MAKER: Automated Pill Dispenser

Mr. Christopher Chariah, Vaughn College of Aeronautics and Technology

Christopher Chariah is a senior in the Mechatronics Engineering program at Vaughn College of Aeronautics and Technology. He also has a Bachelor's of Science in Respiratory Care. He hopes to merge his expertise in the medical field with his experience in engineering to develop innovative solutions to human problems. He has published a paper that takes a numerical approach to computing a one story structures response to an earthquake. He is also a member of the Vaughn College UAV Club and is volunteering in an NSF research project.

Nicholas Kumia

Senior in the Undergraduate Mechatronics Engineering Program at Vaughn College

He graduated high school at the age of 16 and has completed the 4-year Mechatronics Program in 3-years. Recently, He co-founded the UAV (Unmanned Aerial Vehicles) Club at Vaughn College and has been working as Lead Programmer. He plans to pursue a master's degree in Computer Science to supplement this expertise in Mechatronics Engineering.

Mr. Jonathan R. Zubarriain, Vaughn College of Aeronautics and Technology

Jonathan Zubarriain is a senior in the Mechatronics Engineering program at Vaughn College of Aeronautics and Technology. He is co-founder of the Vaughn College UAV Club and has held the position of vice president for two years. He has worked full time as a bench technician while also attending school full time in pursuit of his bachelor's degrees. As much as he loves acquiring knowledge, he also loves sharing this knowledge with other students by working as a student instructor and tutor. He hopes to one day utilize his experience in an impactful and meaningful way.

Dr. Shouling He, Vaughn College of Aeronautics & Technology

Dr. Shouling He is an associate professor of Engineering and Technology at Vaughn College of Aeronautics and Technology, where she is teaching the courses in Mechatronics Engineering and Electrical Engineering Technology. Her research interests include modeling and simulation, microprocessors and PLCs, control system designs and Robotics. She has published more than 45 journal and conference papers in these research areas.

Dr. Hossein Rahemi, Vaughn College of Aeronautics and Technology

Dr. Hossein Rahemi is a professor and department chair of Engineering and Technology at Vaughn College of Aeronautics & Technology. He is the author of two books, Vaughn College Journal of Engineering and Technology (VCJET), numerous conference papers in the areas of solid mechanics, computational mechanics, vibration analysis, fracture mechanics and reliability analysis. He is also a principle investigator for the NSF S-STEM grant and the HIS-STEM grant and a student adviser for a number of technical papers in the areas of mechanics, robotics and industrial automation.

A Low Cost Automated Pill Dispenser for At-Home Use

Abstract

This paper outlines a project idea for an Automated Pill Dispenser (APD) for home usage. It is developed using CAD software, 3D printed parts, Arduino Mega Microcontroller, continuous and non-continuous servos, optical sensors and a 5-inch LCD display interface to create a cost effective and reasonably priced alternative to the traditional medication dispensers. The design is modular and able to house up to four dispensing units on one control unit. The basic housing for the dispensing unit consists of three pieces which connect to the control unit which holds the LCD interface. The target users for this project are senior citizens. According to an article published in the New England Journal of Medicine, between 2007 and 2009, 99,628 emergency room visits were made by seniors. Two thirds of them were due to accidental overdoses. The design of the machine could be improved by adding a safety measure that would prevent an incorrect amount of pills being dispensed. Aside from this, the current design is effective in showing the potential safety benefits of a low cost at-home pill dispenser.

Keywords: Medical Assistance, Automation, Commercial Modular Design, C++ Programming

Introduction

On December 2nd, 2015 the population of the United States was 322 million people, of which 14.5% of Americans were age 65 or older. According to the Administration on Aging, by 2060, there will be about 98 million older persons, more than twice their number in 2013, accounting for 21.7% of the population by 2040[1]. As of 2014, 34% of the 4 million prescriptions filed, were for people over 65. This group also accounted for 30% of all over the counter (OTC) drug use[3]. An article published in New England Journal of medicine, estimated that annually from 2007 to 2009 there were 99,628 emergency hospitalizations for adverse drug events in individuals 65 years and older, with two thirds due to unintentional overdoses, 88 percent of which were preventable, compared with 24 percent among young persons[4,2]. According to the New England Healthcare Institute (NEHI) this amounts to a staggering estimated cost of $21 billion in annual US healthcare spending[6]. In just outpatient costs alone according to NEHI it was estimated that preventable medication errors cost $4.2 billion per year[6]. To address this, need in the market, a medical device was proposed that would automate home prescription usage, resulting in reduced errors. It had to be affordable, and simple to operate while meeting the safety standards current medical devices require. The proposed device was named APD an acronym for Automated Pill Dispenser.

