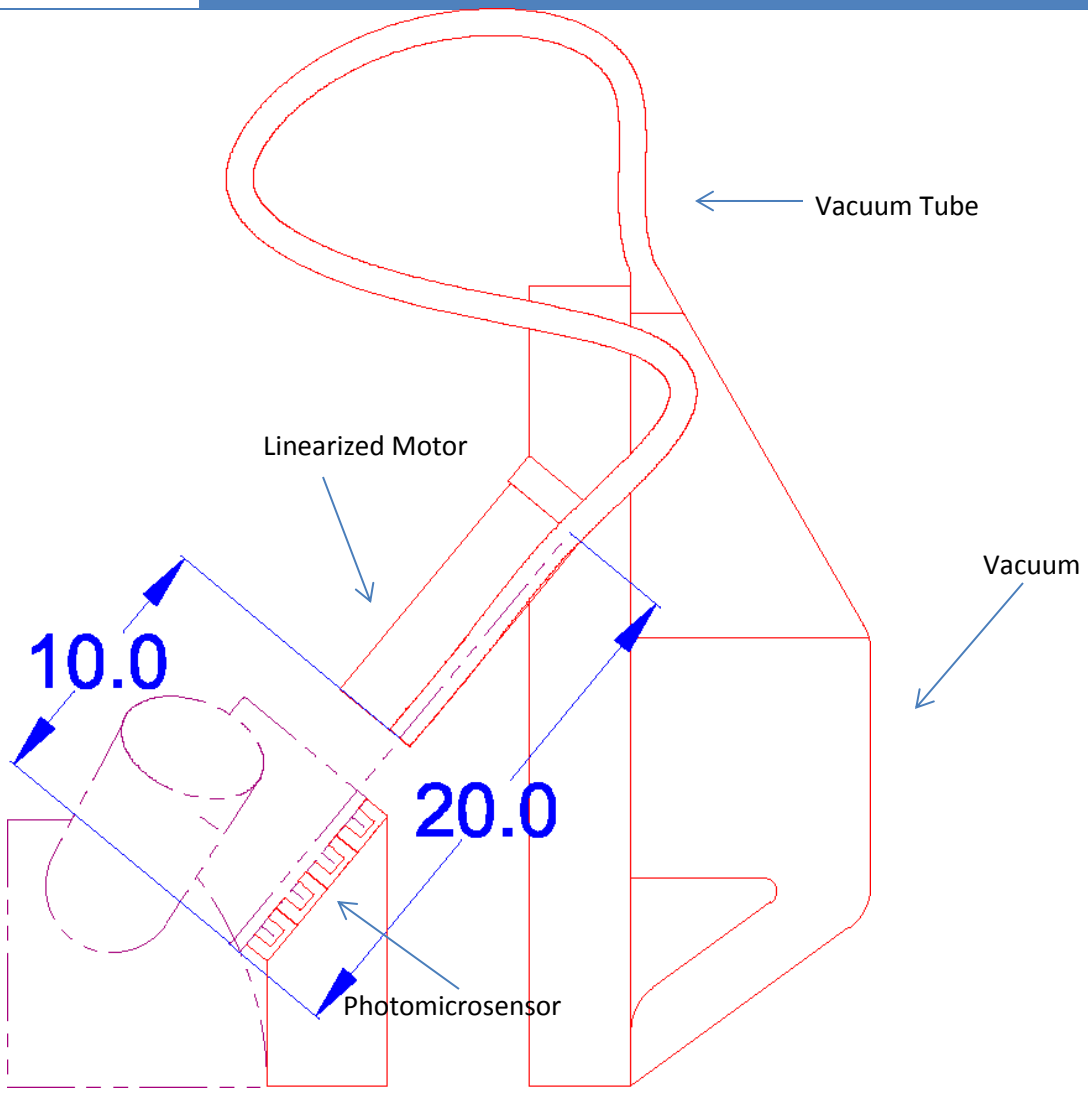


Figure 6 - The vacuum arm manipulator (VAM) and photomicrosensor alignment to SPC

Table 1 - Photomicrosensor truth table

Sensor	Not Lined Up	1	2	3	4	5	6	7	8
s(0)	0	0	0	0	0	0	0	0	1
s(1)	0	0	0	0	1	1	1	1	0
s(2)	0	0	1	1	0	0	1	1	0
s(3)	0	1	0	1	0	1	0	1	0

Through this method of feedback, the Arduino is capable of determining the position of the SPC at all time. An alternative to this is to use short range infrared sensors paired with a barcode of sort. However,

we felt this method, although not as compact and elegant as using the infrared sensors, would be easier to construct and debug since the barcode reader requires some external circuitry to be built whereas the photomicrosensors are designed to work out of the box. Another solution was to simply use a stepper motor and a few gears to track the SPC, but this could cause drastic errors due to the motor slipping or not turning as far as thought. Therefore, we chose to use the photomicrosensors due to its ease of use and repeatability factors.

To pick up the pills, the prototype PillPal utilizes a DC motor to generate vacuum to lift up the pills. The DC motor is a 7.6V, 7 amp generator placed at the bottom of the PillPal. We managed to find an appropriate vacuum by taking apart and slightly modifying a handheld vacuum intended for cleaning. Although there are standalone vacuum solutions available, we found that they tended to be far more costly than we intended for a proof of concept of the PillPal. In our final product design we chose a powerful specialized vacuum made by Thompson, a renowned vacuum/ compressor pump maker. It has an AC motor, capable of more power, and can produce a flow rate maximum 13 LPM (liters per minute) to a lower 3.8 LPM when sustaining maximum vacuum pressure.

A rubberized hose is attached to the connected to the vacuum and fastened to a linear motor placed 5 cm above the SPC. The linear motor moves the hose in and out of the SPC to pick up pills. Running off 12VDC rails, the linear motor travels at 200mm/sec, delivering pills at a quick pace.

The two main contributing factors to the ability of the vacuum to pick up an object is the force generated by the difference and of pressure created by the vacuum, and the air flow rate at which the vacuum displaces air. From trial and error with various vacuums, we successfully managed to roughly spec out a viable vacuum solution.

2.3 Pill Dispenser

The Pill Dispenser is where the pills fall and are finally dispensed for the patients. This crucial module is the last line of defense to ensure the correct patient is taking the correct drugs. When the VAM picks up the pill, it is dropped into a funnel and into a tunnel where a laser checks to make sure a pill is picked up and only a single pill is dropped into this compartment. A 5mW laser diode [2] is used in conjunction with a photodiode that is placed at the bottom of the funnel. This ensures that the pill will pass through it no matter the angle the pill has been dropped and it can be counted correctly.

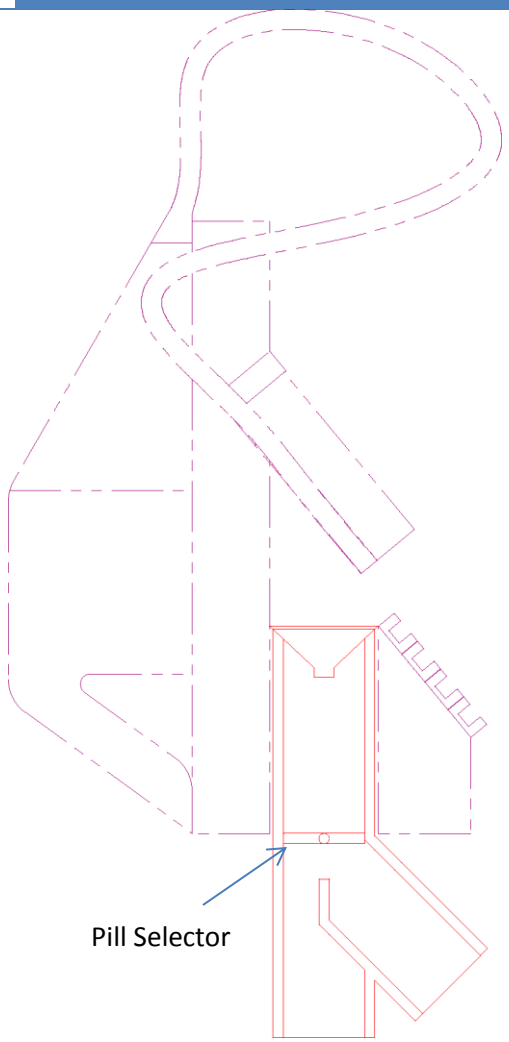


Figure 7 - Pill Dispenser cross section view

When the pill lands on the switch plate, the Arduino will wait until it is sure no more pills will drop. It will then compare the number of pills expected versus the actual detected before finally dispensing. A final check put in place is to check if the dispensing cup is waiting for the medication to be dispensed using a fifth photomicrosensor. Once everything is confirmed, the switch plate rotates and drops the drug into a dispense cup. When the cup is removed the sensor will send information to the Arduino informing the Raspberry Pi the cup is missing and we assume the user has consumed the pills. However, if the user does not confirm within a set time, the switch plate will dispense the pills in a side bin for storage. This bin is used to hold pill that are not consumed or missed to avoid double doses for patients.

2.4 Parts Description

2.4.1 *Photomicrosensor (Transmissive)*

Model: EE-SX3070

This electronics device is a sensor that we used to detect the position of the pill containers. The photomicrosensor uses a LED to send continuous light waves to a receiver with built in amplifier. By connecting to C-MOS and TTL (transistor-Transistor Logic) devices a high or low trigger can be created for detection. Because the LED is always turned on, the photomicrosensors have a built in temperature compensation circuit. The common uses of this device are for the detection of passing objects or for positioning applications. Another physical component called the “” dog”” will pass through between the photomicrosensor and be optically detected and produce an electrical signal. The physical dimensions are shown below in Figure 8. [3]

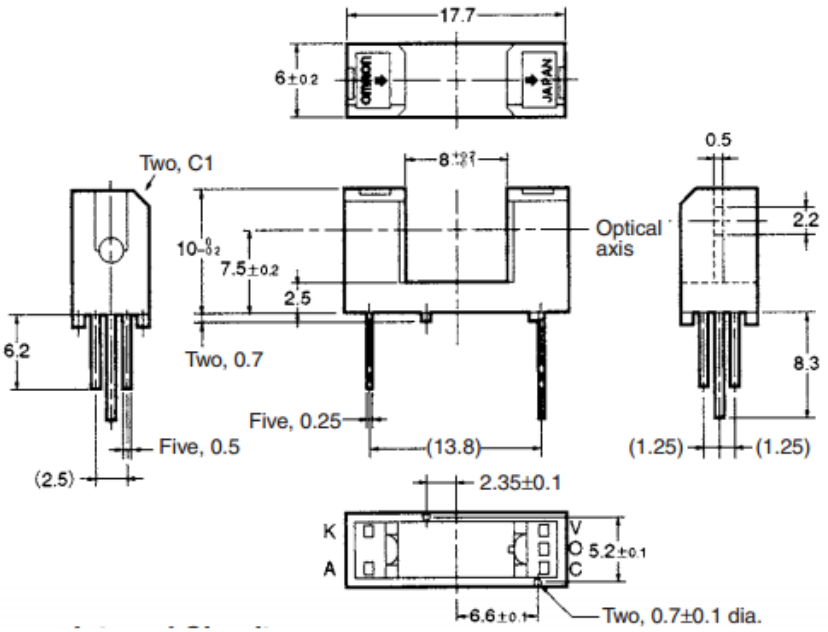
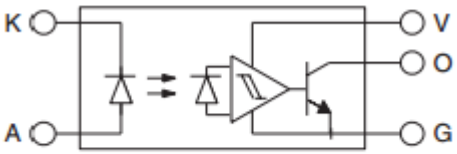


Figure 8 – Cross sectional view of the photomicroscensor from Digikey

We chose this device for its flexible voltage operations at 4.5 all the way to 16 volts. We will be operating this electrical device at 5V for convenience and low current consumption of 1.7 mA. These devices are relatively low price and are very practical for our application for the degree of accuracy and reliability in our product. This device is also contactless, thus will not fail due to mechanical failure or other wear and tear.

The sensor receives an analog input and produces a digital output through a Schmitt trigger which is built in the enclosure. Figure 9 provides the internal circuit of the photomicrosensor while Figure 10 shows the structure of the sensor.

Internal Circuit



Terminal No.	Name
A	Anode
K	Cathode
V	*Power supply* (Vcc)
O	Output (OUT)
G	Ground (GND)

Figure 9 – Internal Circuit diagram of the photomicrosensor

Figure 10 – Phyiscal construction of the photomicrosensor

2.4.2 *TE - Relay (PB1660-ND)*

The relay is a standardized single pole single throw power device. It has two terminals that that will close a contact to drive high current devices with the establishment of a magnetic field with the usage of some current. It is capable of handling 30VDC and 10A. This device cannot be directly connected to a C-MOS output device as it requires at least 70mA, which normal I/O pins are unable to support. The other "output" terminals on the relay are labeled NO (normally open) or NC (normally closed), denoting the standard state of those pins when no current flows. Shown below are the mechanical dimensions of the relay device.

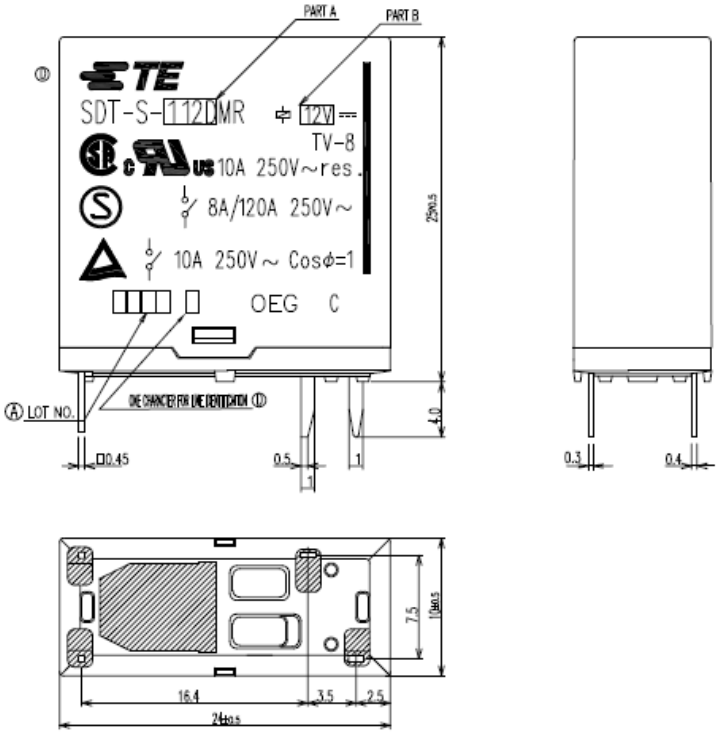


Figure 11 – Orthogal view of the 10A relay

In our design we are utilizing the relay to drive higher power devices with the help of a standard BJT configured as a simple switch. The diode seen in the configuration is acting as a flyback device, so when the relay is switched off the current from the collapsing magnetic field of a motor or inductive load can have a path to flow and dissipate.

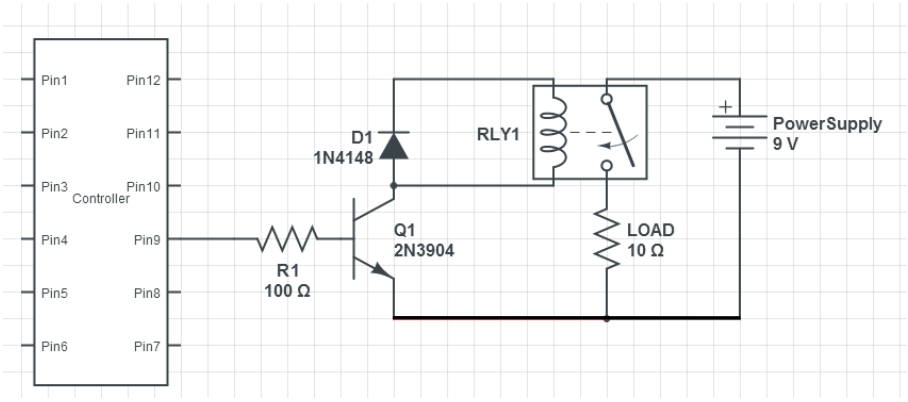


Figure 12 – High level overview of relay design to power motor (10Ω symbol)

2.4.3 *Shift Register (SN54HC595)*

The shift register is a device that uses a cascade of flip flops and can take in serial data and provide parallel outputs (SIPO). The SN54HC595 shift register is an 8bit storage register requiring a minimum of

3 control pins in order to assert 8 output pins. Commonly, a shift register is used to expand the number of pins for a micro controller while utilizing only a little bit of head room. [4] The chip itself allow 2 more pins for master clear, to clear data in all the registers, as well as a output enable, which places the output pins either in a high output impedance state or asserts the stored data bits. The chip is able to achieve a fast speed with only 13 nanoseconds in the propagation delay of each serial data clocking speed. The chip also requires only 5V operation voltage, which we readily have available for and the input current draw is exceptionally low at only 1 microamp.

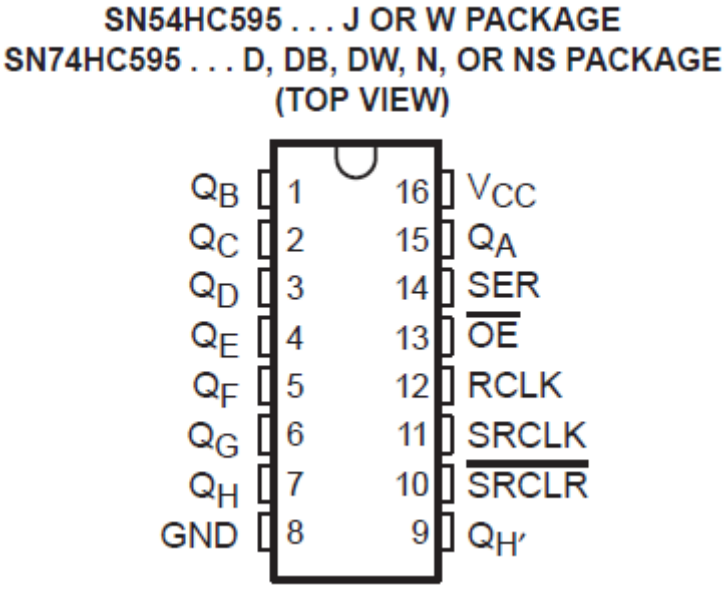


Figure 13 – Pin layout of the SN54HC595 Shift Register Chip.

We chose this chip, the DIP16, (dual inline package) for its abundance availability in the electronics community and its well-balanced set of functional specifications. This chip will be used as output control for the Arduino to control the included devices in the PillPal.

Figure 14 - DIP Shift Register Chip

2.4.4 *J-FET-Input Operational Amplifiers (TL082)*

The J-FET (junction field effect transistors) operational amplifiers are used in a few locations throughout the device. The operational amplifier is used in the circuit for the photo-diode in our laser module to

detect the acquisition of the pill. Also, the op-amps are used in a Schmitt trigger design to set threshold levels for the photo-diode output. Figure 15 demonstrates the use of op-amps in a Schmitt trigger design. [5]

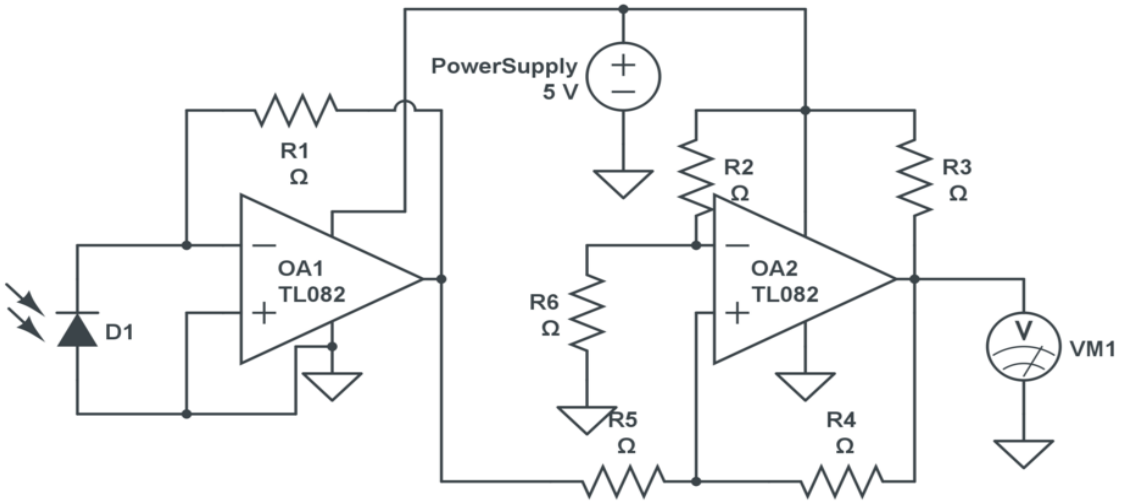


Figure 15 - Schmitt trigger design for pill detection

Lastly, the op-amps will be used in a simple voltage amplifier for our speakers. Figure 16 highlights our voltage amplifier design.