Automated Pill Dispenser (APD) is a medical device designed for home usage. The purpose of this machine is to reduce drug errors by automating the dosage process for patients, through the use of visual, and auditory prompts, that tell a patient when, and how much medication should be taken. While the idea of a medication dispenser is not new, all current pill dispensers on the market require the user to presort their medications. This leaves room for error, by patients and caregivers while requiring a significant amount of work by the user. Additionally, most machines only hold a limited amount of medication that varies significantly based on medication size, and amount taken. In some cases, certain machines capacity is reduced to a 7-day supply with a user who requires 3 medications per day compared with a 30-day supply for one medication per day. Comparing this with APD, each compartment holds a thirty-day supply of medication, calculated based on common medication vial volumes. APD also removes the need to presort medication, as by isolating each medication to a compartment the machine can now count each dosage individually. It is hoped that APD results in a significant reduction of the 88 percent of preventable overdoses, as well as emergency hospitalizations due to accidental overdoses[4], in the US which have been estimated to cost $21 billion in annual US healthcare spending according to the NEHI study, by reducing the total outpatient preventable medication error cost of $4.2 billion per year.[6]

Hardware and Design

APD was designed to have dimensions of 7×9×5 in^3 (17.8×22.8×12.7 cm^3) as shown in Figure 7. This would allow APD to fit in nearly every room of a home, as well as provide portability. One of the goals of APD was it had to be cheap to manufacture, and affordable which meant a simplistic design. The solution to this was to use CAD software and 3D printing for most of the structure as it resulted in a low manufacturing cost, and strong, light structure. The user interface had to be designed to allow a patient to have as simple a user experience as possible. This was accomplished by various prompts and asking the user answer a few simple questions. After the user selects the option to add medication, and indicates which unit to fill, the user will be asked a series of questions. APD will ask the number of times per day the medication is indicated to be taken, the number of days per week it should be taken, and the number of pills that is indicated on the vial. After this the machine will calculate the dosage times, and use a timer to display time until the next dose. When it is time for the patient to take their medication, an LED will light to indicate the dispensing unit where the medication will be dispensed from. Additionally, a prompt on the screen will ask the user to confirm, that they want the pill to be dispensed. Only when the user chooses to, will the pill actually be dispensed.

The mechanism by which the pills are counted involves two rollers. One roller will be turned by a servo, and the other will be free spinning. As a pill passes between the rollers the friction between the rollers, will force only one pill out at a time. This is due to both spacing between the rollers and the actual sizes of the pill. The spacing and size of the rollers used for the design were determined by experimentation, as well as research. According to a FDA study, the recommended pill size is not to exceed 17mm in its largest dimension[5]. Given that this is an extreme we spaced the rollers 15mm apart to pass what we felt was a slightly larger than average pill. Additionally, the flexibility of the sponge was taken into account, as the shaft design is 3mm and the sponge 7.5 mm in diameter. This allows for an additional 1 mm or 2mm to be squeezed out of the roller allowing a 17mm pill to pass. To prevent any additional medication from passing through the rollers, as soon as a pill passes a sensor, the rollers would reverse. Since there is no space between the rollers the pills would sit on top without being in danger of falling. This mechanism was developed, and tested and will be further discussed later.
To detect the presence of a pill being passed through the roller, a photocell was used. It is mounted below the rollers on the bottom plate seen in figure 6. The sensors are spaced approximately 30 mm apart. This is due to the size of rollers. The photocell works by sitting in a sleep state until the light is interrupted. When the light stream is interrupted the counter built into the code counts this as a pill. This triggers the servo to stop turning and reverse a half a turn from its current position, which will place any remaining pills on the rollers back in the chamber. All pills that drop from the roller are carried out of the container on a built in ramp to an external collecting bin.

Figure 1: *40 Dram Medication Vial*

In designing the holding chamber, the volume of a standard medication vial was considered. A 40-dram vial was the targeted volume for the chamber size as this is safely larger than the typical 8-30-dram vial. The dimensions were based off of Figure 1.

Using the height of the container and the width we were able to design a container that would hold the equivalent of at least 40 drams of medication. As mentioned earlier, because the rollers were designed for a maximum size of 17mm, the opening through which the medication passed from the container to the rollers had to at least fit that size. A dimension of 1.5cm x 1.9cm opening was used to allow the medication to fall out in one direction in its longest dimension. This design choice was chosen not because of the size of the rollers but rather to slow the flow of medication from the chamber onto to the rollers. This meant that the width dimension was chosen as 15mm, to allow the most common sizes to pass through in the width but larger medication would not, preserving more area on the rollers to hold the medication.

In order to verify the design of the dispensing mechanism with the roller device, a prototype was created to test the roller system. The experiment indicated that when rotated at a slow enough speed only one pill falls from the rollers one at a time. As previously mentioned the idea for the mechanism revolved around being able to choose pliable material that would still create enough fiction to have the pills “stick”. For the test rollers Scotch Brite Dobie was chosen for its fine gritty surface and soft pliable nature. It was also readily accessible cost less than a $3.00 per pair of rollers. For the design we cut the sponge to a 7.5mm thick piece. Two of these were glued together to make one 15mm roller. Below in Figure 2 is a picture of the various pill sizes and shapes used to test the mechanism.

Figure 2: *Tested Pill Medication*

The pills in Figure 2 were chosen for their size and shape. As can be seen in the picture, some of the pills were larger than others which allowed us to test the flex in the sponge and the shafts. While some bending was present it is not significant enough that the strength of the shaft was ever in danger being compromised. In Figure 3 seen below, a time lapse is shown using the red pills for clarity. Each frame shows the pills being passed through the rollers starting from left to right, row by row. Beginning at the third row, the pills being passed through the roller are shown from the bottom view, until the last frame which shows a pill has dropped. Notice the last row of the picture shows that a single pill is left in the roller. After this any remain pills can be reversed back to the top of the roller. From our testing we found that a 7.5-inch roller diameter with a shaft size around 3mm was ideal separating the pills with a distance of 10.5mm between the rollers from shaft center to shaft center.

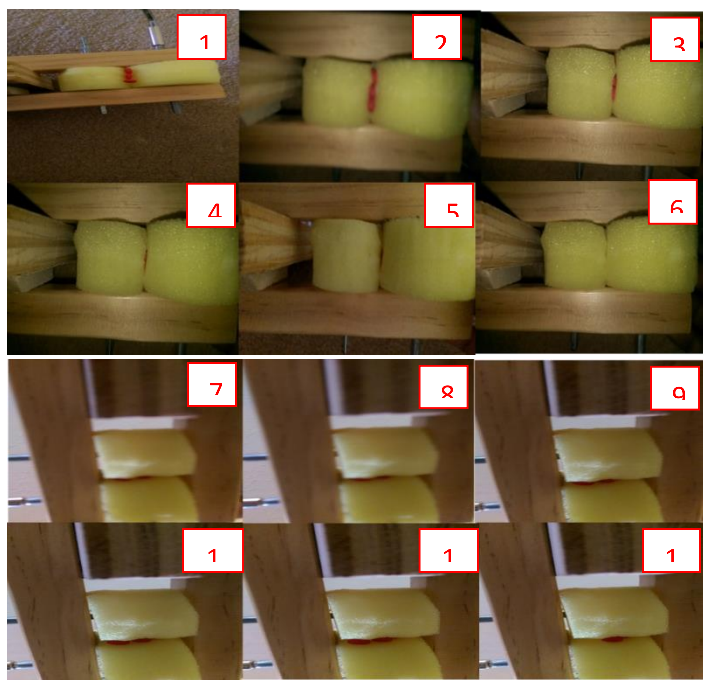


Figure 3: Time-lapse of dispensing mechanism. Photos 1-6 are seen from above and photos 7-12 are seen from below.

Manufactured Parts

I. *Control Unit*

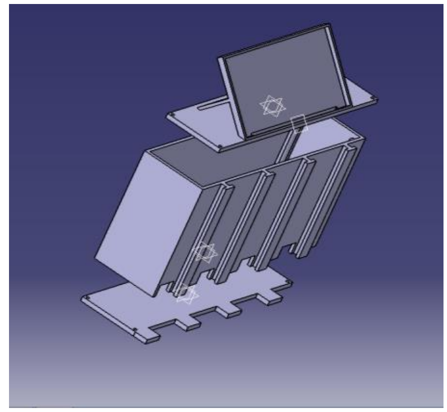


Figure 4: *APD Control Unit*

- The control unit's primary purpose is to house all the main electrical components and the LCD screen.
- *Dimensions:* 209.5mm× 68.5mm X 132.3mm
- *Screen:* 125mm X 61.3mm @ angle 50 degrees
- *Houses:*
  - Arduino Mega Microcontroller
  - LCD TFT screen
  - Driver Board
  - Female Header Pins
  - Proto-board
- *Assembly*:
  - M3 screws: Machine screws for metal and plastics