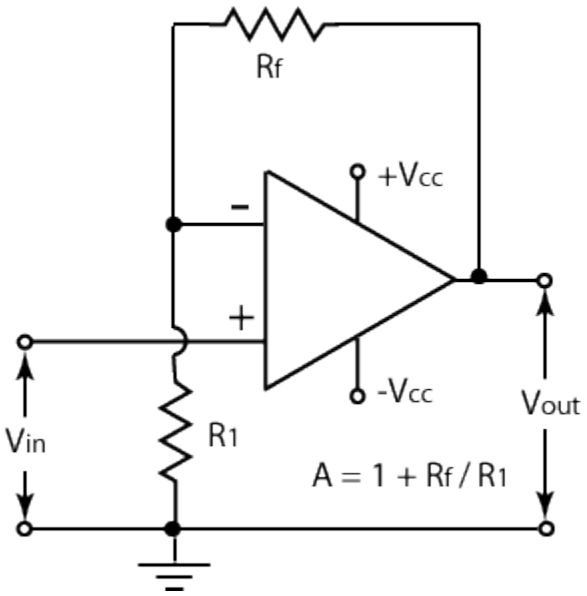


Figure 16- Non-inverting Op-amp design for Speakers

The output of this signal will be fed to the Arduino. We chose J-Fets in our design is due to the lower input current draw, in pico-amps instead of nano-amps.

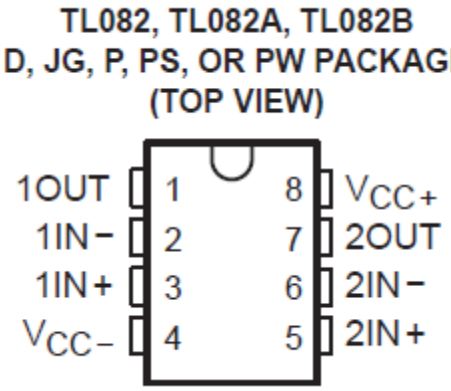


Figure 17 – Pin layout of J-FET op-amp [6]

I_{IO}	Input offset current‡	$V_O = 0$	25°C	5	200	5	100	5	100	5	100	pA
			Full range		2		2		2		10	nA
I_{IB}	Input bias current‡	$V_O = 0$	25°C	30	400	30	200	30	200	30	200	pA
			Full range		10		7		7		20	nA

Figure 18 – Input pin information regarding current biasing and current offset of J-FET

Input Offset Current	T_A = 25°C		3.0	30		20	200		20	200	nA
	$T_{AMIN} \le T_A \le T_{AMAX}$			70		85	500			300	nA
Average Input Offset Current Drift				0.5							nA/°C
Input Bias Current	T_A = 25°C		30	80		80	500		80	500	nA
	$T_{AMIN} \le T_A \le T_{AMAX}$			0.210			1.5			0.8	µA

Figure 19 – input current biasing and current offset of the TL0741 op-amp

The TL082A comes in a variety of packaging, but the one chosen is the 8 pin DIP (dual inline package). There are many operational amplifiers to choose from, this specific amplifier was chosen for the very high input impedance and very high slew rate of 13 V/us. The J-FET op-amp also have a wide common/ differential mode operating Voltage range when compared to a standard operational amplifier 741 which was designed in the 70's.

2.4.5 *Electrical Power supply*

To provide power to all the electrical components, a Dell power supply is use to supply power. The Dell NPS-275BB B is a 275W power supply with single ATX, P4 and SATA connector. The ATX connector is a 24 pin connect producing three main output, +3.3VDC, +5VDC, and +12VDC. A table below summarizes all the outputs and maximum current draw per each pin.

Table 2 - Power supply output pins

Output	+5VFP	-12V	+12V	+5V	+3.3V
Max Load	1A	0.5A	12A	17A	3A

The $45.00 power supply provides chosen contains a high range of output voltages and allows for high current draw. This is optimal for our motors and Raspberry Pi computer as they all run on 5 V or 12 V rails.

2.4.6 *Motor Power*

The design of PillPal requires a total of ~~3~~5 motors. Each motor is designated to complete a single task. There are 3 types of different motors in total, 1 stepper motor, 2 servo motors and 2 normal DC motors. The basic difference between stepper and servo motors is the physical characteristics of the motor and how it is controlled. Typically stepper motors is wounded in such a way that the motors create steps. These steps are created using magnetic fields. [7] The number of steps present allows for higher precision. These steps allow the motor to know the exact position at all times, compared to a servo motor, a servo motor utilizes an internal or external encoder to determine where the motor is positions. Because a servo motor does not use steps, it is able to produce much more torque and speed. [8] One of the DC motors is used for the linear motor, using a belt to create linear movement from the motors rotation. The other DC is used to create the vacuum by simply rotating very fast. The three different motors are selected to perform specific task catered to the strengths of the motors.

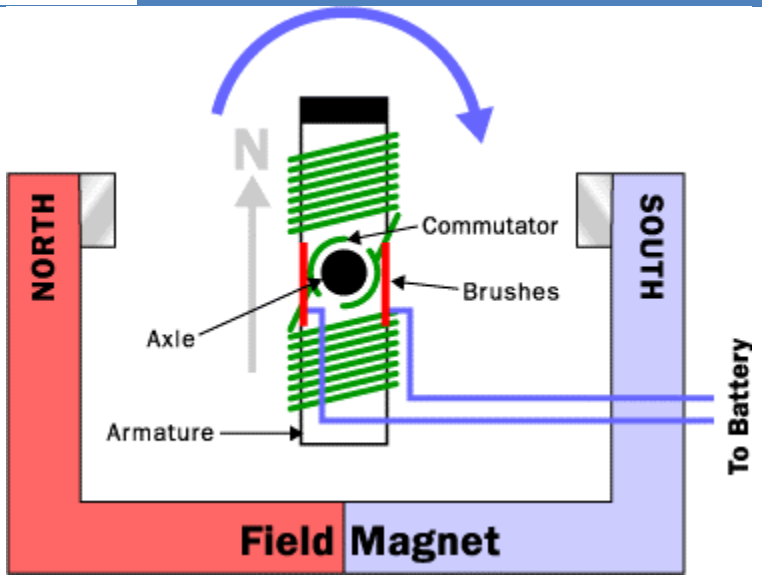


Figure 20 – General brushed motor design [9]

2.4.7 *Back EMF*

Back EMF (electromotive force) is the voltage generated or the electromagnetic force generated by a spinning motor that is established in the opposite direction of the input voltage. This is due to Lenz's law of electromagnetism thus the magnetic field generated is directly related to the voltage and the number of turns of wire in the armature. The generated back EMF will oppose the input voltage thus defining the final max rotational speed of the motor itself.

2.4.8 *Servo motor*

The servo motor simply rotates the pill holders so that pills can be reached by other modules. Our servo motor is purchased for the amount of torque it is capable of producing on 7.2VDC. At 7.2VDC the motor is able to produce 13kg cm of torque. Using Equation 1 we are able to find the force required to move our SPC. [10]

$$\tau = \vec{r} \times \vec{F} \qquad \text{Equation 1}$$

Where τ is the torque and where r is the single point vector relative to the fulcrum, and F is the force acting on the single point. We can calculate the force required to move the pill holder when it is at maximum capacity. By utilizing the cross products definition, we can change Equation 1 to Equation 2

$$\tau = rF \sin\theta \qquad \text{Equation 2}$$

where θ is 90, thus the equation is further reduced to Equation 3.

$$\tau = rF$$ Equation 3

given the torque from the datasheet and the radius of our arm, the required force to move our pill container is determined to be roughly 1 N.

Most servos are only capable of rotating 180 degrees, thus 2 servos are typically required to reach full 360 degree rotation. Unlike most servo motors, the Metal Gear Digital Servo is able to rotate 360 degrees. Because of this feature, a single servo is sufficient. However, with 2 servos the speed can significantly increase but the price follows. With the Metal Gear servo, a maximum 0.84sec / 360 degrees is obtained. This speed shall swiftly provide pills to medical patients.

2.4.9 Stepper Motor (42BYG011-25)

The stepper motor is a precision motor which is accurate to +- 0.1 degree per 360 degrees rotation. We chose the stepper motor for the precision required to take accurate picture with the label reader. This step is crucial in obtaining perfect images. To do so, we use a stepper motor purchased at Sparkfun Electronics. The motor has a stepping angle of 1.8 degrees and is powered using 12VDC. The current rating is 0.33A. [11] The fully loaded pills bottles do not carry a significant load and the 2.3kg cm torque is more than sufficient to rotate a bottle on its side.

Assuming the pill bottle weighs$m = 500g, r = 2.5cm$ radius and stepper has holding torque of .23NM the formula for Torque of a cylinder is stated in Equation 4

$$\tau = I \cdot \alpha$$ Equation 4

Where I is the moment of inertia, which is represented as

$$I = \frac{1}{2}mr^2$$ Equation 5

And α is the angular acceleration

$$\alpha = \frac{v^2}{r}$$ Equation 6

Substituting Equation 5 and Equation 6 into Equation 4, torque is now redefined as Equation 7

$$\tau = \frac{1}{2}mrv^2$$ Equation 7

Inserting our know values, under the assumption that the speed it goes at is $1\ \frac{cm}{s}$, we get

$$\tau = \frac{1}{2}(0.5kg)(0.025m)(0.01)^2$$

$$\tau = 6.25e^{-7}N \cdot m$$

so according to the math we have more than enough torque from our stepper to rotate a pill bottle as expected from such a light bottle.

Figure 21 – View of Sparkfun Stepper motor

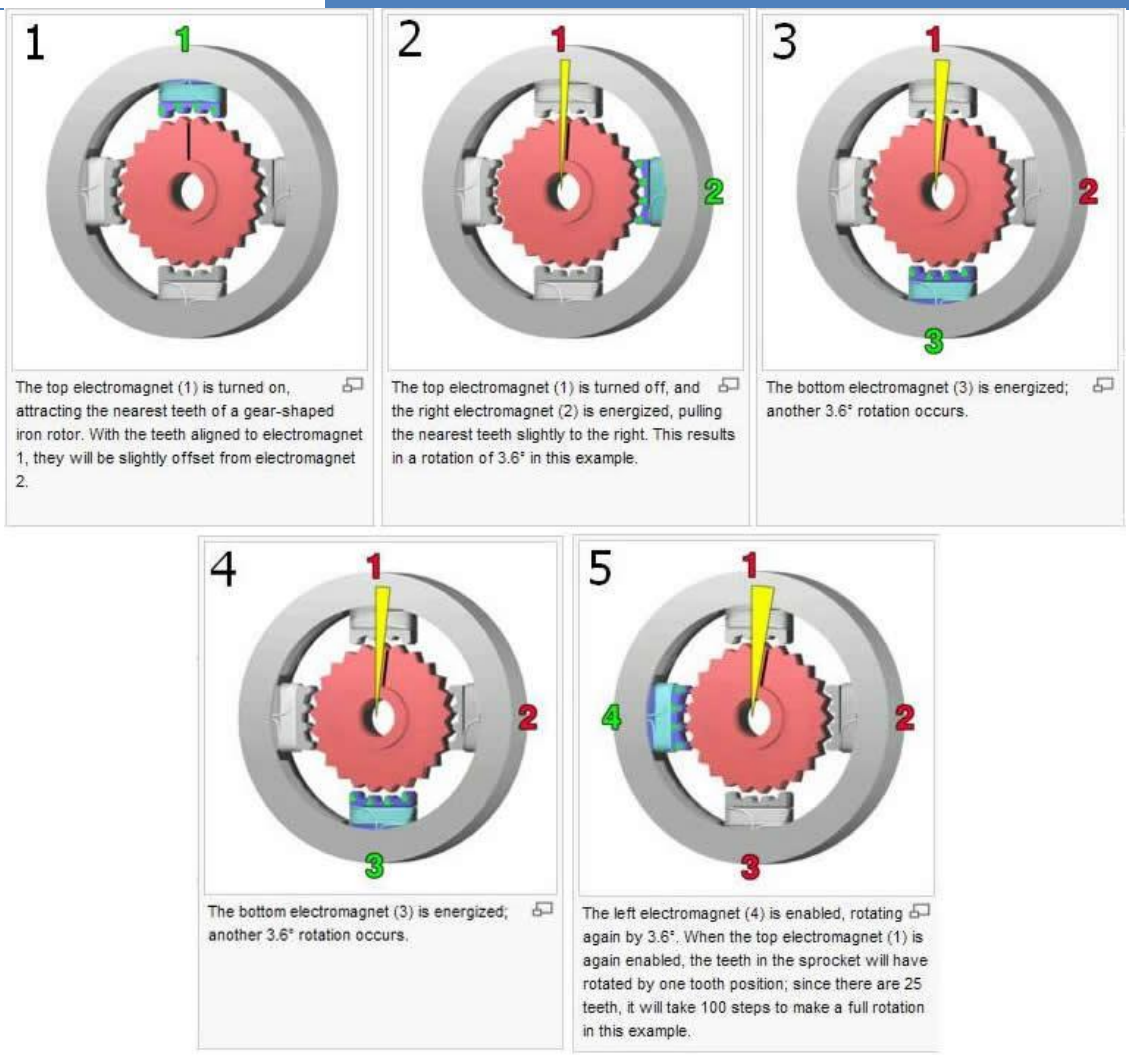
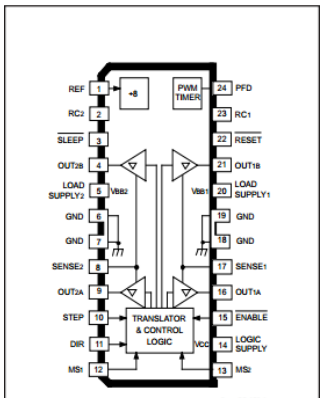


Figure 22 – Step by step explaination of how stepper motor control works

2.4.10 *Stepper Motor Controller*

Since the stepper motor is designed for two pole, four pin layout, we chose the EasyDriver Stepper Motor Driver from Sparkfun to driven our motor. This stepper motor driver uses the A3967SLB chip made by Allegro, which is capable of driving a device at 30V +- 750 mA. The driver chip can operates at a 3.0V to 5.5V logic level and has thermal shutdown capability for safety reasons. It has a built in H- bridge which is regulated by PWM (pulse width modulation) and is designed to work at a variety of step sizes: full, half, quarter, and eight-step mode. These fine adjustments give up better control over the actual mechanical movements of our device. [12]

Figure 23 – Stepper motor driver



Dwg. PP-075-2

ABSOLUTE MAXIMUM RATINGS
at T_A = +25°C

Load Supply Voltage, V_{BB} ..... **30 V**
Output Current, I_{OUT}
Continuous ..... **±750 mA***
Peak..... **±850 mA**
Logic Supply Voltage, V_{CC} ..... **7.0 V**
Logic Input Voltage Range, V_{IN}
(t_w >30 ns)..... **-0.3 V to +7.0 V**
(t_w <30 ns)..... **-1 V to +7.0 V**
Sense Voltage, V_{SENSE} ..... **0.68 V**
Reference Voltage, V_{REF} ..... **V_{CC}**
Package Power Dissipation,
P_D..... **See page 8**
Operating Temperature Range,
T_A ..... **-20°C to +85°C**
Junction Temperature, T_J..... **+150°C**
Storage Temperature Range,
T_S ..... **-55°C to +150°C**

* Output current rating may be limited by duty cycle, ambient temperature, and heat sinking. Under any set of conditions, do not exceed the specified current rating or a junction temperature of 150°C.

Figure 24 – Pin layout and operation data of the Stepper motor Controller

As we can see from the data sheet provided by the driver chip, the voltage supplied, the current capabilities, and the degree of accuracy is more than sufficient for our purpose on the label reader to operate the mechanisms to rotate the pill bottles. We chose this product due to its popularity, as it is currently the version 4.4 which means most bugs and issues are ironed out and performance maximized. The support for this driver chip is very broad as it is one of the more commonly used driver chip by Arduino users and designers.

2.4.11 *Linear Motor*

The linear motor is used to control our vacuum tube. The tube will reach into the pill containers via linear motion and pick pills up. As mentioned above, the linear motor module is actually a standard brush motor that drives a belt causing a trolley to move in a linear motion. Unlike, the stepper motor or our servo motor, there is no mechanical or electrical encoder to tell the motor where the position of the trolley is located. Instead, a linear potentiometer is placed and a reading must be taken in order for the Uno to know where the trolley is currently located. There is a single 1k ohm potentiometer and 4 viable pins to read from, by continuously reading the center tap voltage of a constant known voltage across the potentiometer when the motor is in motion, we can determine the location of the linear motor effector and control it as necessary.

As mentioned above, the motor offers very low torque but is able to travel at 200mm/sec. [13] Since the motor is not carrying much weight, a high torque motor is not required.

2.4.12 *Camera*

The label reader utilizes the camera to take multiple images of the circular pill bottle. By taking multiple images, the Raspberry Pi will stitch the images creating a flat image. Utilizing the HP camera 3110's 720p, and 5.7 Megapixel still picture resolutions, the images are taken with extreme clarity. The camera also supports autofocus feature which assists in the image clarity. The camera cost $11.99 retail and provides us with excess features including 30 FPS video resolution.

Figure 25 - Front view of HP3110 Camera

The HP camera is powered through USB 2.0, and sends data via the same cable. The data is compressed via the built in JPEG and YUY image encoder located inside the camera housing. For this reason, the JPEG images require decompression before it may be processed further using standard RGB (Red, Green, Blue) pixel values. [14]

The camera is also chosen because it is UCV compliant and is able to communicate to the Raspberry Pi via V4L (Video4Linux) without any additional drivers. Using V4L, we are able to adjust the focus settings, which is critical for taking clear macro shots of the pill bottle's label. The main reason for choosing this device is for its low retail price and wide range of functions.

2.4.13 *USB HUB*

The PillPal utilizes many USB powered devices. The Raspberry Pi only has two lower power output USB ports, thus a USB hub was purchased to power our many USB powered devices. The D-Link H7BL 7 Port USB 2.0 Hub contains 7 downstream USB 2.0 ports along with a single upstream port. Currently, the USB hub is used to power the Raspberry Pi, Arduino Uno microcontroller, the USB touch screen and the USB camera.

Figure 26 – D-Link USB Hub for USB communication and power

The USB hub requires a 5VDC power supply and draws up to 3.0A peak. Each USB port supplies 0.5A for charging and current draw, however, The D-Link hub provides a feature for a Fast Charge Mode for two specified ports. This allows two ports to draw up to 1.2A instead of the conventional 0.5A. [15]

The device measures 100 x 57 x 23mm (LxWxH) weighing 85g. The compact device was selected for its size and compatibility with the Raspberry Pi. The extra ports will be left as it can be used for future upgrades or for changes which require USB ports.

2.4.14 *Touch Screen*

To offer interaction with the PillPal, a multipoint capacitive touchscreen is added. The LCD LED backlight touch panel employs a Silicon Thin Film Transistor (TFT) to allow for the 3.35mm total thickness. The 10.1 inch TFT-LCD screen provides a 1280x800 resolution with a maximum luminance of 400cd/m^2. The touch screen provides an auto brightness feature to save power, by using a built in ambient light sensor, the brightness of the screen adjusts to the brightness of its surroundings. [16] A manual mode is also offered. Because of the maximum luminance value, it is not suggested to use in direct sunlight.

Figure 27 - Raspberry Capacitive Touch screen

The touch screen is purchased from a company named Chalk Electronics. The $134.99 purchase comes complete with HDMI-LVDS converter board which regulated voltages for LCD and power the Raspberry Pi. The converter board contains a PIC controller which does LVDS to HDMI / USB control for us. [17] Though expensive, the purchase of the touch screen complete with the controller has save us an immense amount of time. By simply plugging an HDMI and USB cable into the touch screen and Raspberry Pi, connection is automatically detected and works immediately.

2.4.15 *Microcontroller*

To control all motors and sensors in the PillPal, the Arduino Uno was chosen. The Arduino Uno utilizes an ATmega328 chip to complete and fetch instruction provided by the Raspberry Pi. The Atmega328 chip provides 6 PWM channels, 6-channel 10-bit ADC, programmable USART and programmable Master/Slave SPI Serial Interface. This chip also has 20 programmable I/O lines. [18] [19] The choice of the Arduino Uno over other Arduinos came down to the size and the already attached female pins. The larger size of the Uno allows for clean wiring, this reason alone is why the Uno was purchased over other Arduinos.