1. Design:

   The control unit will not only house the microcontroller, but also create a place to mount each dispensing unit. Each unit will attach to the ribs seen on the unit above. Each rib is approximately 10mm wide, a width chosen based on past experience with 3D printing for strength. In order for the control unit to connect with the electronics housed in the unit a locking system was created. On the bottom plate seen in figure 6 above, female header pins will be mounted that will allow connection with a male header pin housed on the dispensing unit. Each respective pin will be soldered to a Proto-board to which all electrical wiring will be soldered to. Looking at the top half of the control unit a stand up screen housing was made for the TFT screen. While unable to rotate, the prop allows the screen to be placed at an angle which will be easier for the user to operate. It also allows for the unit to sit flat against a wall without the screen touching the wall. All pieces of the control unit were connected with M3 screws.

II. *Dispensing Unit*

The purpose of the unit is to house the medication, house the sorting mechanism for the medication, and protect the medication from the environment. The dispensing unit is also the place from where the patient will retrieve their medication after its dispensed. This means that the unit also includes an external slot to which the medication will be dispensed to and retrieved.

- Dimensions: 193mm X 47mm X 132mm

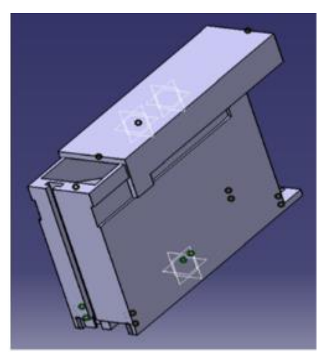


Figure 5: *Assembled Dispensing Unit*

This was not the first iteration of the design, as we had multiple problems that we encountered. The first was that the dispending unit was originally going to be three parts with a contact fit. However, the design was too fragile when printed and easily broke. Secondly a three-part design only allowed us minimal space to design a way for the pills to be brought to the outside. Thirdly the dimensions of the shafts were too tiny and were subject to breaking at an original diameter of 3mm. The diameter was increased to 3mm on the shaft with a 5mm center because the plate was now two pieces and as such more room was allowed which kept the same spacing between the rollers which was 11mm to allow the pills to pass through. Additionally, the sponge rollers diameter was increased to 9.5mm as we found that more surface area allowed the pills to pass between the rollers easier. The assumption is that the larger surface area allows more mechanical grip because of the increased ability of the roller and pill to make contact. This was something that we first noticed when evaluating our proof of concept in figure 5. Although the diameter was the same the rollers were longer which allowed the pills to pass through easier, when compared with the shorter rollers used in design 1. As previously mentioned, the material chosen was (Dobe by Scotch Brite) because of its pliable nature and ability to contour to any surface.

III. Top Plate

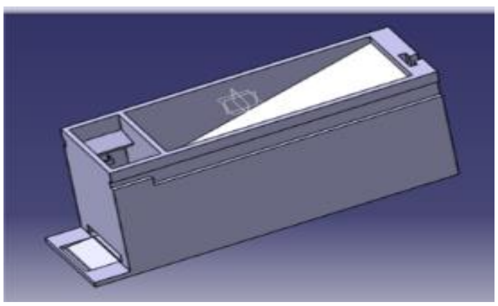


Figure 6: Top Piece

The Top Plate seen below in figure 6 is the first part of the redesigned dispensing unit. Its function is primarily as a storage area for the pills as discussed earlier. To reiterate the container had to be able to hold 40-drams worth of medication a number we came up with after finding most common medication vial sizes fall between 8-30 drams of medication. Using the dimensions of the vial given as a reference in figure 3 the container was designed with dimensions of 130.13 X 46.125 X 61.5mm.
Volume was calculated as follows:

Vial Container: $105.849 * 46.125 * 61.5 + 61.5 * 41.62 * 24.281 = \mathbf{152,288.9752}\ mm^3$

As discussed earlier, due to an FDA study the pill size chosen to optimize the design was no greater than 17mm. As a result, the opening for the bottom of the container was chosen to be 19mm*15mm as we felt those dimensions would allow the best balance of “controlled flow” for the pills to fall into the container. Since most medication, fall within the range of sizes significantly less than 17mm, this allows pills that are closer to 17mm in size to fall in only one direction, while small pills flow freely preventing medication from sitting on the bottom of the container. Within the front of the container, is an area for mounting the second servo for the locking mechanism. The locking mechanism can be seen in figure 6 and labeled as new locking mechanism.

IV. Locking Mechanism

The locking mechanism was designed as a mechanical system that would prevent the cover (bottom left in figure 9) from being able to slide forward and allowing unwanted access to the medication. The idea behind it was that the cover would have a rib cut out within it and the locking mechanism would be mounted inside the dispensing unit at an angle. Because of the angle and the design of the lock as it rotates it would experience a change in height. At the highest point the cover would “jam” against the lock which would be secured against the front wall in a custom holder that would provide the lock leverage. When it is desired that the cover be opened, the lock would rotate, lowering its height and allowing the cover to slide forward over it. The lock piece itself was designed first and all subsequent design was based off the locks geometry.

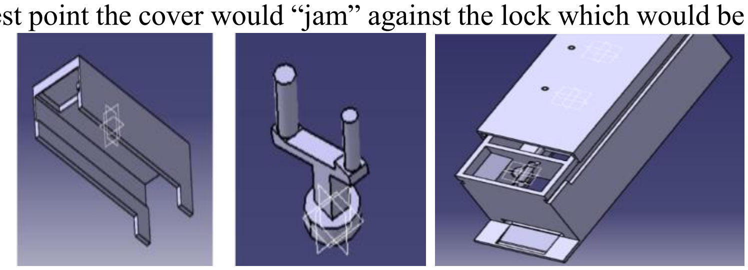


Figure 7: *Cover, Locking Mechanism and Assembled locking mechanism*

To accomplish our goals, a second servo was placed at a 55-degree angle which based on testing gave us the desired height and clearance to allow the variable height mechanism to work as attended. This was in conjunction with the piece itself which is set at a 69-degree angle. The left arm of the locking mechanism set at a height of 10 mm and the right side at 9mm which were chosen arbitrarily. To mount to the servo, the locking mechanism will be screwed through the base of a servo accessory using the 3M screws.

In reference to the cover, a second feature can be seen that allows the sliding mechanism to be used. The tracks, as seen in the assembly, were created for the cover to slide forward on. At a certain point the end pieces will reach a built in geometric stop which was designed to stop the piece from passing a certain point. Not only is this an intricate part of how the lock works, but it also allows for the cover to not fall off and be damaged. Additionally, the geometric stop point allows the servo and lock to remain hidden potentially protecting them from damage.

V. Bottom Plate

The most important part of the dispensing unit, the bottom plate houses the mechanisms which are responsible for allowing connection with the top plate, and control unit. Additionally, it houses the rollers, and carries the dispensed pills to the outside.

- <u>Dimensions</u>: 170.62 X 41.625 mm
- Houses
    - FS90R servo
    - Header Pins
    - Photocell
    - Neo Pixel LED
    - Rollers
    - Voltage Regulator

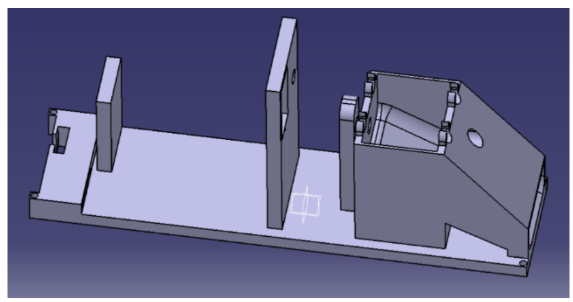


Figure 8: *Bottom Plate*

Starting from the left side of the bottom plate there are a number of features built into the design. The Step on the left is actually a recessed piece that is hollow on the bottom. Its purpose is to allow connection to the 90 degree pins that will be used to connect to the control unit. All wiring will be connected next to small wall near the left on a proto board. The pins will pass through a small opening in the raised piece before connecting with the header pins on the control unit. The small wall is for mounting a voltage regulator. The center wall is the location where the continuous FS90r can mount. When determining the height of the wall the servo was mounted on, the rollers placement was the most important consideration. This is because the location where the rollers are mounted had to be allocated a certain height, to allow a minimum drop from the container to the roller, which according to tests increase reliability. For our design this meant a maximum distance of 2mm of separation. As the pills pass from the chamber to the bottom plate they will fall through the rollers housed on top of the structure on the right. The pills will rotate through two circular rollers sized at 5.5mm in the center by 13mm long. A late change in the design dictated that the rest of the shaft diameter be changed to 3mm diameter, which allowed for some flex in the shafts. This was necessary as testing showed the pills weren't able to freely pass through a more ridged structure. After passing through the rollers the pills will shroud a photocell which will detect the shadow of the pill as it obscures the light. This results in the rollers reversing and extra medication being returned to the holding chamber. The location of the photocell will be on the small wall, between the right side of the structure and the center wall. Based on testing, a distance of 3mm was chosen as the ideal distance for the photocell as it allowed the most light to saturate its surface. Each hole was dimensioned as 6mm or one mm over the manufacturers given dimensions as we found that any variance with our first iteration of the project less than .20mm produced little to no difference in size when printed. It was determined that a tolerance of .5mm produced parts that fit together but were very tight. From this point, tolerance sizes were doubled as we found that the extra .5mm produced fitments that were within the desired range.