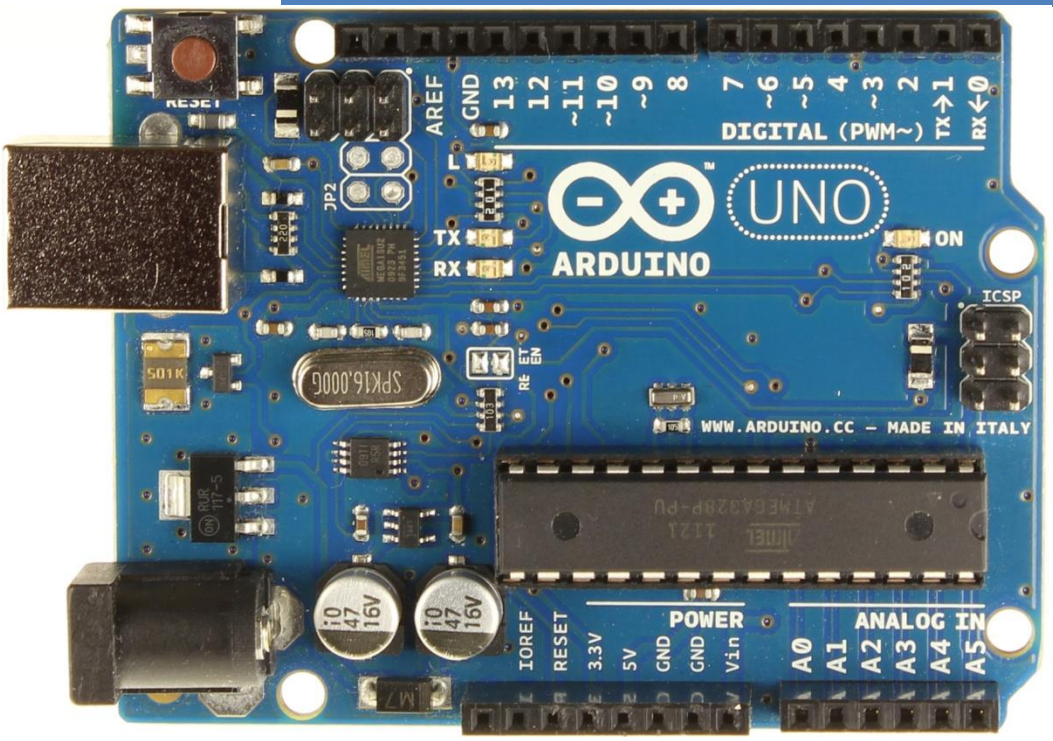


Figure 28 – Arduino Uno module device

2.4.15.1 Power

The Arduino Uno is operates at 5VDC and requires a 6-20VDC input. The stated inputs are maximum and minimum limits the Uno may produce hazards at the maximum voltages and unstable values at the minimum input voltage. Therefore, 7-12VDC is the recommended voltages to run the Arduino Uno. Given these ranges, the power supply provides 12VDC and is capable of producing enough power for the Uno. However, the Uno can also be power by USB. When powered by USB, we do not need to worry about overheating or unstable voltages. The USB circuitry implemented by Arduino allows the USB to create a stable system. However, the USB may limit current depending on the amount of I/O ports utilized at once. The Uno I/O ports provide a maximum of 40mA.

The USB 2.0 connection provides 5VDC for the Uno, connecting the USB to the USB hub's high power port; a maximum 1.2A can be delivered to the Uno.

2.4.15.2 Memory

The Atmega328 Chipset has 32kB of memory, also has 1kB of EERPOM and 2kB of SRAM.

2.4.16 Raspberry Pi

In the end, one module controls the entire operation, the Raspberry Pi. The Raspberry Pi currently has three models, Model B rev. 1 and Model B rev. 2. We will be using the latest model, Model B rev 2. The Raspberry Pi is a small single board computer developed by the Raspberry Pi Foundation. Developed in the UK, the Raspberry Pi measures 85.60mm x 56mm x 21mm, this credit card size computer was purchased for $35.00 and contains all the features of a standard PC today.

Figure 29 - Raspberry Pi Module

The design of the Raspberry Pi is an embedded SoC design. Using the Broadcom BCM2835 layout, included in the chip is an ARM1176JZF-S 700 MHz processor, VideoCore IV GPU and 512MB of RAM. This SoC design allows the Raspberry Pi to remain small while having all the necessary components.

2.4.16.1 SoC

The SoC (System on Chip) is an integrated circuit designed by Broadcom and given the part number BCM2835 which contains the CPU, GPU, DSP, SDRAM and single USB port. The processor for the Raspberry Pi is the ARM11 chipset. The ARM processors are a specialized CPU architecture used to do Reduced Instruction Set Computer (RISC). Currently the ARM11 architecture design is used in many cell phones and now is used in the Raspberry Pi for its processing power and low cost design.

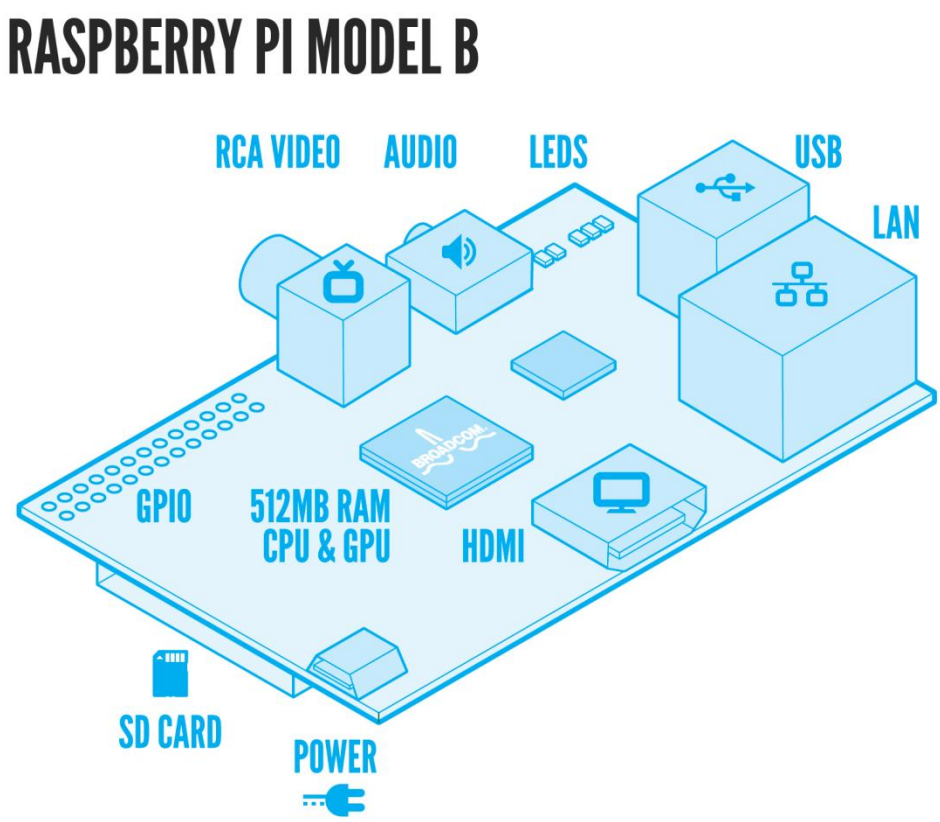


Figure 30 - Raspberry Pi Model B, peripheral layout

The GPU is designed Broadcom and branded as the VideoCore IV. VideoCore is a low power mobile multimedia processor architecture. The GPU chip is flexible and efficient enough to decode as well as encode multiple multimedia codecs in software while maintaining low power. The VideoCore IV is able to support 1080p resolution and support faster 2D and 3D graphics at very low power. The Raspberry Pi is capable of producing composite RCA (PAL and NTSC) and HDMI outputs.

Lastly, the Raspberry Pi has 512 MB of RAM shared with the GPU. Depending on the application, the amount of RAM shared with the GPU can be changed to suit our operation. Currently, The RAM is required to run the Linux Debian wheezy operating system. With the recommended RAM value at 256MB, the Raspberry Pi exceeds the recommended value.

To drive the Raspberry Pi, 5VDC micro USB is required. However, using a power supply with more than 5VDC will also be sufficient. The Raspberry Pi will draw up to 1A of current during peak operations. Overall, the Raspberry Pi is an inexpensive computer capable of producing video, audio, bluetooth, and WIFI while utilizing the Linux operating system.

2.4.17 *Uninterruptible Power Supply*

Understanding that medication can be life or death of some patients, it is important that a backup battery to be installed in case of blackouts. It should be first noted that the UPS system is not installed as part of this project as it is intended for the production model of the PillPal and not the proof-of-concept. It is a concept we understand to be extremely important. For that reason all calculations are completed and are to be implemented when final product is developed. To choose our UPS system we determine the current consumptions of all our modules. Below is a list of components and their priorities in blackout situation. The priorities are set depending on the amount of time the module is required to be on and the importance of the operation a module must perform. For example, the Raspberry Pi must be on at all times and performs the more important task of scheduling and instructing. Thus, we set the priority as high.

For example, the servo motors perform very important actions; however it is only turned on only when it is called upon. Also, the motor is only on for a few second, thus we set the priority to medium.

Other equipment such as a Vacuum may not be on at all times, but the amount of power used by the vacuum is large, thus we must consider it as a high priority module.

Table 3 - Priority list of component during power outage

Components	mA/h	Priority
Raspberry Pi	1A @5V	High
Arduino	780mA @5V	High
Stepper Motor (Label reader)	1A @12V	Low
Servo Motor (Pill Allocator)	400mA @5V	Medium
Camera (Label Reader)	500mA	Low
Linear Motor (VAM)	700mA (max) 300mA(typ.) @12V	Medium
Servo Motor (Pill Dispenser)	400mA @5V	Medium
Touch screen	3A @5V	Medium
Finger Scanner	120mA @ 5V	Medium
Optical interrupter (photomicrosensor)	380mA @ 5V (All on)	High
Pill detector	300mA @ 5 V	High
Vacuum	7A @7.75V	High

USB hub	3A @5V	High

The low priority level items are expected to not be turned on when there is a black out. This will save power and prevent usage of extra power during critical times.

To determine what type of batteries to use, the total power consumption of PillPal is calculated. To find the power consumption, wattage is calculated using equation;

$$P = Sum(V \cdot A)_{all\ components} = 111.15\ W \quad \text{Equation 8}$$

Once we determine the wattage of each module, the summation determines the overall power usage at an instantaneous moment. From a 10Wh uninterruptible power supply it is possible to sustain for this instantaneous power consumptions for 6 minutes. We do not expect every module to be operating at full power consumption, we estimate a 35% usage when averaging overall power consumption.

Figure 31 - Uninterruptable Power Supply (not implemented in prototype)

In British Columbia, the average black out time is about 2.25 hours thus our goal is to select a UPS that can last 3 hours long. Thus, we selected is a 12 V Li-ion battery pack rated at 7400 mAh. [20] Assume our device needs to dispense twice in the 2 hours blackout, the backup battery shall last about 5 hours. So we are determined to place a backup battery pack in the future final design, the prototype will work without a UPS.

2.4.18 *Finger Scanner*

The finger scanner is a safety feature implemented to differentiate between users of the PillPal. Before the pills are dropped into the cup, the finger scanner will be the last line of defense to make sure the correct medication is going to the correct patient. If the correct patient scans their finger, only then will

their medication be dispensed. The finger scanner will also be used as a means to control user sign-in and ensure a user cannot modify another user's settings and/or schedule.

Figure 32 – Demonstration of the Finger Print reader

The fingerprint sensor from Adafruits is small device which reads fingerprints by taking images and processing the images through a DSP chip. The images are taken via a 14 by 18 mm windowed area and it takes less than one second to complete the scan. The device requires a supply voltage from 3.6-6.0VDC and will draw up to 150mA. It communicates via UART with the Arduino Uno, at the baud rate of 57600. [21] The image processing performance has a 0.001% false acceptance rate which results to one error in 100 000 scans. The false rejection rate is roughly 1%, but this will not be an issue as the user can rescan within two seconds to gain access. The module also has a built in password for security reasons when utilizing this fingerprint scanner, and is required to be transmitted when establishing a connection to it via UART. This device also has built in flash to store the scanned credentials and the device password in case of power outages and other unforeseeable power related issues.

2.4.19 *Gears*

To provide movement to our mechanical devices, motors attached with gears are used in the design. The gears are for transferring mechanical circular motion from one end to another and provide methods to reduce the sideways shear force on the linear axle of the motors. Mounting a device directly onto the shaft of a motor stresses the motor with shear forces not related to the rotation, so to avoid this issue we need to use gears. When using gears in tandem, they are capable of producing a mechanical advantage, thus deciding on gear sizes is crucial. The sizing of the gears is relative, with a smaller gear to a bigger gear we have the ability to produce higher resolution final motion utilizing more motor turns.

The gears used in this design vary in sizes of bores and diameters. We decide to use 32 pitch gears for our design for simplicity. To accommodate different bore sizing for a number different geared mechanisms, we had to be very selective in the gears themselves.

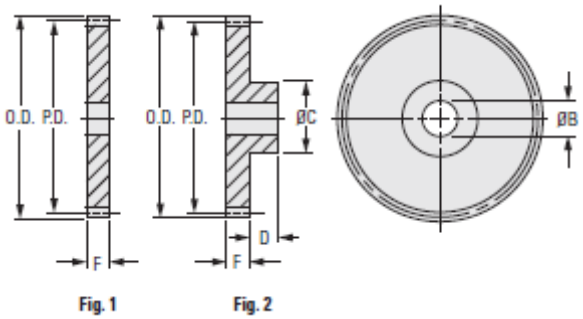


Figure 33 – Measurement of typical gears used in the PillPal [22]

OD: outer diameter of the whole gear
PD: pitch diameter of the gear
F: thickness of the gear
OC: outer diameter of gear bore if flanged
D: protruding flanged gear size

There are two places we used gears:

- One place is the label reader used to turn the pill bottles for reading the labels.
- The other is the servo motor used to turn the pill holders.

The servo required a special made gear that fits directly onto the servo motor shaft.

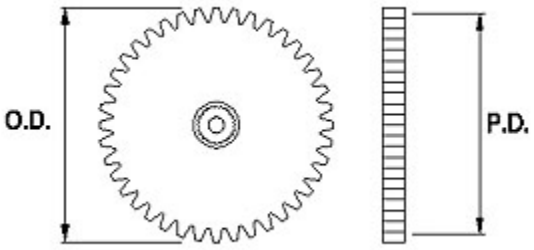


Figure 34 – Demonstration of outter diameter and pitch diameter

Utilizing gear ratios the table below demonstrates the mechanical advantage achieved.

Teeth Ratio (Motor → Target)	Mechanical Advantage

Label Reader	24:44	• Capable of fine movements • Higher Torque
Servo motor	20:38:27	• Capable of fine movements • Higher Torque • Middle gear act as extension to connect outer gears

2.4.20 *Plexi Glass (Poly (methyl methacrylate))*

The Plexi Glass is the material chosen for the final enclosure of the PillPal proof of concept. We chose this material for its relative strength, cheap cost, is non-conductive and easy to work with properties. It also does not contain harmful bispheno-A that are usually found in other polycarbonates. Plexi glass itself has a high degree of clarity and was chosen to give a view into our prototype without sacrificing the weight by using a glass enclosure. It has the chemical composition molecular formula of (C5O2H8)n. Figure 35 demonstrates the chemical bond of Plexi glass.

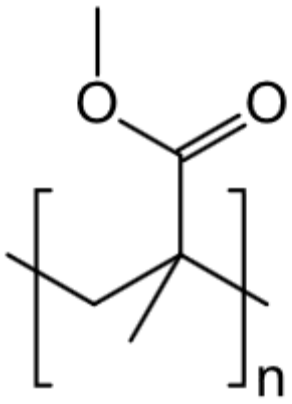


Figure 35 – The chemical bond of Plexi Glass [23]

Plexi glass has a density of 1.17 - 1.20 g/cm^3 significantly less than glass (2.4-2.8g/cm3), but still have good mechanical strength and chemical stability in our environment making it light weight. [24] Our material has a thickness of 0.118” which is roughly 3 mm. We chose this thickness because it was thick enough for good rigidity in our components while still maintaining the workability with our available tools. The acrylic panels are cut using a scoring knife to create a deep cut in the plastic and snap it along its score line.

Figure 36 – Example Sheet of Plexi Glass [25]

2.4.21 *H-Bridge*

To control the linear motor, an H-Bridge circuit is required. The H-Bridge circuit is designed to allow motors to be driven in two different directions. By changing the voltage across the motor terminals, we can cause the DC motors to run forwards and backwards. A simple circuit is illustrated below in Figure 37. The H-bridge requires two different power supplies, a 5VDC is require to supplied the chip as a reference for the digital logic and the other power supply is require to power the motor. In our case, we require 12 V to power the motor.

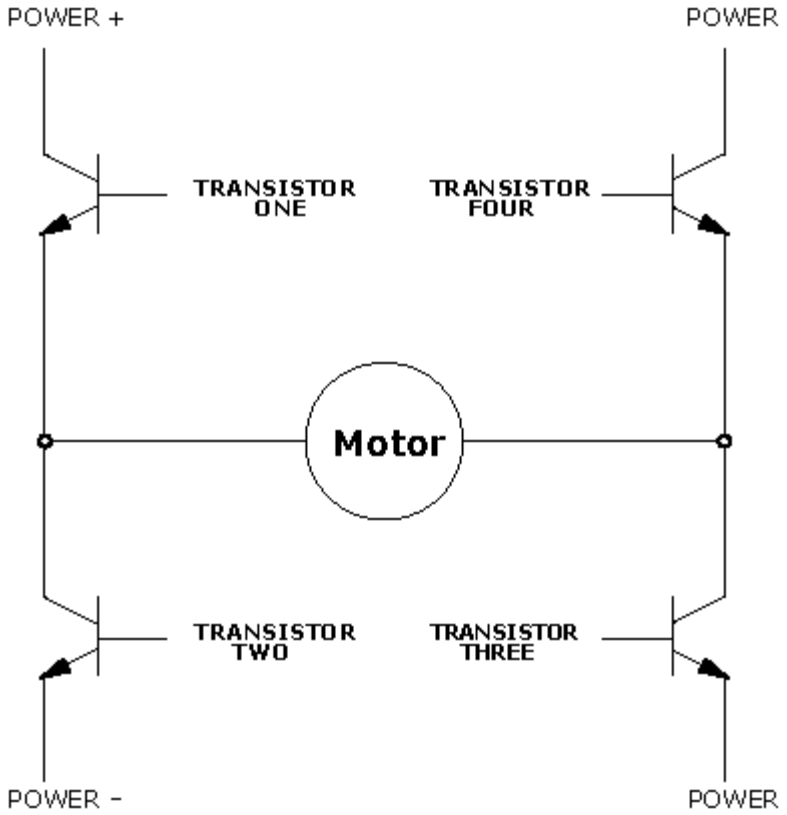


Figure 37 - Example H-Bridge Circuit

To do the H-bridge switching, an IC chip is purchased. The TI SN754410 is designed to be to a quadruple high current high-H driver. The IC chip is able to drive currents up to 1A at voltages from 4.5 to 36VDC. [26] Because the linear motor is a small and only requires up to a maximum of 800mA, the SN754410 is capable of handling the current.

The H-bridge is also capable of switching current at a rate between 400-800ns. The maximum switching speed of the linear motor is 5ms, thus we are sure that the switching speed of the H-bridge is sufficient at handling the linear motor.

2.4.22 *Power Switch*

To turn on the entire device, we have fitted a rocker switch for power. The switch is capable of switching 110 VAC at 16 amps. The device is placed on the back side of PillPal and requires a cut out of 12.00x31.5mm. The switch is the main power/ emergency shutoff switch during the prototyping phase.

Figure 38 – Image of the on off module

In the final design, the power switch will be relocated such that it will also cut off the UPS in case of an emergency.

2.4.23 *Speakers*

The PillPal will use audible notifications in order to alert users which are nearby that it is time to take their medication. In order to implement this, we are using the 3.5mm audio jack on the Raspberry Pi and connecting it to a speaker driver. In order to ensure that the speaker is loud enough, there will also be an amplification stage for the audio signal before being the signal is fed to the driver. The speaker driver we are using is 0.25 W with a resistance of 8 Ohms. The maximum sound level we have recorded for it is 90 dB. The amplifier will use a simple operational amplifier using a non-inverting amplification setup. Since we are only using one speaker driver, the Left and Right channel's from the Raspberry Pi need to be summed together prior to amplification.

3 Software

3.1 General Software Requirements

- C++ will be the programming language used to develop the GUI, scheduling, and image processing software
- The Qt framework will be the chosen API for the GUI and scheduling
- Python and Bash scripts will be used to control external modules through the user interface
- The XML format will be the means of data storage/access

3.2 Software Overview

Our software consists of two main components: the GUI and image processing/OCR software. Each of these components will work together to create the full software system for our product.

We will be using the Qt framework and C++ to create our GUI and overall scheduling system. Our engineering team has decided to use C++ as our primary language as we have the most experience and expertise in it. C++ is simple to use and comes with extensive libraries. The main downfall of conventional C++ programming is that it is difficult to develop GUIs. But that disadvantage is turned into an advantage when combining C++ with Qt.

"Qt is a full development framework with tools designed to streamline the creation of applications and user interfaces for desktop, embedded and mobile platforms". [27] Qt is cross platform framework which means that software developed on one platform such as Windows will also work on all other platforms such as Raspbian Linux in our case. We will be using Qt to develop software that will run on the Raspberry Pi and will also communicate with outside modules such as the touch screen and Arduino microcontroller. Qt allows us to use an extensive and easy to use API with maximum feature set and support. "Qt uses standard C++ but makes extensive use of a special code generator (called the Meta Object Compiler, or moc) together with several macros to enrich the language". [28] Qt allows us to create software easily and efficiently and ensures compatibility with the Raspberry Pi. Table 4 below shows us the advantages and disadvantages of using Qt compared to other platforms such as generic C++ and .NET development. As can be seen from the table below, many of the disadvantages are due to memory and disk requirements which can be disregarded since we are running on the Raspberry Pi and not a typical microcontroller.

Table 4 - Advantage and Disadvantage table for Qt Platform

Advantages	Disadvantages
• **It is cross-platform and uses system resources to draw windows, controls, etc.** • **Open source so it comes with a large community and support** • **Extensive libraries and macros that abstract many functions and low level design** • **Comes with a very functional IDE that can be used on many platforms/operating systems** • **Excellent API design** • **Easier to create GUIs**	• The size of apps developed in Qt are large • Need a large amount of disk space for compilation • Not as many 3rd party widget libraries • Not as many testing solutions

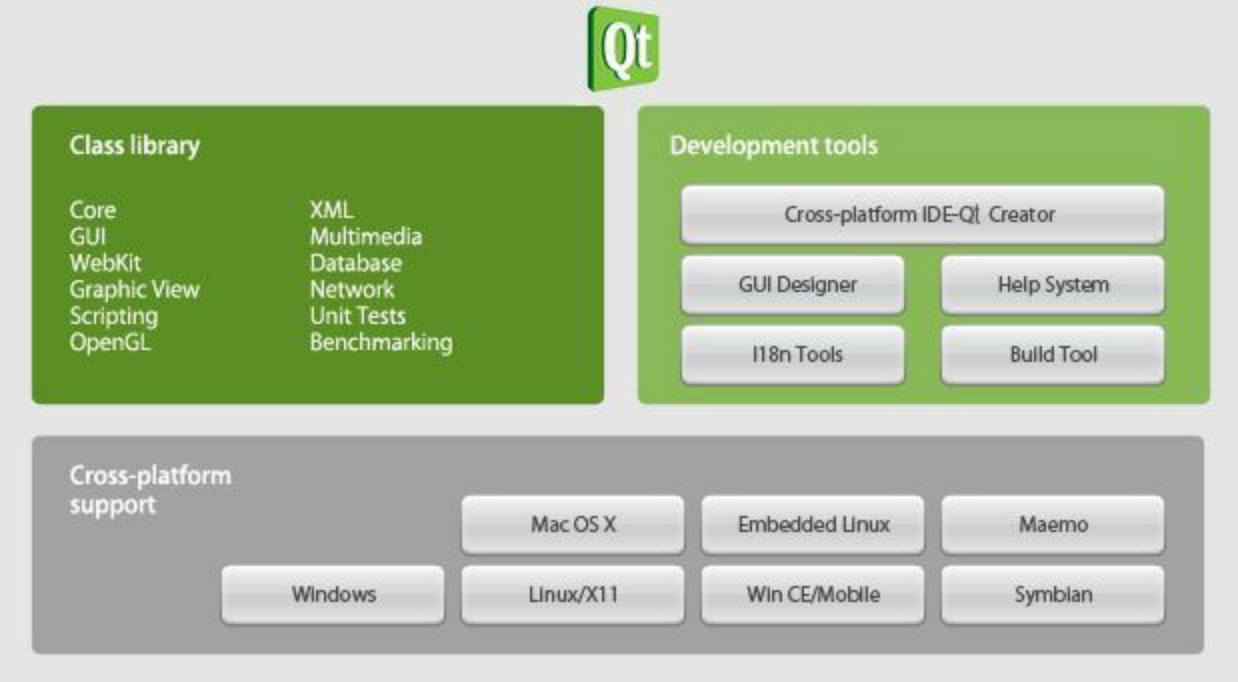


Figure 39 - Qt feature overview

We will also be developing Python and Bash scripts to control modules external to the GUI such as the wireless module of the Rapberry Pi. We will use C++ code from the GUI software to execute the scripts and display returned information in the GUI. Python and Bash will be used based on the situation, but more or less will be used in equal amounts. Python is a very easy to learn scripting language and allows our team to ramp up quickly. Python will be used in creating and parsing text files to retrieve information in external module communication. Bash will be used to run external applications and commands that are exclusive to the Raspberry Pi Linux terminal.

3.3 Graphical User Interface

The GUI is the primary control interface for our system. It provides the high level abstraction of all of the functionalities of our system. The GUI is fully designed in C++ and the Qt framework. The GUI displays all relevant information and provides access to all functions to the user in a clear and easy manner. The responsibilities of the GUI include but are not limited to:

- Displaying and managing all scheduling information
- Ability to access low level features such as pill loading and pill dispensing
- Displaying and managing user information
- Allowing the user to customize user information, scheduling, hardware settings such as brightness and volume, and emergency alert information

The GUI displayed in this document is for proof-of-concept and is designed from the engineering team's perspective of the intended audience. Therefore it is subject to change and all necessary changes will be

made as we get closer to the User Acceptance Test and get more feedback from potential users. These changes will be made available in the prototype and production versions of our product.

The GUI is designed for a touch screen and thus provides an alternative to a mouse and keyboard. The functions of a mouse will be used by touching the screen where it could be "clicked". For the keyboard alternative our engineering team has used 3rd party open source software to implement a virtual on-screen keyboard. [29] This virtual keyboard is the primary method of user data input besides touch clicking. Figure 40 below illustrates the virtual keyboard. Whenever a user touches an editable field in the GUI a separate menu displaying the virtual keyboard is displayed. The user can enter information just like any regular keyboard and when he is satisfied he clicks the "Done" button to hide the keyboard.

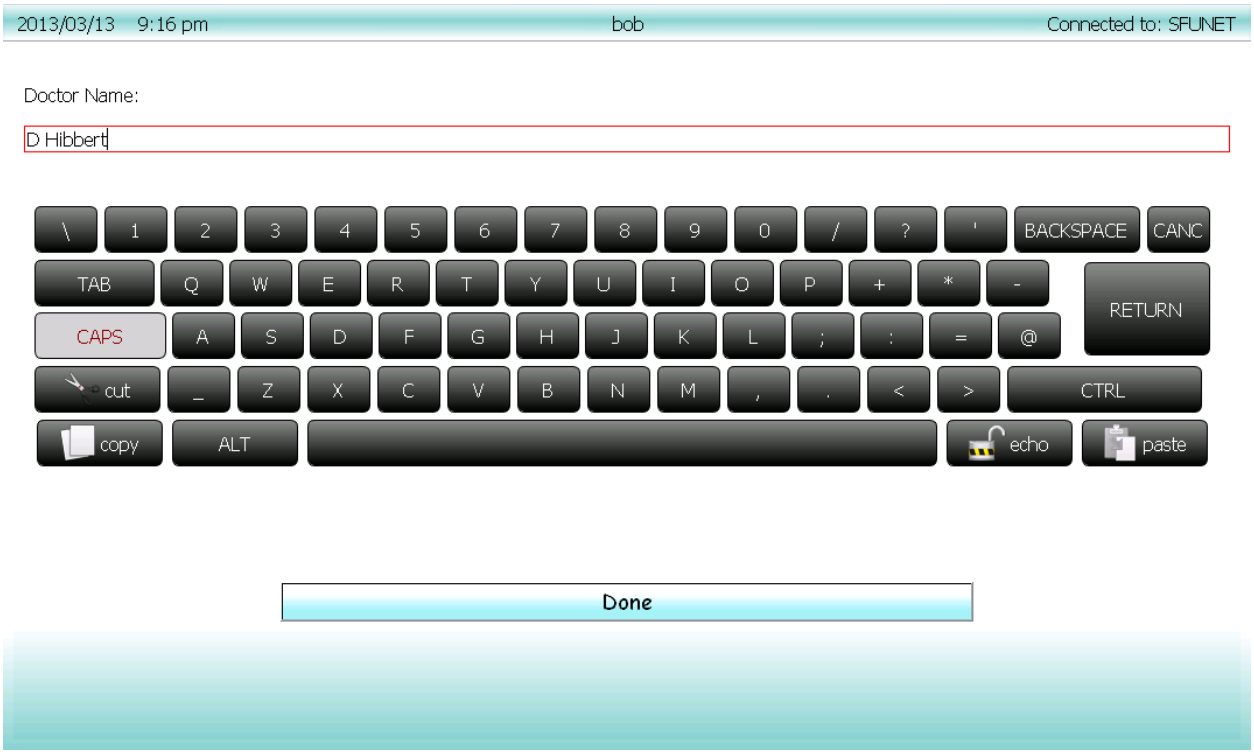


Figure 40 - Qt keyboard design

The key entry point of our GUI is the home menu as displayed in Figure 41. From this menu the user can access the main functions of our product. Every menu in the GUI also displays a taskbar at the top that displays the current date and time, current user, and WiFi connectivity information. All menus aside from the home menu also include a menu bar that displays the name of the current menu as well as "back" and "home" buttons to navigate between menus. The home screen also displays general details of the next scheduled pill as well as the option to view further details by pressing it on the touch screen.

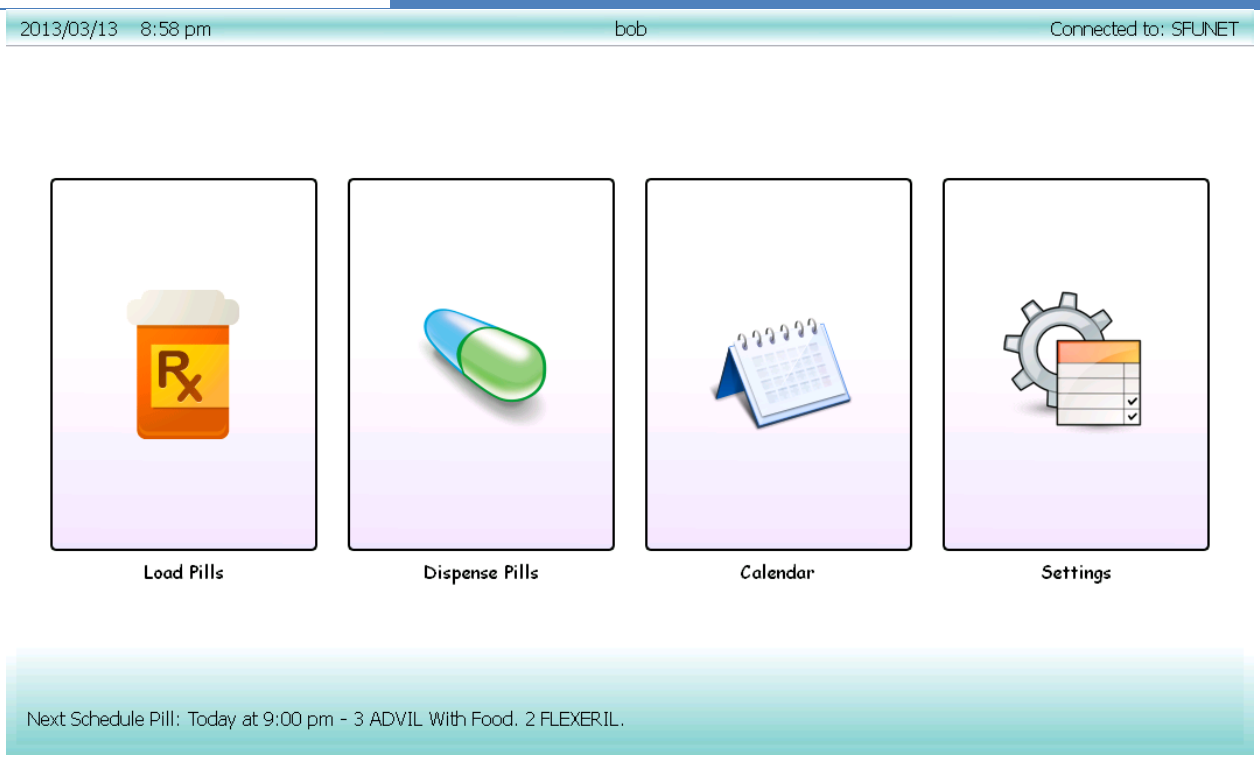


Figure 41 - The PillPal home screen

The home menu provides access to the four main submenus: Load Menu, Dispense Menu Calendar, and Settings.

3.3.1 *Load Menu*

The load menu is responsible for all the user interaction and control to load the pills and read the medical label. The user will be first prompted with a confirmation screen to ensure loading does not take place in case the load menu button was mispressed. Once the user has confirmed, the loading process can begin. The GUI software runs C++ code to send instructions to the Arduino microcontroller through USB using the Arduino's UART chip to control the motors. It also runs C++ code to control and take pictures with the webcam, stitching all the images together, and execute Tesseract OCR software to convert the image into a text file. The software will then parse the resultant text file to retrieve necessary information and display it to the user. The user then has an option to modify information that may have been incorrectly translated by the OCR software. Once user has confirmed the information he has the option to select what time to take the pills with accordance to the information listed on the medical label. When the user has selected the times and pressed the "Finish" button, the prescription information is stored in the schedule through in an XML file and the user is returned to the home screen. The flowchart below in Figure 42 illustrates this process.

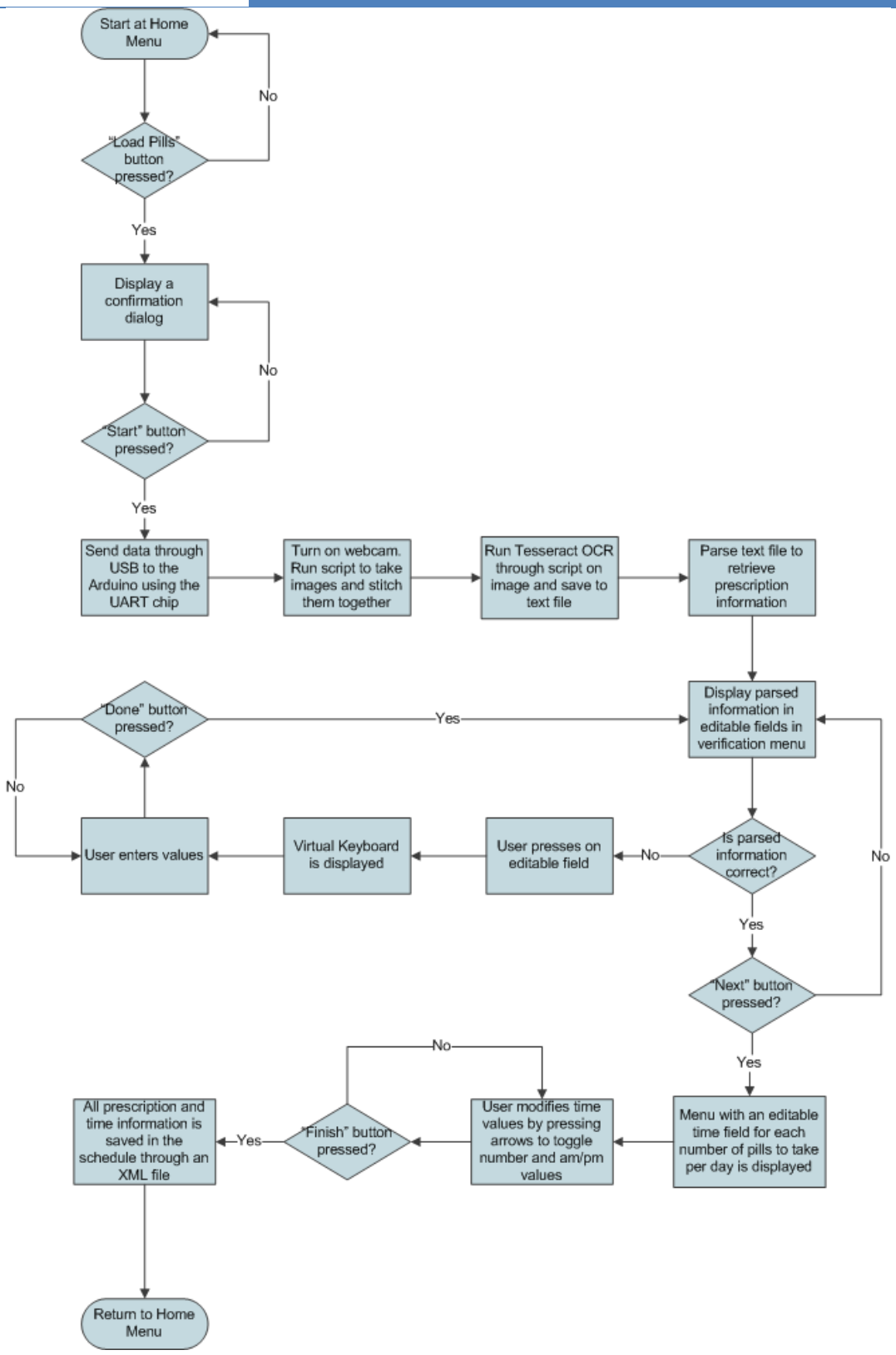


Figure 42 - Pill loading flow chart

3.3.2 *Dispensing menu*

The dispense menu is responsible for allowing the user to signal the product to dispense the scheduled pill. The user is first prompted with a confirmation screen that displays the scheduled pill to be dispensed and details such as the number of pills and whether to take it with food so that the user is sure he is dispensing the right pills. On confirmation the GUI runs C++ code through USB to send instructions to the Arduino microcontroller to control the motors to dispense the pills. Once the pills have been dispensed the user is returned to the home screen.

3.3.3 Calendar

This menu displays the detailed pill schedule in a calendar view. As can be seen in Figure 43, this menu contains a monthly calendar, a list of times, a list of prescriptions, and the details of the chosen prescription. The user is able to select a date on the monthly calendar, which results in the prescription times to be displayed in a list. Selecting one of the times in turn lists the prescriptions to be taken at that time in another list. Finally, selecting a prescription allows the right information pane to display details of the prescription such as prescription number, doctor name, dosage, and whether to take the pill with food.

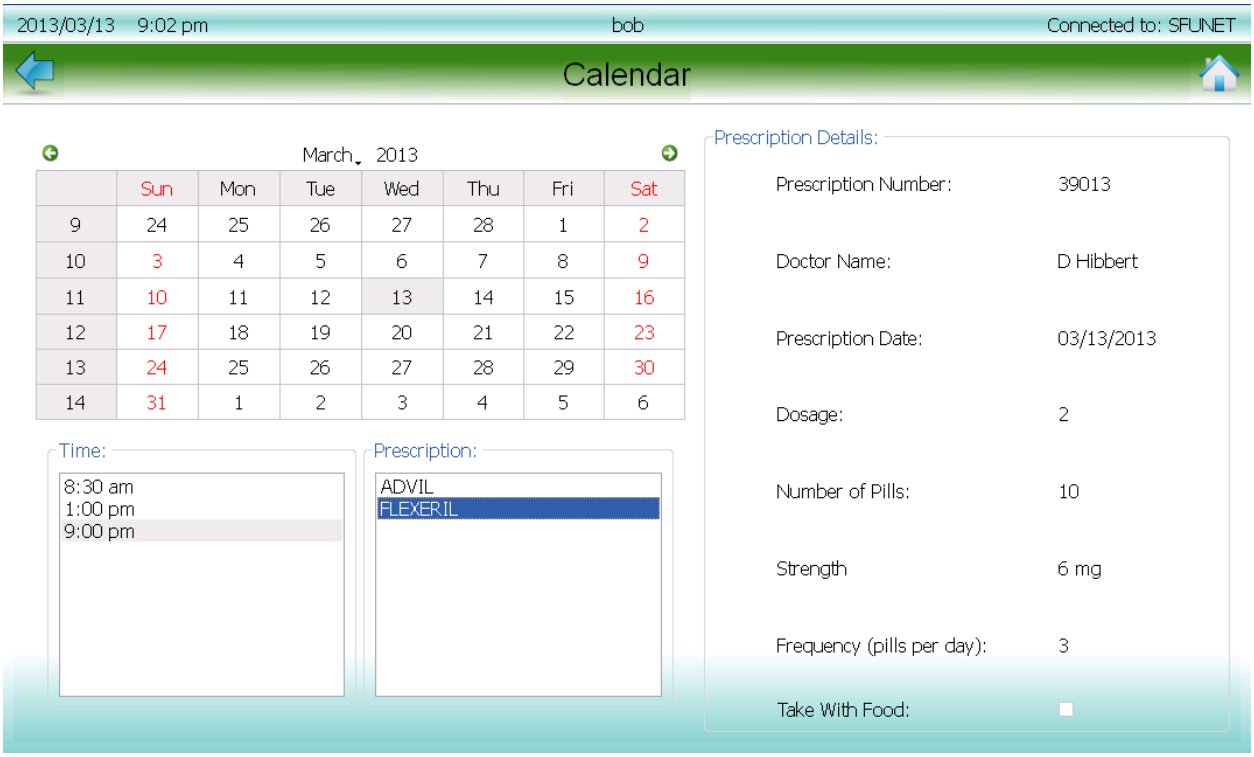


Figure 43 - PillPal calendar page

3.3.4 *Settings*

The settings menu contains all customizable information of the user settings and system settings which include:

1. **Wifi Settings:** Displays all wireless access points within range and its respective encryption by running a Python script that returns the SSID and encryption of all wireless access points that are accessible from the Raspberry Pi. The user will then be able to select a wireless access point and enter a password. Once the password is entered a Bash script is run to connect to the wireless module of the Raspberry Pi and confirmation is displayed in the taskbar.
2. **User Settings:** Displays all the user options obtained from the XML file. User is able to sign in, add a new user, delete a user, edit a user, and view prescription information. The flowchart in Figure # shows the steps in detail.
3. **Brightness:** Displays an adjustable slider that controls the brightness of the touch screen through a Bash script. The value will be stored in an XML file.
4. **Alarms:** Allows the user to choose between three different alarms (more can be added for the prototype and production versions). The user is also able to change the volume through an adjustable slider which controls the operating system volume through a Bash script. These settings will be stored in an XML file. The user is also able to preview the alarm.
5. **Outside Alerts:** Allows the user to enter emergency contact information such as the name, email, and phone of the contact as well as the option to choose whether to send an email, text, or call as well as when to send an emergency alert. All these settings are stored in an XML file.
6. **Power Saving:** Allows the user to toggle between turning on/off power saving. Power Saving turns off modules that are idle as long as they don't conflict with the scheduling.
7. **Help:** Displays the help contents for the product. Not available in the proof-of-concept but will be available for the prototype and production version.
8. **About:** Displays copyright and company information.