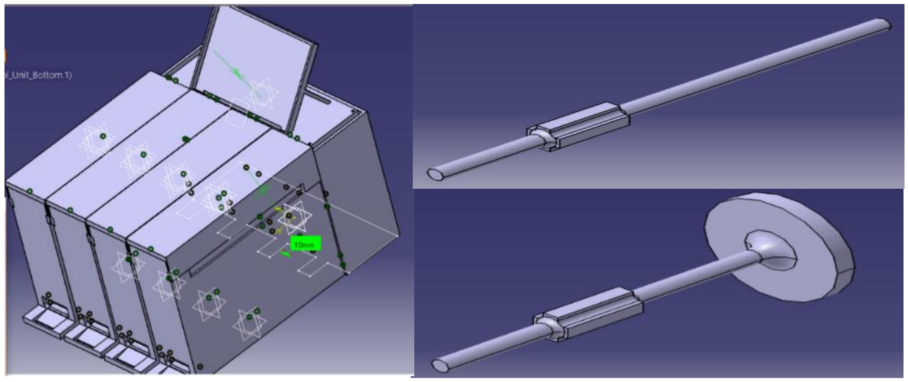


Figure 9: *Completed assembly. Top right: Free shaft. Bottom Right: Servo Shaft*

VI. Shafts

- <u>Servo Shaft:</u> 60mm long, 13 mm center piece, 3mm diameter except center where it is 5mm.
- <u>Free Shaft:</u> 83mm log, 13mm center piece, 3mm diameter except center where it is 5mm.

Both shafts were designed in order to minimize the wear on the sponge. In early testing it was found that the sponge was wearing down due to friction caused by passing the pills through the rollers. This resulted in tearing in the body of the sponge, which over time necessitated the rollers be replaced. To solve this issue, a ribbed surface was created to “grip” the sponge better and minimize the wear of the sponge rollers sliding on the shafts. Additionally, chevrons may be implemented in the future to provide better mechanical grip between the pills, and the rollers.

Development of each part of the design involved using research, CAD software, tolerances and design considerations. To design the parts, the overall objectives was considered. This involved making a list of theories as to how the mechanism should operate to satisfy the requirements. Research topics included pill size, shape, target audience, cost, and simplicity. As mentioned, the first design involved a two – piece assembly that didn’t work due to spacing issues and 3D print tolerance issues. This resulted in a part that did not meet all of the design requirements. This included not being able to dispense the pills into a receptacle and not replicating the safety cap mechanism. Through this process, the best tolerances were determined to be approximately 0.35mm for the Stratasys printer. In addition, design for assembly of the electronics on the bottom plate could be optimized. This highlights the importance of design assemblies to ensure part fitment after 3D printing. It is also important to consider whether or not the part was modular. Questions asked during assemblies included, if need be, where could the part be modified? This came in handy when the pin connector design needed to be modified after it was printed. To solve the issue, the existing architecture was then modified with a new piece based on what was there already. It is important to consider both mechanical and electrical components when designing either to optimize both areas. Placement of parts is crucial to ensure long term reliability and function. For electrical components, this involves making room for wiring and accommodating for heat generation. To avoid this problem, it is good to perform circuit design before hardware design.

Electrical

The Arduino Mega AT2560 was used as the controller, with an approximate cost of $30.00. It was chosen for its number of pins and ease of programming. A RA8875 Driver Board, $35.00, is going to be used to control the 5-inch touchscreen using 5 SPI pins for a pi 800x480 displays. The FS90R Continuous Rotation Micro Servo, and Tower Pro SG92R Micro Servo will control the rollers and locking mechanism respectively. The continuous servos do not have a limited turn radius, and the input signal adjusts the speed which is important for the roller design to ensure one pill falls at a time. The Super-Bright LED's (25 pack $6.95) were chosen along with an optical sensor. The LEDS were chosen because of their brightness, and the optical sensor for its ability to work with almost any microcontroller. The entire system will be powered by a 9V 1.5A wall adapter. Figure 6 shows the core components of the system.