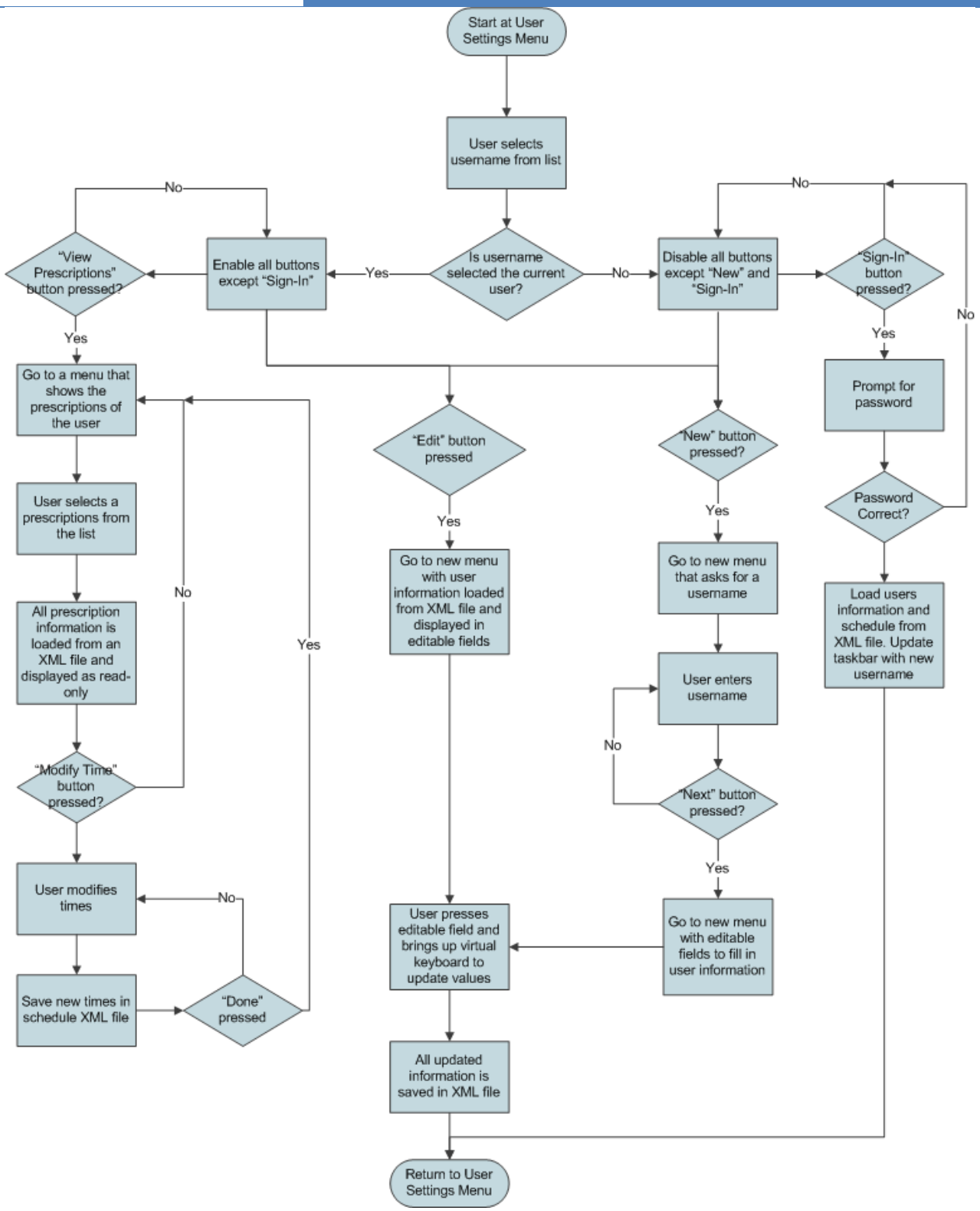


Figure 44 - User setting flow chart

3.4 Scheduler

The scheduling software will be used by the GUI to keep track of pill scheduling for each user. Our team of engineers has designed the scheduling software to ensure that the user is able to customize the time to take their pills as long as it fits within requirements, eg. if the requirement is take a pill 3 times a day the user has the option to choose a time in the morning, afternoon, and evening that suits them. Another key point in the design is to ensure that the user is reminded to take the pill so at the specified time to take the pill an alarm is sounded. This alarm keeps playing until an emergency alert needs to be sent according to the information given by the user. Also to ensure that there is not an issue with unused pills staying in the machine for too long, unused pills will be automatically dispensed into a garbage section after a an allotted time. The flowchart in Figure 45 below illustrates the scheduler:

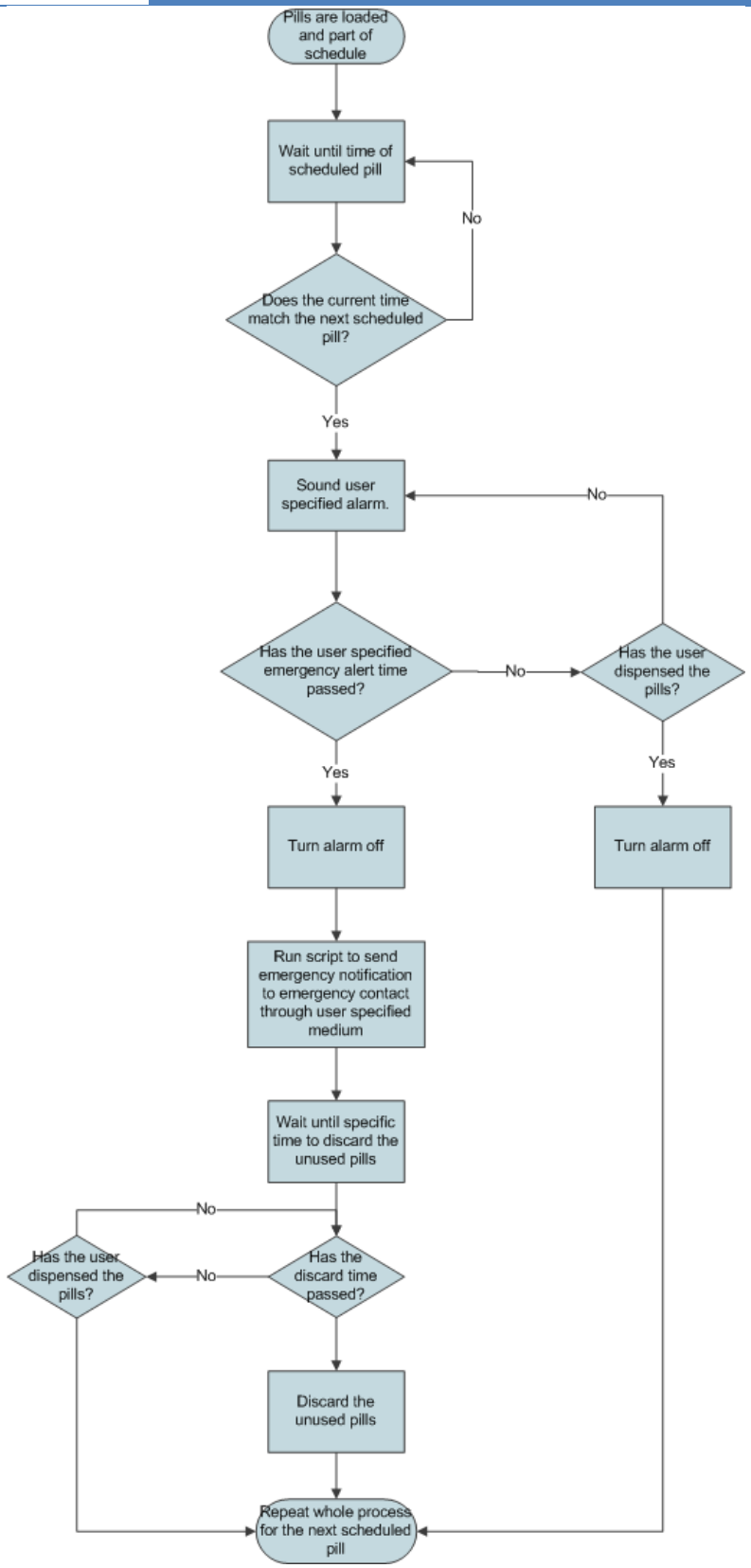


Figure 45 – Scheduler flow chart

3.5 Image Processing/OCR

The image processing component of our software is responsible for using multiple images taken from the webcam to form a single image of the medical label that can be converted to text using OCR software. The image processing software will be written in C++. It will create anchor points in each image and try to match anchor points in adjacent images. Once matched we can ensure that the images are to be concatenated, the matching anchor points are then concatenated to form a single image. This process is repeated until there is only one image.

To retrieve the text from the stitched image of the medical label we are using an open-source OCR software named Tesseract. Tesseract was originally developed at Hewlett-Packard labs and is now open-source and sponsored by Google. It is one of the most accurate OCR software available. [30] Tesseract uses a complex algorithm which first uses adaptive thresholding to convert the image to a binary image. It then does text line finding by approximating baselines by quadratic splines. Finally it uses polygon approximation to match with its dictionary to find the matching letter. [31]

3.6 Data Storage

The software needs to store data for user information, system settings, and the calendar. We need a storage medium that is compact, easily transferred, and has structure. Taking these constraints under consideration, our engineers decided to use the XML format.

“XML is a markup language that defines a set of rules for encoding documents in a format that is both human-readable and machine-readable. [32] XML allows the storage of textual data as well as data structures. “XML was created to structure, store, and transport information”. [33]

To utilize XML files in our software development we will make use of the “QDomElement” library of the Qt framework. The QDomElement provides high-level functions to read and write data to XML files in a specified format. This provides us the benefit of storing and accessing data structures such as dictionaries efficiently.

3.7 SMTP

To provide email reminders for our patients, Simple Mail Transfer Protocol (SMTP) is implemented into the Raspberry Pi. The SMTP is an Internet standard for emailing using the internet. This protocol communicates using Transmission Control Protocol (TCP) port 25. Utilizing open SMTP code, it is possible to send emails and text messages.

The open source code found is called libcurl; it is a multiprotocol file transfer library (http://curl.haxx.se/libcurl/). In the multi-protocol file transfer library is the SMTP. The code requires specific defines to be set in the code. Like generic email, the message or email must be directed to someone and from someone. It is also possible to carbon copy to multiple patients.

```
#define FROM    "<pillpal@gmx.com>"
#define TO      "<charanpreetp@gmail.com>"
#define CC      "<csp6@sfu.ca>"
Example Code
```

Using the predefined functions, the SMTP begins by contacting the SMTP server, which in our case was the GMX server. Following we must enabling the Secure Sockets Layer and Transport Layer Security. Once complete, the PillPal has established a full connection to the SMTP server through a secure network.

The code then prompts the login of the PillPal followed by the password. Once logged in, the PillPal then begins the process of sending emails or messages to correct recipients. The recipients and sender is already defined earlier above and filled into the correct locations. To write the email, a predetermined messaged is fed into a buffer and uploaded as a message for all. The message is checked for its size to ensure a message is being sent and is uploaded to the server. Once uploaded, the message is sent and is immediately checked for errors. If failed, a prompt will appear and inform the device. Otherwise, the message is assumed to be sent correctly. To complete the task, the terminal to the SMTP server is closed and all recipients are removed from the “TO” list.

This will complete the sending of emails and messages to the patients for reminders to take their medications or it can be used to send messages to care takers or loved ones.

3.8 Arduino Software

In order to control the various motors and sensors in our design, we chose to have the Raspberry Pi send commands to a microcontroller. The primary reason for doing so is because of the lack of protection for the IO pins on the Pi itself and we felt that it would be much safer to offload these tasks to an external microcontroller. An external microcontroller would be much easier and cheaper to replace and reprogram if anything went wrong with the control circuits and thus provides an extra layer of protection for the Pi. There were many options to choose from, but in the end we chose to go with an Arduino Uno. Although the Arduino is much more expensive than competitors such as TI’s MSP430, there is a great deal more support and available libraries to use for Arduino. For example, the necessary libraries for the fingerprint reader, stepper motor, and servo motor already exist for the Arduino which allows us to focus our time and effort elsewhere. We feel this benefit justifies the additional cost.

In addition to providing an added level of protection between the hardware and Raspberry Pi, the Arduino Uno has certain functionality that the Raspberry Pi is lacking. In particular, the Uno comes with built in special-purpose features such as dedicated hardware for ADC, PWM, and externally interruptible IO pins. Although it is possible to get an external ADC, code libraries to run PWM, and polling input pins for an interrupt, the fact these features are built into the Uno provides a tremendous benefit. An overview of all these pins can be seen in Figure 46 below.

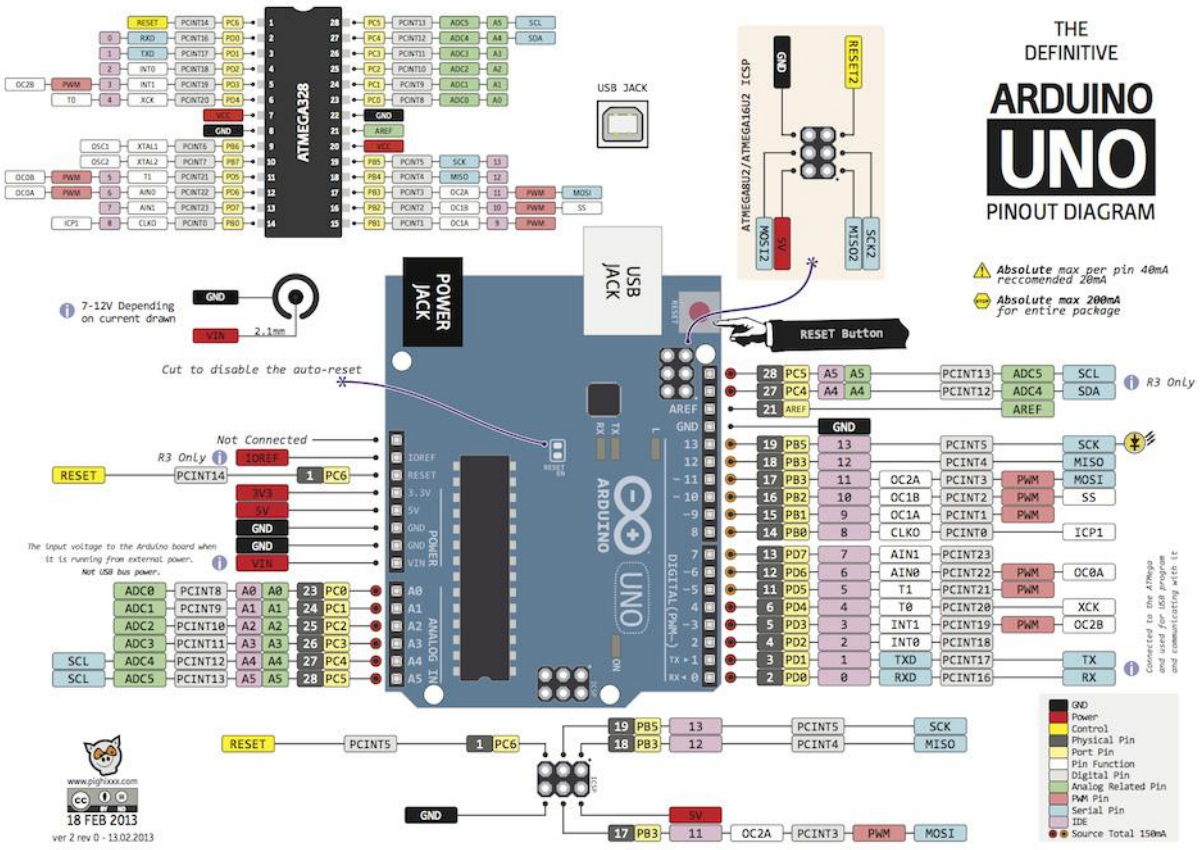


Figure 46 - Arduino Uno Pin Overview

3.8.1 *ADC*

The Arduino Uno is paired with a 6-channel, 10-bit ADC. The corresponding pins are labeled A0-A5 and are essentially just digital pins connected to the ADC. The ADC is necessary to get feedback from the linear motor for its current position by reading the analog voltage from the wiper of the linear motor and digitizing it. This will allow for precision control on the linear motor, which we require for our purposes.

3.8.2 *PWM*

The Arduino is capable of driving up to 6 PWM channels. The PWM signal will also be used for the linear motor in order to control the speed of the motor via an H-bridge chip, which also controls the direction of the motor. The PWM signal controls the speed of the motor by varying the ratio between the ON and OFF time for the motor over a set Period. Having a higher ON to period time ratio, or duty cycle as it is commonly referred, translates into higher average energy provided to the motor, which then translates into a higher overall speed for the motor. The Arduino physically controls the PWM signals by essentially having special registers, which are tied to the clock signals within the Arduino through various counters and clock dividers, toggle the 6 associated Arduino Pins according to the values set in the special control

registers. By having the hardware setup in this way, the PWM pins can effectively be toggled in parallel to the MCU's regular calculations without needing to interrupt current operations taking place making the process extremely efficient.

3.8.3 *Interrupts*

The interrupt pins will be used for counting and checking the number of pills dispensed by the VAM and for checking if the VAM has reached its maximum extension length. Interrupts work by triggering on special conditions for internal and external signals and register of the microcontroller. An interrupt can be triggered on a rising edge of a signal or register, the falling edge of a signal or register, or a certain threshold of a register. These events and triggers occur in parallel with the regular CPU cycle so the microcontroller will not have to dedicate any additional resources to track these events, just enable the interrupt flags for the events desired. Once the event is triggered, the microcontroller will halt whatever it is currently doing and perform the interrupt's subroutine before resuming normal operation. Interrupts themselves are typically set to be uninterruptible to insure there are no sporadic errors while running them. This allows the microcontroller to handle these events in real time and removes the need to poll to check if an interrupt event condition is met, effectively freeing the MCU to perform other tasks in the meantime.

The Arduino only has two external interrupts which we will be using in order to keep track of the number of pills dispensed by the VAM via the pill counter and the other will be to check for if the VAM has reached its maximum extension length. The pill counter works by connecting a photodiode to a Schmitt trigger. The photodiode will count the number of pills by having a laser shooting light energy into it and then triggering the Schmitt trigger whenever a light blocks the laser. The Arduino will then use the output of the Schmitt trigger to have an external interrupt trigger on the falling edge of the Schmitt triggers output in order to count the number of objects dropped between the laser and the photodiode. Since the time between when the vacuum releases the pill and when it begins dropping can vary greatly depending on the pills weight, size, and shape, we felt that it would be appropriate to use an external interrupt as opposed to polling the Schmitt triggers output to reduce the number of calculations required by the Arduino and to allow us to count the pills in real-time. An approximation of the device can be seen below in Figure 47.

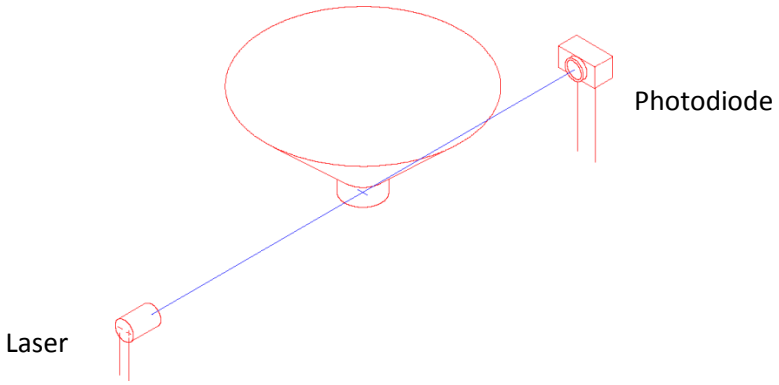


Figure 47 - Pill Detector

The second interruptible pin will be used for a push button attached to the end of the VAM. This will be used to detect when the end of the VAM makes contact with either the end of the pill container or with a pill in order to alert the VAM to stop and begin retracting. We chose to also use an interrupt for this because over extension of the VAM may either damage the pills or the VAM itself so it is critical to stop the VAM from extending at the correct time.

3.8.4 *UART*

The communication between the Raspberry Pi and the Arduino is done using a serial connection. On the Arduino's end, this translates to transceiving serial data through digital pins 0 and 1, which are the dedicated serial pins in the Arduino Architecture. [34] For the Raspberry Pi, the Arduino will simply be connected a USB port on the USB Hub and will show up as serial device within the Linux operating system under */dev/ttySX*, where *X* is the enumerated device ID number. There are also dedicated IO pins for UART communication on the Raspberry Pi, but for simplicity we chose to use the USB port since it would also provide power for the Arduino. The actual communication between the two microcontrollers will be done via UART. The Arduino has a built-in, pre-programmed, Atmel microcontroller to transfer data between the Arduino and a host machine, in this case the Pi. From personal experience and preference, we have chosen to use the default baud rate of 9600.

The UART implementation in the Arduino Uno utilizes a 64 byte long input and output buffer with 8 byte character framing with no parity bit. During transmission the data bits are framed in a byte sized chunk and framed with a start (logic low) and end (logic high). As mentioned earlier the baud rate we use between the Arduino and the Pi is 9600. Baud rate means the symbols per second transmission speed. This means we are transmitting at 9.6 kilobits per second. A device will read from this buffer frequently as there is a hardware interrupt to signal the device to read from the buffer to prevent overflow. The operating speed of the AtMega328 is 16 MHz, meaning each instruction only takes about 86.8 microseconds and we expect to receive a character as quick as every 1.04 milliseconds, which means roughly 5 milliseconds to overflow the buffer. The operating speed of the microcontroller should be sufficiently fast to prevent buffer overflow which results in new arriving data bits to be discarded.

In addition to the serial connection between the serial connection between the Arduino and the Raspberry Pi, the Arduino has another serial connection between itself and the Adafruit Fingerprint Reader. Again using a UART connection, this time with a baud rate of 57600. In the previous case with the Raspberry Pi and the Arduino there was actual hardware dedicated to the UART connection for digital pin 0 and 1. For the fingerprint reader, the UART is incorporated via a software library for Arduino to extend this functionality to the other digital pins on the Arduino completely through software. The drawback for this is that the Arduino's processor needs to dedicate itself to monitoring the serial connection so it is only capable of reading data from one software serial connection at a time. The hardware UART can transceive data at any time as new data received is simply placed into a small data buffer and is thus not limited by how busy the Arduino is at any given time, only by space available in the buffer.

3.8.5 *Servo*

One of the more basics of the Arduino we will use is the Servo library. In order to provide control of the servo motors, a special signal is used. The servo has a microcontroller embedded into it that will read in the signal, in this case a simple pulse width of a varying time length, and then use that signal to turn. The servo will then decode that pulse width into a certain value on its internal potentiometer that needs to be achieved. For one of the servo's we use, this translates into an angle between -90 and 90 degrees. For the other, the potentiometer is removed and there is no limit for how the servo can turn. These are referred to as continuous rotation servos and provide continuous rotation in either direction at very high torque. The previously mentioned are normal servo motors which have limits placed on the amount the internal gears can turn and use a potentiometer as feedback for its current angular position.

3.8.6 *Shift Register*

We utilize the shift register to expand the Arduino Uno's output capacity. We are currently using it to control the illuminator LED, two stepper motor driver control pins, relay control circuit, and two H-bridge control pins. We are utilizing only three control pins to control the shift register: SRCLK (shift register clock), RCLK (register clock), and the SER (serial input). Using only SER and SRCLK pins we first allow data to shift in while holding the current value steady on the 8 output pins. After all the data are written in, we then toggle RCLK and use the rising edge to latch the values from the shift registers in output registers.

3.8.7 *General IO Pins*

The rest of the functionality we use on the Arduino uses the remaining available pins as simple logical inputs and outputs. The optical-interrupter IC, for example, provides a simple digital HIGH or LOW value based off of whether or not the optical signal is interrupted. Using this functionality, we have tagged each pill container with a binary value between 1 and 8 (0001 and 1000) in order to use four optical interrupters to track which container is lined up with the VAM currently. They are connected directly to the Arduino as they have an internal Schmitt trigger to toggle between digital HIGH and LOW. They will read 0000 when there is nothing lined up and a value between 0001 and 1000 when one of the 8 containers is aligned. This removes the need for calibration on boot at the cost of a few more IO pins on the Arduino. We also use a fifth optical interrupter to check if there is a cup placed for pills to be dispensed in, as seen in Figure 48. Since we were limited on the number of external interrupt pins available on the Arduino, we will be polling continuously while the containers are being rotated until the correct container is aligned. Although not ideal, there is not much of waste for the Arduino's resources since the only other task the Arduino will be performing is providing a turn signal to the continuous motion servo connected to the dispensing unit's main shaft and most of the work for this is already offloaded to the servo as is so overall performance should not be an issue. As already mentioned previously, another IO pin is used for the pill counter which functions similarly to a larger optical interrupter

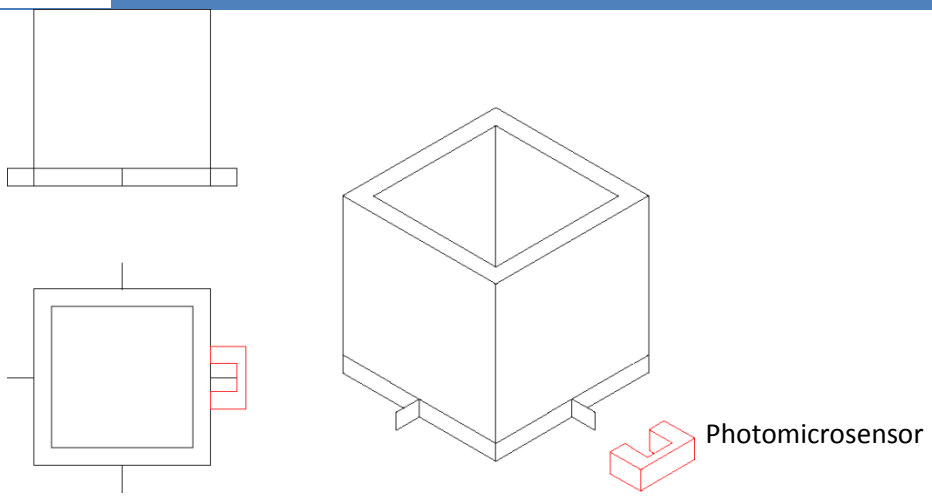


Figure 48 - Dispensing Cup and Photomicrosensor

3.8.8 *Stepper Motor Driver*

The stepper motor driver requires two power rails, 12 V for the motor itself and 5 V for the control logic and other circuitry on the PCB. We control the motor indirectly, using the driver chip (A3967 by Allegro) controlled by the Arduino Uno microcontroller. Four pins connect the two poles of the stepper motor, one to control the direction, one to sleep the device for lower power consumption, and one more to command the stepping action of the motor itself. The driver recommends a 50% duty cycle stepping control line at least 2 microsecond cycles, which is 500 kHz. We utilize simple functions from well supported Arduino libraries to send our command signals to maintain a higher level control over our devices without spending time to work on details and timing sequences which may complicate our prototyping.

The driver chip allows control for a variety of step sizing, but we will simplify our code and design by forcing the driver to operate only at the 1/8th stepping.

3.8.9 *H-Bridge*

The H-bridge is controlled by three pins, two directional pins and an enable pin. The directional pins work by having one set to HIGH and the other set to LOW. Having both HIGH or both LOW will effectively sets the voltage across the motor to be zero since both output pins will be the same. When they one is set to HIGH and one to LOW, there is a potential difference across the motor which allows current to flow through it. The H Bridge by design allows letting current flow in either direction. In our case, having pin 1A set to HIGH and 2A set to LOW, the motor will spin clockwise while having 1A LOW and 2A HIGH causes the motor to spin counterclockwise. All the different cases for the H-Bridge are summarized in Table 5 below. In order to control the speed of the motor, we toggle the enable pin with a PWM signal with the Arduino since pulling enable LOW causes the motor to coast while making it HIGH makes it go in its intended direction. Coupled with the feedback from the sliding potentiometer

built into the motorized slider, which is what the H-Bridge will drive, we can precisely control the position of the VAM and the speed at which it moves.

Table 5 - Truth table for H-Bridge

1A	2A	Enable	Output to motor
0	0	X	Brake
0	1	0	Coast
0	1	1	Counterclockwise Rotation
1	0	0	Coast
1	0	1	Clockwise Rotation
1	1	X	Brake

The wiring diagram and schematic can be seen in Figure 49 and Figure 50. These provide a summary of how the Arduino is hooked up to the various sensors and motors.

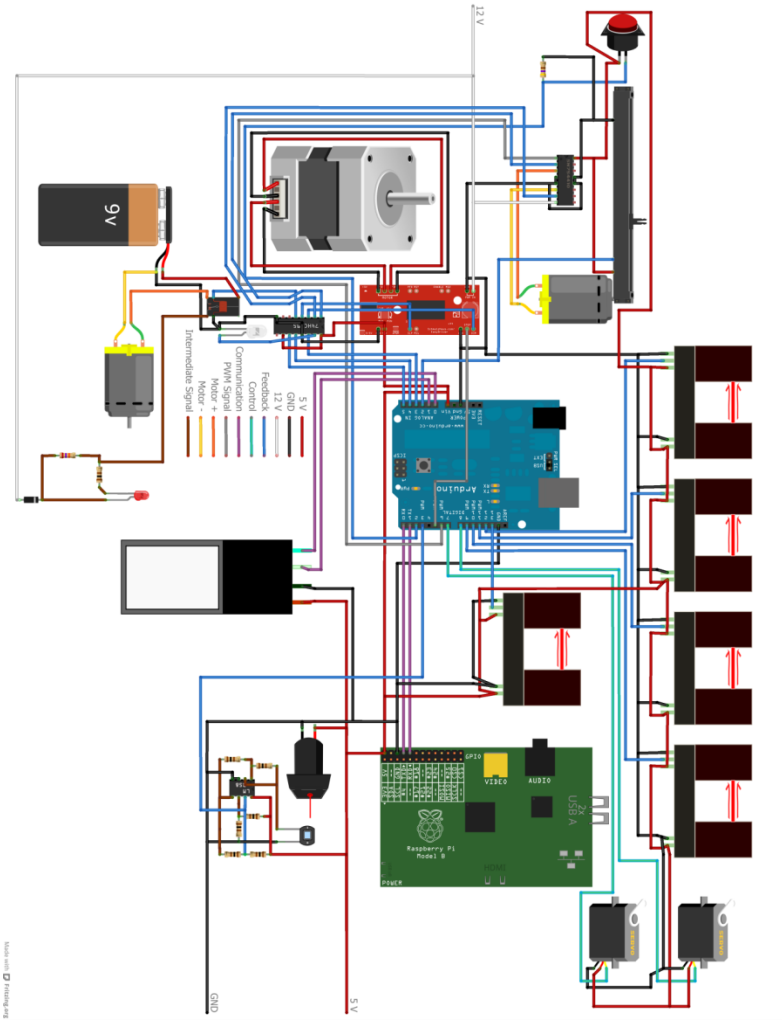


Figure 49 - Wiring Diagram Overview for Arduino

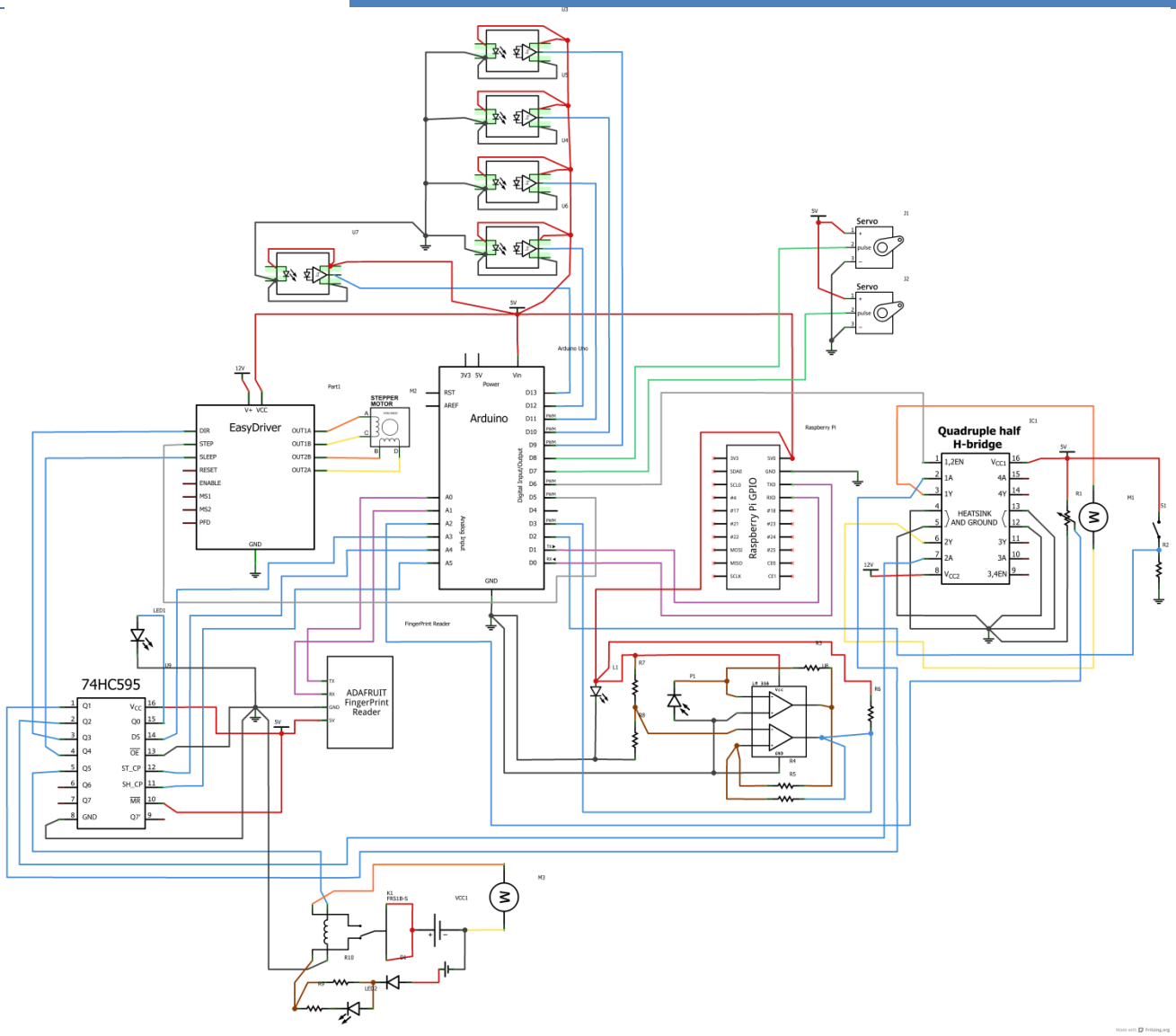


Figure 50 - Schematic Diagram Overview for Arduino

3.8.10 *Arduino Coding*

The Arduino code itself is broken up into two sections. There is the ***setup()*** function, which is run once during the Arduino's boot-up, and then there is the main ***loop()***, which is simply a continuous loop the Arduino will continuously run through, as is typically the case in most embedded systems. This is very useful for us to handle errors from power loss and improper shut downs. Using the ***setup()*** function, we can ensure that all mechanical components are set to their zero positions, for example the VAM is retracted, the VAM is aligned with a compartment, and the garbage pill selector is in the correct position to wait for pills, before resuming normal operation in the ***loop()***. This ensures that the mechanical systems are ready to go when needed and will greatly increase the repeatability for these systems.

The boot up sequence is only one of the ways we intend to ensure that the mechanical components will function safely for the user as well as ensuring that there will be no mechanical failures. While running in normal operation mode, we intend to ensure only one component is used at a time. That means when the Raspberry Pi needs to interact with the VAM, the SPC, or the Fingerprint reader, the Arduino will purely focus on that task. We do this by putting in a hardware mutex of sorts so that the Arduino can only access one piece of hardware at a time until the hardware is done being used and is in a safe operating state. This is particularly important for interactions between the VAM and the SPC since if the SPC begins to rotate while the VAM is extended, the VAM could be critically damaged and thus we need to ensure such a situation does not arise. Also, since the Fingerprint uses a software serial connection to fetch and send data, the Arduino needs to constantly monitor the transmitting and receiving pins in order to transceive the data correctly. Because of these possible errors, the simplest solution is to simply have the Arduino perform one task to completion, or until the user sends a cancel command, before moving onto the next set of instructions.

In order for the Raspberry Pi to communicate efficiently with the Arduino using the Arduino, we need to carefully predefine how the data exchanged will be formatted. Since the UART will exchange byte sized messages, we will limit the size of each command to 8-bits to keep things simple so there will be no need to handle exchanging multi-byte messages. With this in mind, tasks can be divided into tasks related to the VAM, the SPC, the Label Reader, the Fingerprint Reader, or general querying and error passing. Having 4 main categories for commands, we feel it is appropriate to have a 2-bit header to identify the type of commands given and using the remaining 6-bits to specify the exact command and associated parameters required. This will make it easier to debug since each message can be easily broken down into two parts to identify commands quickly, and this makes it easier to modularize the Arduino code for testing and implementation purposes. The message design can be seen below Table 6.

Table 6 - UART Framing bits

Type	Header		Body					
Bit Number	7	6	5	4	3	2	1	0

This allows us to have up to 4 types of commands with 64 different commands each.

As of now, we have broken tasks up as follows:

Table 7 – Commands to be decoded for Arduino

TASK	Required Functionality
General	• Debugging information for task (Verbose or Brief information for everything) • Cancel Commands and Verification where applicable • Query for Arduino busy (time's out when busy)

VAM	• Grab Pill
	  ○ Return Pill grabbed at VAM extension length Y
	  ○ Return fail code if Pill Counter does not detect Pill after 3 tries
	  ○ Return no pills detected (VAM reaches maximum extension length and is unable to pick up any pills)
	• Check number of pills remaining
	  ○ Return length VAM extends to estimate remaining pills

SPC	• Go to Bottle X in direction Z
	  ○ Return Confirmation/Failure (echo Bottle number on success)
	• Go to nearest Container in Direction Z
	  ○ Return Bottle number Y reached

Label Reader	• Rotate Bottle X amount in direction Z ○ Return Success/Failure when attempt is complete

Fingerprint Reader	• Send check status command
	  ○ Return whether or not Fingerprint reader is detected and password verification has passed
	• Return status of Fingerprint reader
	  ○ Return if Fingerprint reader is detected and password verification is successful
	• Enrolment command with accompanying fingerprint slot number
	  ○ Return Ready command when reader is ready for fingerprint
	  ○ Return Success when Fingerprint detected, snapshot taken, and fingerprint needs to be removed
	  ○ Return when Fingerprint check is required for verification and completion of enrollment
	• Send command to check fingerprint
	  ○ Return ID number for fingerprint that is detected and confidence value
	  ○ Return Failure codes according to failure type
	• Send clear all memory command for first time boot to clear enrolled fingerprints

The following figures give a high level overview of the Arduino code: Figure 51, Figure 52, Figure 53, Figure 54, Figure 55, and Figure 56 .