Part 1: LED

Part 2: Optical sensor

Part 2: Arduino Mega

Part 2: Driver board for touchscreen

Figure 10: Various APD electronic components

The servos have a 3 pin female connectors (ground, power, signal) which along with the three pins from the IR sensor (ground, power, signal) and two from the led (ground and power) will be routed to the back of the dispensing unit in Figure 5. They will be soldered onto a plug in receptacle that will be used to connect to the dispensing unit.

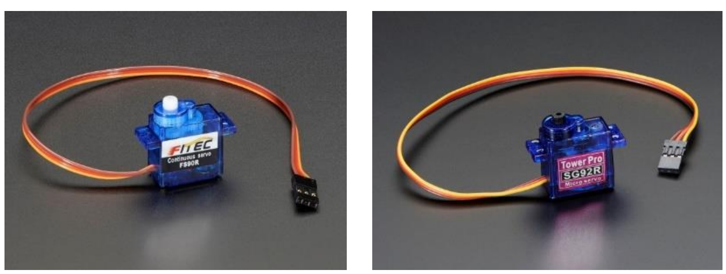


Figure 11: Servos used in the APD

I. Current Draw

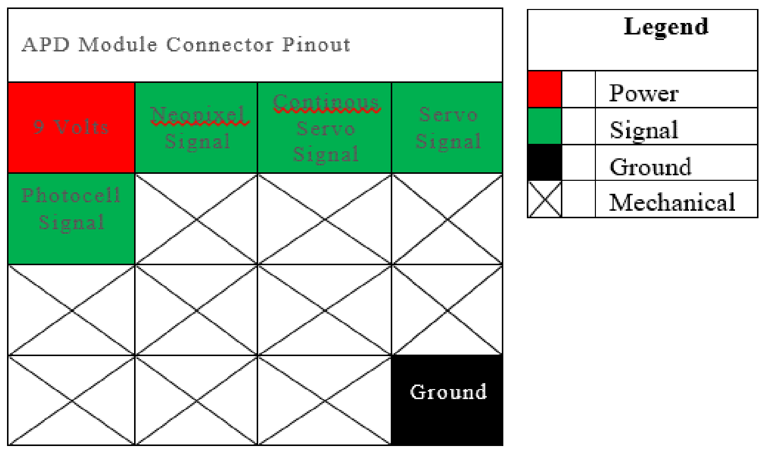
Each dispensing unit will consist of two servos, an LED, and a photocell. All of these components are powered by 5 volts and have the capability of pulling over 1.1 amperes. The power being supplied into each dispensing unit is 9 volts from the control unit. For this reason, a LM7805 5-volt regulator with a max amperage rating of 1.5 amperes will be placed before the components. In order to prevent any damage to the circuit, the datasheets for each component needed to be referenced before committing to any changes. It is imperative to note that the operating frequency and heat generated are also crucial pieces of information needed to meet programming communication as well as mechanical stability requirements.

Current Draw Per Dispensing Unit		
Component	**Voltage (V)**	**Max Current (A)**
Continuous Micro Servo	5 V	.550 A
Micro Servo	5 V	.550 A
Neopixel LED	5 V	.060 A
Photocell	5 V	.001 A
TOTAL:		**1.161 A**

The 5-volt regulator chosen allows for a safety buffer of 339 mA before reaching its operating current. This ensures that the regulator will not overheat and that a heatsink will not be required.

II. Connection

To make the electrical connection between the control unit and a dispensing unit, standard headers will be used. The control unit will be fitted with a 3 x 4 female header and the dispensing unit will have the accompanying 3 x 4 right angle male header. The circuitry does not require this many pins, but to make a more mechanically secure connection a large connector was chosen.



Programming

The center piece of the program for the APD is an easy to use graphical user interface (GUI) with touchscreen capabilities. By using a GUI, users can efficiently navigate through options and view important information. When customers of the APD power it on, the first task is to set the current regional time which is a one – time operation. When a new dispensing unit is installed, the machine will automatically run a *Module Setup Routine* specific to the position of the new dispensing unit. After that is complete, the user will receive alerts when the medication needs to be taken. When the medication is depleted, the APD will alert the user to input the new set of medication and the APD will remember all of the information from the first set.