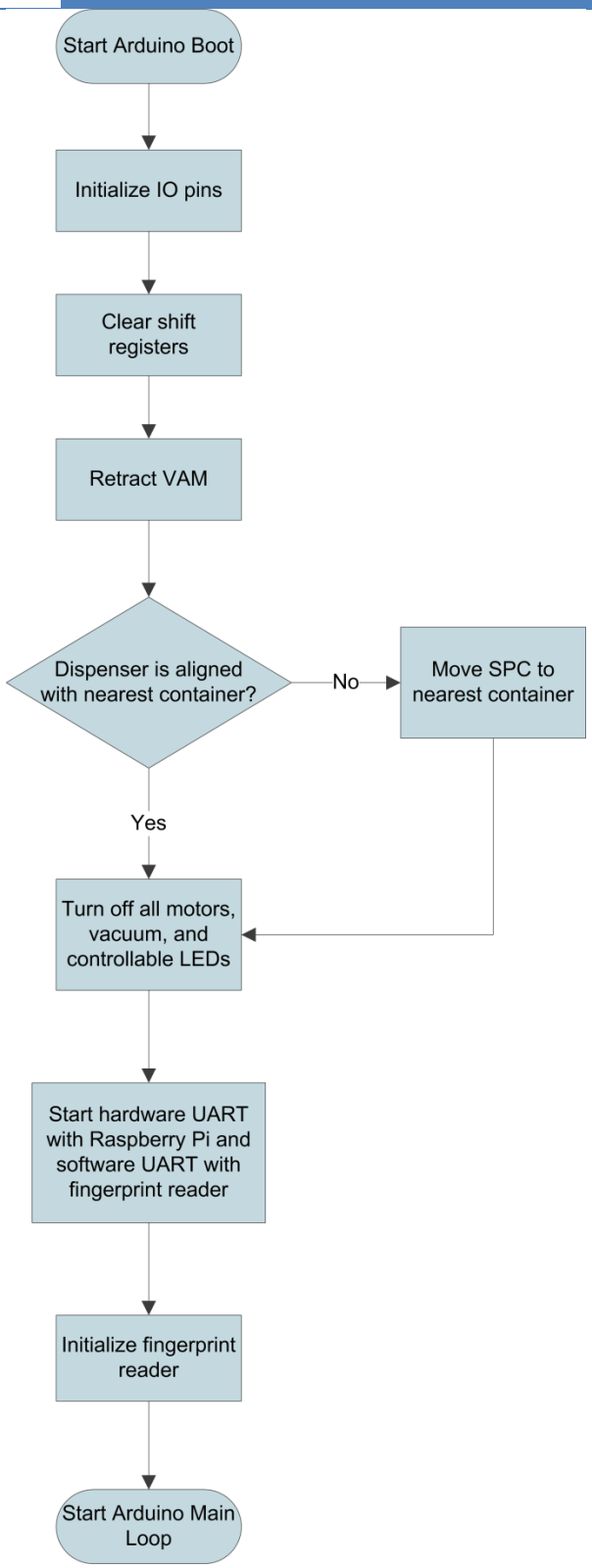


Figure 51 - Arduino Boot up flow chart

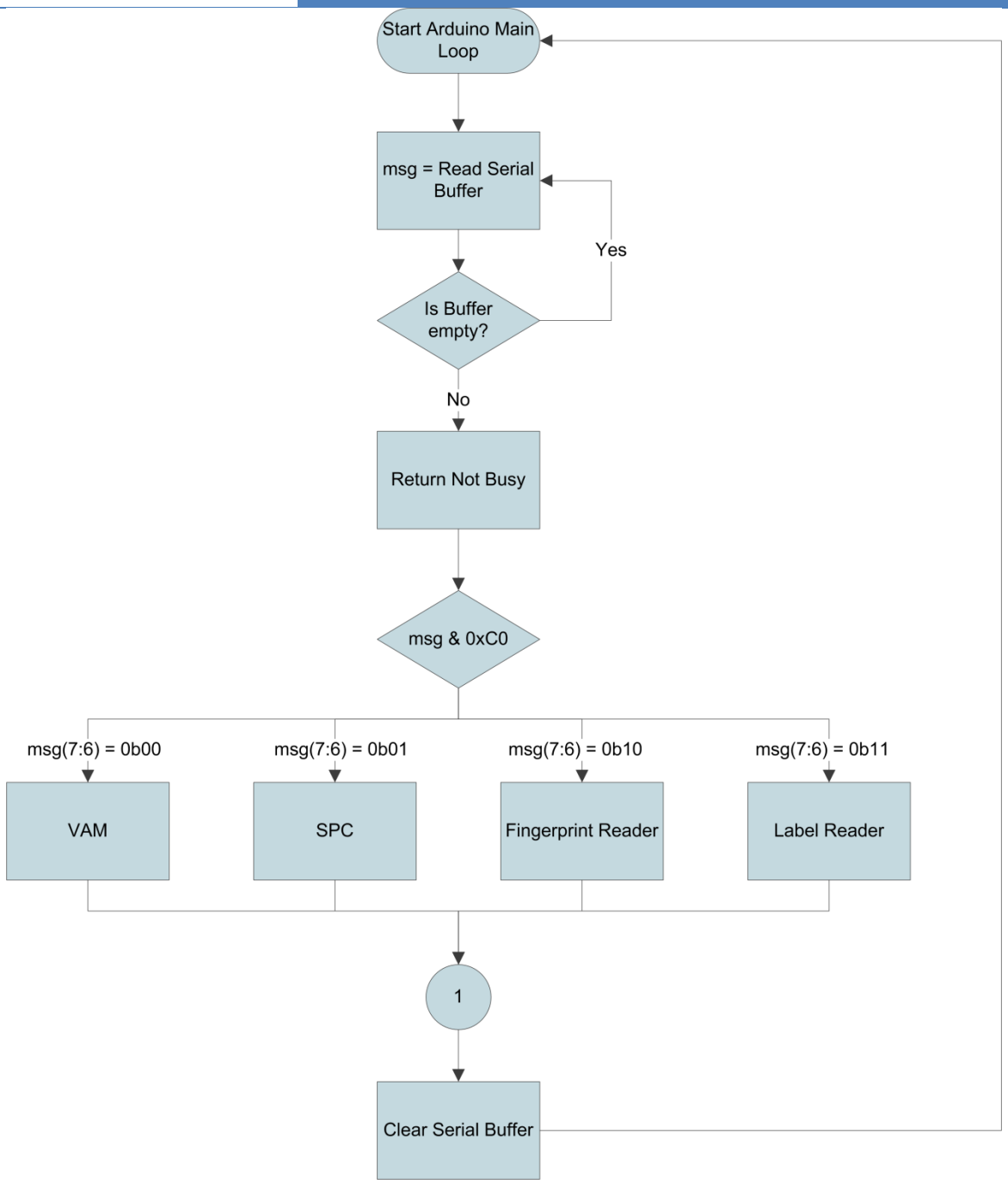


Figure 52 - Arduino Main Loop flow chart

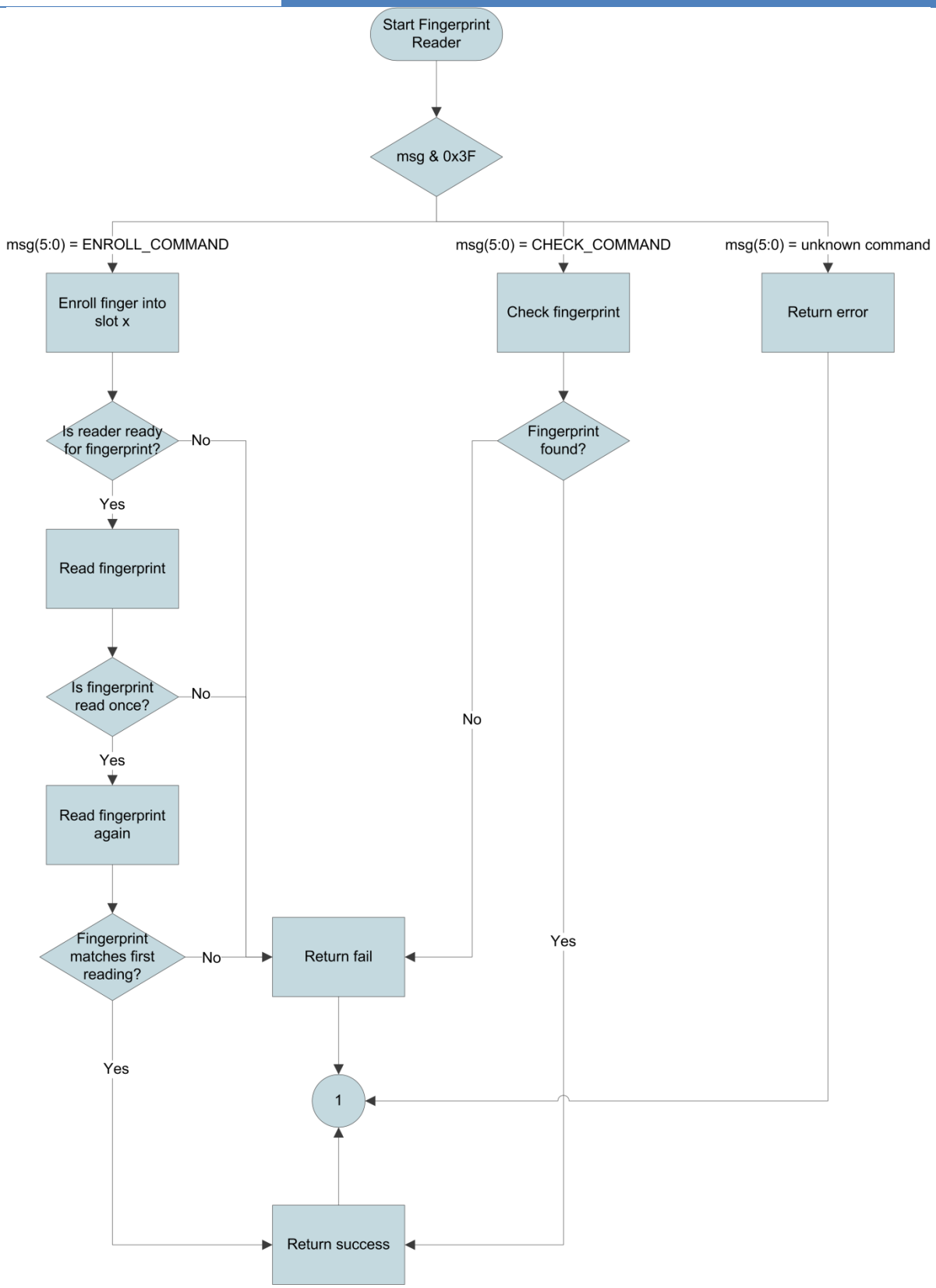


Figure 53 - Arduino Finger Print Reader flow chart

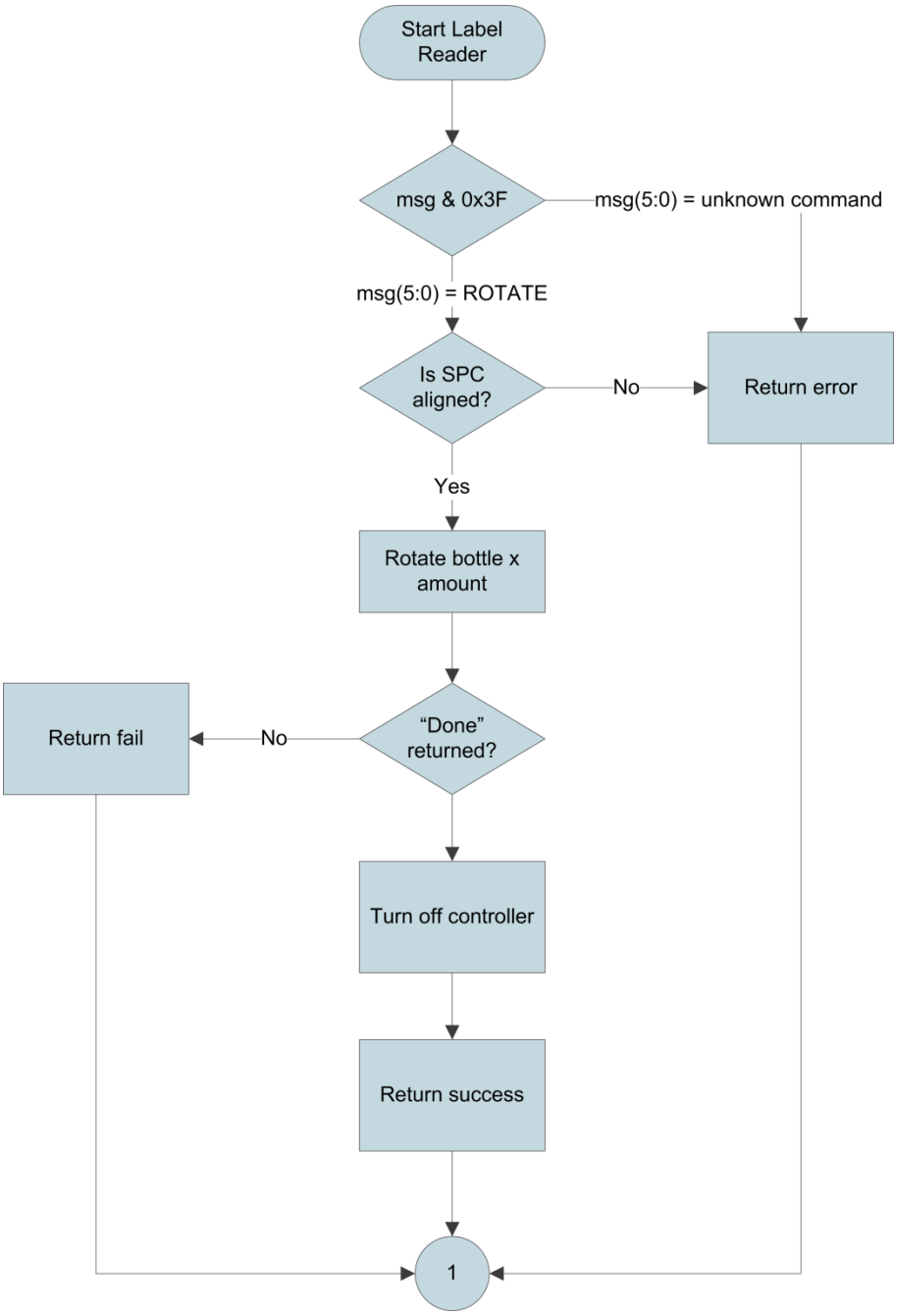


Figure 54 - Arduino Label reader flow chart

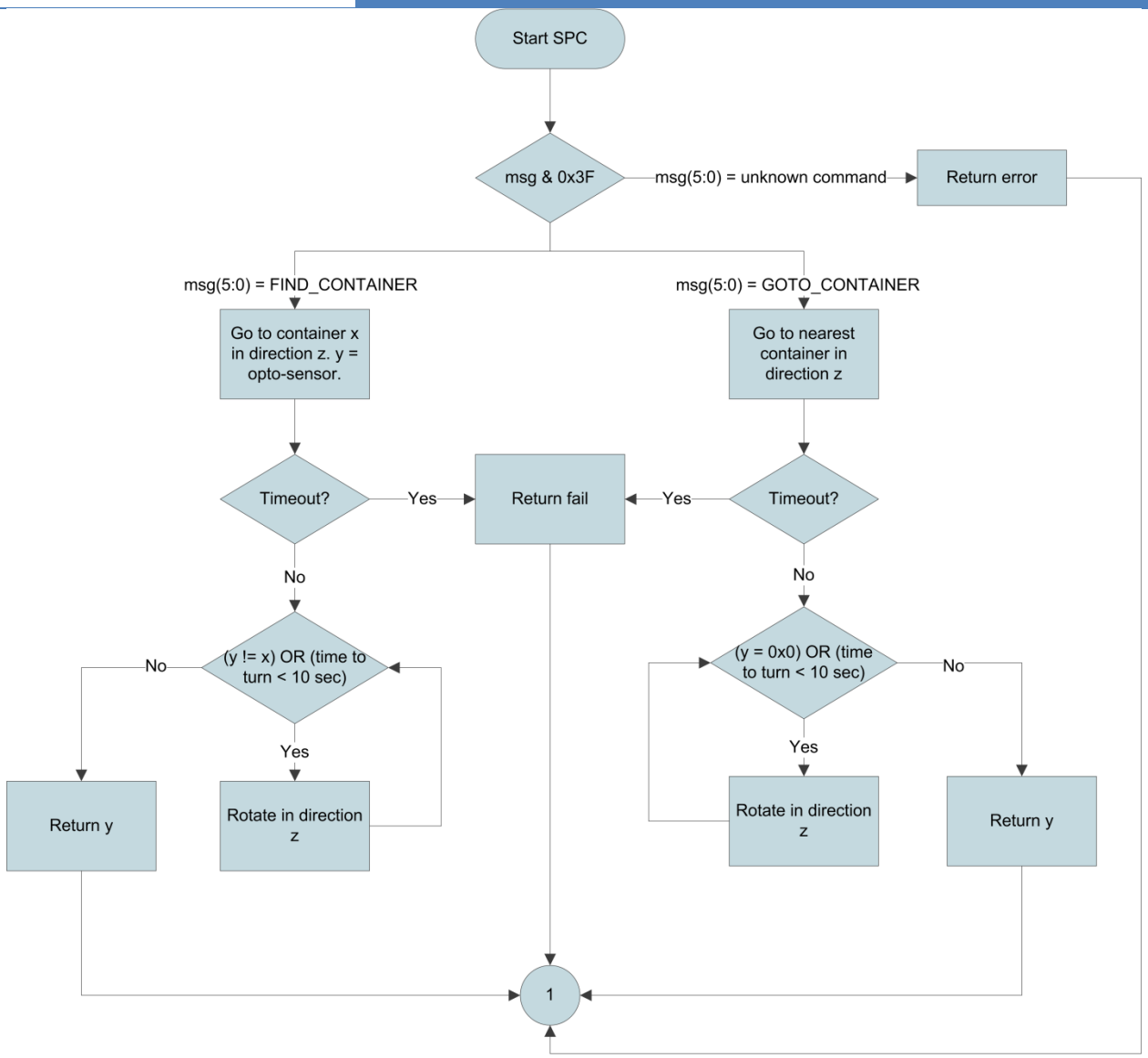


Figure 55 - Arduino Smart Pill Container flow chart

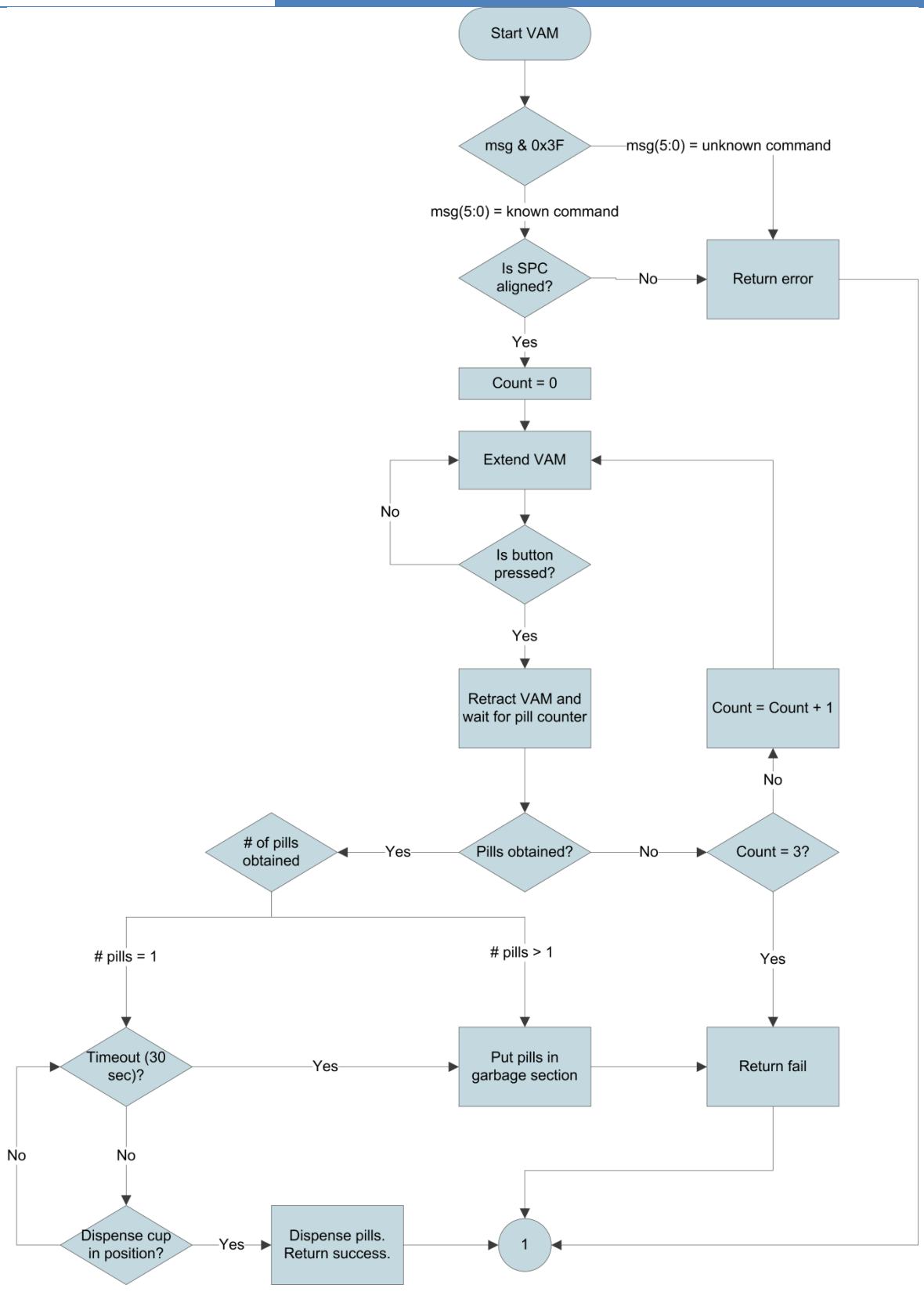


Figure 56 - Arduino Vacuum Arm Manipulator flow chart

4 Test Plan

4.1 GUI Unit Testing

4.1.1 *Navigation Testing*

Task: Test the ability to navigate through each menu of the GUI using the “back”, “home”, and “Finish”/”Done” buttons
Test Steps:

1. Go through each menu and press the back button
2. Go through each menu and press the home button
3. In appropriate menus press the finish/done button

Expected Result: Pressing the back button should take you to the previous menu. Pressing the home button should take you to the home menu. Pressing the finish/done button should take you to the main previous menu.

4.1.2 *Home Menu Testing*

Task: Test the functionality of the buttons on the home menu
Test Steps:

1. Press each button on the home screen

Expected Result: Each button takes the user to its appropriate menu. The general details of the next scheduled pill are displayed on the home screen and pressing it takes the user to the calendar with further details of the pill given.

4.1.3 *Pill Loading Testing*

Task: Test the ability to go through the steps to load pills and edit prescription information
Test Steps:

1. From the home menu press the “Load Pills” button
2. In the subsequent menu press the “Start” button and wait for the system to load the pills
3. Once the pills are loaded verify prescription information read from the medical label
4. Edit information and press the “Next” button
5. Add the times to take the pills and press the “Finish” button

Expected Results: Pressing the “Load Pills” button should take the user to a confirmation screen. Pressing “Start” in the confirmation screen should start the process of loading the pills and reading the medical label. Once that is done all relevant information read from the medical label is displayed in editable fields. User is able to edit each field through the virtual keyboard. When the user presses the

"Next" button a menu with the option to select time for each number of pills to be taken in a day is displayed. The user is able to edit the times. When the user presses "Finish" he is taken to the home screen and all the pill information is stored in the schedule and viewable through the calendar and user settings menus.

4.1.4 *Pill Dispensing Testing*

Task: Test the ability to go through steps to dispense the pills
Test Steps:

1. From the home menu press the "Dispense Pills" button
2. In the subsequent menu press the "Dispense" button and wait for the system to dispense the pills
3.

Expected Result: Pressing the "Dispense Pills" button should take the user to a confirmation screen. This confirmation screen should display the name of the pill to be taken, the dosage, as well as other information such as whether to take it with food. Pressing "Dispense" in the confirmation screen should start the process of dispensing the pills. Once the pills have been dispensed the user is taken to the home menu.

4.1.5 *Calendar Testing*

Task: Test the functionality of the calendar and the schedule
Test Steps:

1. From the home menu press the "Calendar" button
2. In the subsequent menu press on one of the dates shown in the monthly calendar
3. In the list of times select a time
4. In the list of prescriptions select a prescription

Expected Result: Pressing the "Calendar" button should take the user to the calendar menu. This menu should contain a monthly calendar, a list of times, a list of prescriptions, and a details pane. Pressing each date on the calendar should display a list of times that pills are scheduled for on that day. Pressing each scheduled time should display a list of prescriptions that are scheduled to be taken at that time. Pressing each prescription should display all its relevant details such as prescription number, prescribing doctor name, date of prescription, dosage, quantity of pills, strength, and whether to take it with food on the details pane.

4.1.6 *WiFi Settings Testing*

Task: Test the functionality of the WiFi connectivity and settings
Test Steps:

1. From the home menu press the “Settings” button
2. In the subsequent menu press the “WiFi Settings” button
3. Choose an access point to connect to from the list
4. Press the “Connect” button
5. If access point requires a password, enter the password and again press the “Connect” button in the subsequent menu

Expected Result: Pressing the “Settings” button should take the user to the settings menu that displays all the user and system settings. Pressing the “WiFi Settings” button should take the user to the WiFi settings menu. A list of access points with range and the type of encryption is displayed. Selecting an access point and pressing the “Connect” button should automatically connect to the access point and update the status on the taskbar if no password is required. Otherwise it takes the user to a prompt screen that asks the user to enter the password and then press “Connect”. The taskbar should update depending on whether the connection was successful or not. WiFi information is saved so device automatically connects next time it boots.

4.1.7 *Brightness Settings Testing*

Task: Test the functionality of the brightness settings
Test Steps:

1. From the home menu press the “Settings” button
2. In the subsequent menu press the “Brightness” button
3. Move the slider to adjust the brightness

Expected Result: Pressing the “Settings” button should take the user to the settings menu that displays all the user and system settings. Pressing the “Brightness” button should take the user to the brightness menu. Moving the slider should adjust the brightness of the touch screen accordingly. The position of the slider should be saved automatically and be in the same position if leaving and reentering the brightness menu.

4.1.8 *Alarms Settings Testing*

Task: Test the functionality of the alarms settings
Test Steps:

1. From the home menu press the “Settings” button
2. In the subsequent menu press the “Alarms” button
3. Choose an alarm from the drop down menu
4. Move the slider to adjust the volume
5. Press the “Preview” button

Expected Result: Pressing the “Settings” button should take the user to the settings menu that displays all the user and system settings. Pressing the “Alarms” button should take the user to the alarms menu.

Moving the slider should adjust the volume of the operating system accordingly. Once "Preview" is pressed the chosen alarm should play at the chosen volume. The chosen alarm and position of the slider should be saved automatically and be in the same position if leaving and reentering the alarms menu.

4.1.9 *Outside Alerts Settings Testing*

Task: Test the functionality of the outside alerts settings
Test Steps:

1. From the home menu press the "Settings" button
2. In the subsequent menu press the "Outside Alerts" button
3. Edit all relevant information about the emergency contact and when and how to contact them

Expected Result: Pressing the "Settings" button should take the user to the settings menu that displays all the user and system settings. Pressing the "Outside Alerts" button should take the user to the outside alerts menu. All fields should be editable. Virtual keyboard is displayed when trying to edit fields. All information is saved automatically.

4.1.10 *User Settings Testing*

Task: Test the functionality of the user settings
Test Steps:

1. From the home menu press the "Settings" button
2. In the subsequent menu press the "User Settings" button
3. From the list of users choose a user that is the current user
4. Press the "Edit" button and edit all the user information
5. Go back to the user settings menu and press the "View Prescriptions" button and modify times to take the pill
6. Go back to the user settings menu and press the "New" button
7. Enter a username and press the "Next" button
8. Enter user information
9. Go back to the user settings menu and press the "Delete" button
10. Choose a user that is not the current user
11. Press the "Sign In" button

Expected Result: Pressing the "Settings" button should take the user to the settings menu that displays all the user and system settings. Pressing the "User Settings" button should take the user to the user settings menu. The current user should be displayed in the taskbar. All buttons should be enabled when choosing the current user. Pressing the "Edit" button should take the user to a menu that has text fields to enter user information that activate the virtual keyboard when pressed. Pressing the "View Prescriptions" button shows a list of all prescriptions that the user has and selecting a prescription shows details in a details pane. The user also has the ability to modify times to take the pills. Pressing

the “New” button takes the user to a menu with an editable text field to enter a username through the virtual keyboard. Pressing “Next” in this screen takes the user to the same menu as when pressing the “Edit” button. Pressing the “Delete” button deletes the user and the user that is the default user is automatically assigned as the current user. Choosing a user that is not the current user disables all buttons except the “New” and “Sign In” button. Pressing the “Sign In” button makes the selected user the current user. The taskbar and calendar are updated with the newly signed-in user’s username and schedule. All user information in each menu should automatically be saved. The list under “User Settings” is updated for any new/deleted users. Cannot add user with same username.

4.1.11 *Alarm System Testing*

Task: Test the functionality of the alarms to notify user to dispense pills
Test Steps:

1. Have a pill loaded into the device and scheduled
2. Wait for the scheduled time to occur
3. Go to the dispense menu and press “Dispense”

Expected Result: When the scheduled time arrives the user selected alarm should start ringing. The alarm should keep ringing until the given time to send an emergency delay. Going to the dispense menu and pressing “Dispense” should turn off the alarm.

4.1.12 *Outside Alerts System Testing*

Task: Test the functionality of the alarms to notify emergency contacts
Test Steps:

1. Have a pill loaded into the device and scheduled
2. Wait for the scheduled time to occur
3. Wait until the user specified emergency delay time

Expected Result: When the scheduled time arrives the user selected alarm should start ringing. The alarm should keep ringing until the given time to send an emergency delay. After the specified emergency delay time by the user, and emergency alert should be sent to the user specified emergency contact through the user specified medium.

4.2 VAM module

4.2.1 *Suction test*

Task: Test that the Vacuum turns on when required for VAM.
Test Steps:

1. Tell VAM to pick up pill smallest pill

2. Tell VAM to pick biggest pill
3. Tell VAM to pick heaviest pill
4. Test different orientation of the pill.

Expected results: PillPal should pick up and release the different sized pills in all different orientation.

4.2.2 *Pill Container Seeking Test*

Task: Test that will ensure that the VAM can detect Pill containers
Test Steps:

1. Misalign SPC
2. Tell VAM to go to nearest pill container in direction 1
3. Misalign SPC
4. Tell VAM to go to nearest pill container in direct 2

Expected Results: VAM will rotate in direction 1 until the first pill container is aligned . Then it will rotate in direction 2 and find the adjacent pill container in opposite direction,

4.2.3 *Pill Container Selection Test*

Task: Test that will check that the VAM is capable of selecting correct Pill Container
Test Steps:

1. Tell VAM to align SPC
2. Tell VAM to go the container in opposite side going clockwise
3. Tell VAM to return to original container going counter clockwise
4. Tell VAM to return to opposite container going counterclockwise

Expected Results: SPC will rotate 180 degrees clockwise, then 180 degrees counterclockwise and then another 180 degrees counter clockwise, stopping briefly when VAM is aligned with two of the containers.

4.2.4 *VAM Sliding Test*

Task: Ensure VAM extends and retracts correctly and at the desired distance.
Test Steps:

1. Use serial commands to get the Arduino to operate the sliding mechanism.
2. Send commands to move the VAM to different distances and measure the outcome.
3. Get VAM to try and get pill from empty container

4. Get VAM to try and get pill from full container

Expected Results: We expect the VAM to move to precise distance markers as it has a potentiometer feedback and the code controlling the VAM should be able to compensate for any deviations.
In first case, VAM will fully extend and then retract once it hits bottom of container. In second case, VAM will extend slightly before beginning to retract once it detects container is full.

4.3 Label Reader

4.3.1 *Pill bottle Rotation*

Task: Ensure the pill bottle rotates as the stepper rotates
Test Steps:

1. Instruct Arduino to send the stepper motor command via serial commands.
2. Start with ⅛ steps size with small number of steps at a slow speed.
3. Increase the number of steps taken.
4. Increase the speed of stepping.

Expected Results: We should be able to rotate the pill bottles using rubber wheel at a slow speed and small step sizes. We want to be able to maintain accuracy but also rotate the bottle at a reasonable speed. Thus we shall test and obtain the fastest speed of rotation before it fails to rotate the pill bottle as expected.

4.3.2 *Picture taking ability*

Task: To ensure the quality of the pictures taken.
Test Steps:

1. Connect Arduino to the PC directly and use the serial port to send commands to the Arduino.
2. Turn the Illumination LED light on, to ensure proper and even lighting situation.
3. Instruct the Arduino to focus properly.
4. Instruct the Camera to take the picture.

Expected Results: We expect good picture quality with proper lighting, taken at a 90 degree angle. We do not want the picture to be skewed as it will affect our results in stitching multiple images together and OCR.

4.4 Pill Dispenser

4.4.1 *Pill Count Test*

Task: Test that the Pill counter will detect when more than one pill is dropped
Test Steps:

1. Disconnect Vacuum
2. Get PillPal to fetch one pill from somewhere
3. When VAM retracts, dump two pills into funnel for dispenser

Expected Result: Pill Dispenser will dump both pills into Garbage Bin

4.4.2 *Dispenser Cup Test:*

Task: Test that the dispenser will not dispense pills when dispensing cup is missing
Test Steps:

1. Remove dispensing Cup
2. Tell PillPal to fetch a pill

Expected Result: Pill Dispenser will dump fetched pill(s) into into Garbage bin after slight delay. Raspberry Pi will receive “Dispensing Cup Missing Error”

5 Finances

A summary of our finances, including expedited shipping time to speed up development time can be seen in Table 8 - Financial Summary

Table 8 - Financial Summary

Hardware	Cost	Tax and Shipping	
HomeDepot-Building Mics plexi	$45.90	$5.51	
HomeDepot - Acrylic Sheet	$37.06	$4.45	
SPD-SI GEARS x6	$16.93	$23.91	
Stepper	$41.35	$4.96	
Vacuum (for prototyping)	$25.00	$3.00	
	$166.24	**$41.83**	**Sub Total**
		$208.07	**Total**
Electronics and MCU & Pi Miscs	**Cost**	**Tax and Shipping**	
Digi-KEY - Sensors and Miscs	$51.24	$16.91	
Servo-City 0 Servo Gears - Mounting	$50.06	$61.08	
SDHC 8GB- C10	$6.99	$0.84	
WI-FI N USB	$9.99	$1.20	
Finger Print Reader+ PI	$114.90	$13.35	
Spark Fun - Stepper, Drivers, Miscs	$66.54	$46.34	
Coaxil Power DC cable	$2.10	$6.25	
OSEPP Uno R3 Plus	$29.95	$3.59	
TouchScreen 10" LCD LVDS-PI	$128.49	$55.00	
HP 3100 Webcam 720p	$9.99	$1.65	
Belkin Hub 7 Port USB 2.0	$24.99	$3.00	
	$495.24	**$209.21**	**Sub Total**
		$704.45	**Total**
		$912.52	**Final Total**

6 Conclusion

The design specification is written to highlight and give specific dimensions for the design and making of PillPal. Based on the functional specification documentation, the design specification will serve as a guideline when implementing all functional requirements. With the provided clear and concise information we are expected to complete a working proof-of-concept by the April 22nd, 2013.

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8 Appendix - Hardware Test Checklist

Hardware

1.	Electrical and Mechanical			Comments:
	Power Supply Rails are within 10%: 12V, 5V, 3V:	Yes ____	No ____	
	Power Cord is detachable:	Yes ____	No ____	
	Speaker is able to achieve 90 dB:	Yes ____	No ____	
	Motors are secure and operate without significant vibration:	Yes ____	No ____	
	Rotational devices are secure and rotate freely without resistance:	Yes ____	No ____	
	Noise levels are below 60 dB:	Yes ____	No ____	
	Laser is secure and does not pose a threat to the user:	Yes ____	No ____	
	VAM is able to pick up a single pill at a time:	Yes ____	No ____	
	VAM is able to drop the pill precisely 99% of the time:	Yes ____	No ____	
	Stepper Motor dispensing safety stopping mechanism is able to accurately discard or dispense the desired medication:	Yes ____	No ____	
	Laser Sensor is able to trigger on object sliding	Yes ____	No ____	

	by:		
	Power supply can supply sufficient current to run all the motors:	Yes ____	No ____
	Devices do not restart or fail when the vacuum motor starts and stop:	Yes ____	No ____
	VAM is able to have feedback about the relative position:	Yes ____	No ____
	VAM is able to detect when it touches objects when it is extending:	Yes ____	No ____
	Pills empty completely into our storage container:	Yes ____	No ____
	Each storage containers are uniquely and accurately identified by our Photo micro sensor:	Yes ____	No ____

2. Arduino Controls — Comments:

	Able to clearly display its current control state back to the Pi.	Yes ____	No ____
	Able to control stepper motor via the EasyDriver.	Yes ____	No ____
	Can accurately send commands to the stepper.	Yes ____	No ____
	Arduino have fast executing main loop code and interrupt code without missing external hardware interrupt	Yes ____	No ____

	signals.		
	Able to communicate with the fingerprint scanner and authenticate users.	Yes ____	No ____
	Can successfully control both servo motors and obtain accuracy and repeatability.	Yes ____	No ____

9 Appendix - Software Test Checklist

Software

3.	GUI			Comments:
	Taskbar shown in every menu:	Yes ____	No ____	
	Taskbar displays current date and time:	Yes ____	No ____	
	Taskbar displays username of current user:	Yes ____	No ____	
	Taskbar displays WiFi connectivity status:	Yes ____	No ____	
	All menus navigable aside from waiting/progress menus?	Yes ____	No ____	
	All editable fields such as text edits display on-screen virtual keyboard when pressed:	Yes ____	No ____	
	All editable fields can be modified by what the user types on the virtual keyboard:	Yes ____	No ____	
	Virtual keyboard maps buttons to text correctly:	Yes ____	No ____	
	Home menu displays next scheduled pill:	Yes ____	No ____	
	Home menu buttons have icons:	Yes ____	No ____	
	Ask for confirmation	Yes ____	No ____	

	before loading pills:		
	Ask for confirmation before dispensing pills:	Yes ____	No ____
	Show details of pill to dispense in dispensing confirmation:	Yes ____	No ____
	Waiting/progress menus displayed when Raspberry Pi is communicating with the Arduino:	Yes ____	No ____
	Displays the schedule in a monthly calendar:	Yes ____	No ____
	Able to view times and prescriptions in each time for a particular day chosen in the monthly calendar:	Yes ____	No ____
	Displays OCR results in editable fields:	Yes ____	No ____
	Allows user to edit OCR results:	Yes ____	No ____
	Displays nearby access points in WiFi settings:	Yes ____	No ____
	Displays prompts to enter passwords when and where applicable:	Yes ____	No ____
	Displays lists of users:	Yes ____	No ____
	Displays menus for user settings/control:	Yes ____	No ____
	Displays user's prescriptions as read-only:	Yes ____	No ____

	Displays menus for system settings:	Yes ____	No ____
	Displays "About" information:	Yes ____	No ____

4. Raspberry Pi to Arduino communication — Comments:

	Arduino can echo what Raspberry Pi sends:	Yes ____	No ____
	Raspberry Pi can signal Arduino to start loading pills:	Yes ____	No ____
	Raspberry Pi can signal Arduino to start dispensing pills:	Yes ____	No ____

5. User Settings — Comments:

	Can create a user:	Yes ____	No ____
	Cannot create a user with duplicate usernames:	Yes ____	No ____
	Can only edit signed-in user:	Yes ____	No ____
	Can only view prescriptions of signed-in user:	Yes ____	No ____
	Can sign into another user:	Yes ____	No ____
	Signing in requires authentication through fingerprint reader:	Yes ____	No ____
	Default user automatically signed in at system bootup:	Yes ____	No ____
	Can only delete signed-in user:	Yes ____	No ____

	Deleting default user automatically assigns another user as default arbitrarily:	Yes ____	No ____
	Raspberry Pi can signal Arduino to start dispensing pills:	Yes ____	No ____

6. Schedule — Comments:

	Software determines how many days to take the pill based on prescription date, dosage, number of pills, and how many to take per day (frequency):	Yes ____	No ____
	User able to specify pill times for each pill when loading:	Yes ____	No ____
	Pill times are modifiable after loading:	Yes ____	No ____
	Able to take multiple pills of multiple prescriptions on the same day and time:	Yes ____	No ____
	Cannot schedule duplicate prescriptions if date ranges overlap:	Yes ____	No ____
	Prescriptions removed from schedule once they are finished:	Yes ____	No ____

7. System Settings — Comments:

	Adjust brightness of screen:	Yes ____	No ____
	Adjust volume of Raspberry Pi OS:	Yes ____	No ____

	Connect to WiFi network:	Yes ____	No ____
	Change to different alarm types:	Yes ____	No ____
	Able to preview alarms:	Yes ____	No ____

8. Data Storage — Comments:

	User settings stored in XML file:	Yes ____	No ____
	System settings stored in XML file:	Yes ____	No ____
	Schedule stored in XML file:	Yes ____	No ____
	Able to save/load all user settings, system settings, and schedule from XML file:	Yes ____	No ____

9. Image Processing — Comments:

	Able to concatenate multiple images:	Yes ____	No ____
	Able to concatenate images at correct points:	Yes ____	No ____
	Concatenated image is clear and recognizable (no overlap or extra spaces):	Yes ____	No ____
	OCR able to translate image into text with 90% accuracy:	Yes ____	No ____

10. Scripts — Comments:

	Script to get all available wireless access points in range and their	Yes ____	No ____

	encryption settings:		
	Script to connect to wireless access point with password:	Yes ____	No ____
	Script to control touch screen brightness:	Yes ____	No ____
	Script to adjust Raspberry Pi OS volume:	Yes ____	No ____