In order to implement this series of operations, many different levels of C++ programming are utilized. In order to store the information for each type of medication, a class was created that holds the individual pieces of information shown in the *Module Setup Routine* in Figure 13. Figure 12 shows five interrupts that control the system time as well as pill notifications. Careful planning was needed to make sure that the interrupts do not interfere with each other. By using interrupts, the main looping program was able to be shortened and become more efficient. For the touch screen to be operational, Serial Peripheral Interface (SPI) communication had to be reviewed to ensure proper data transfer and update of the touch display.

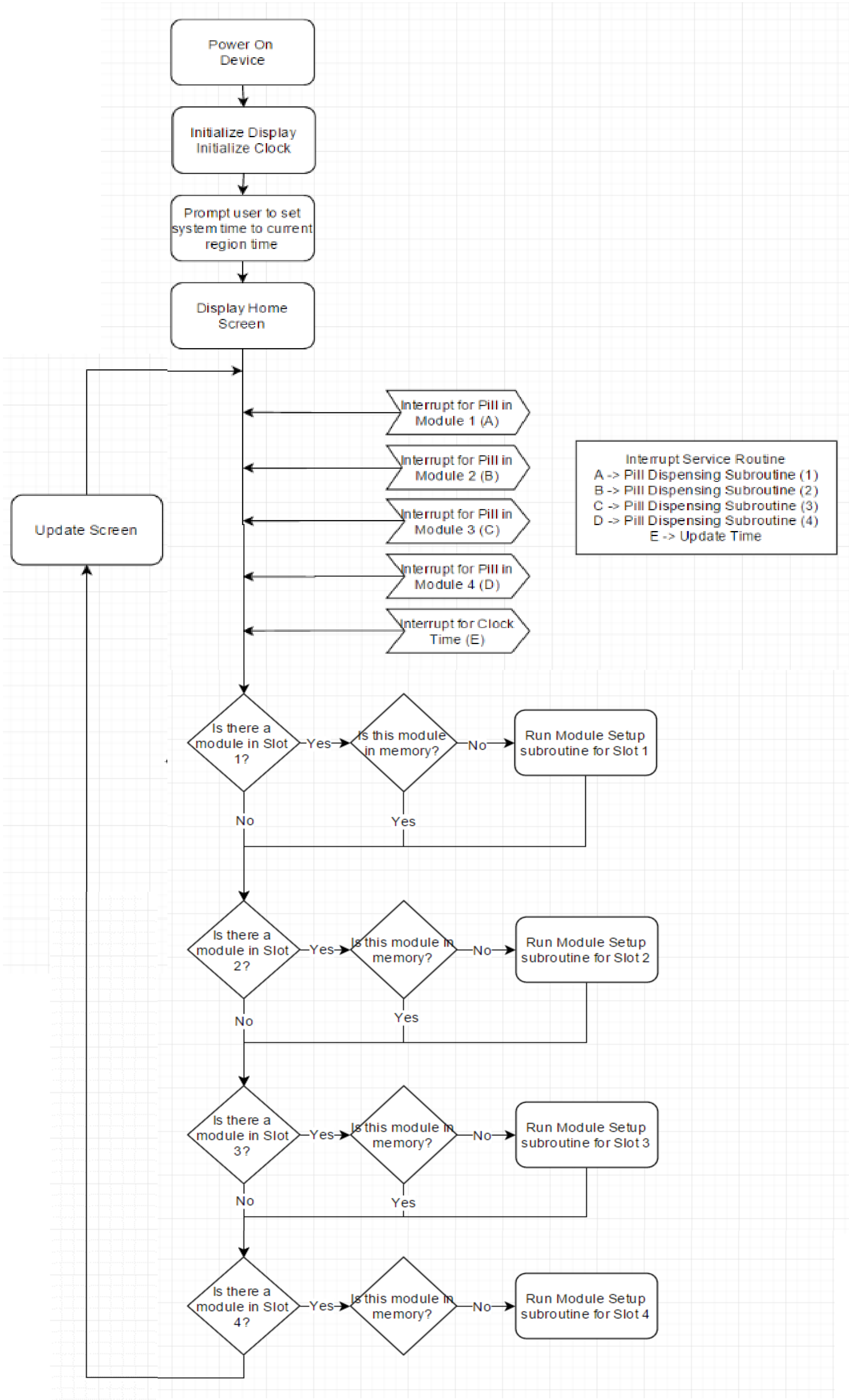


Figure 12: *Main Program Flow*

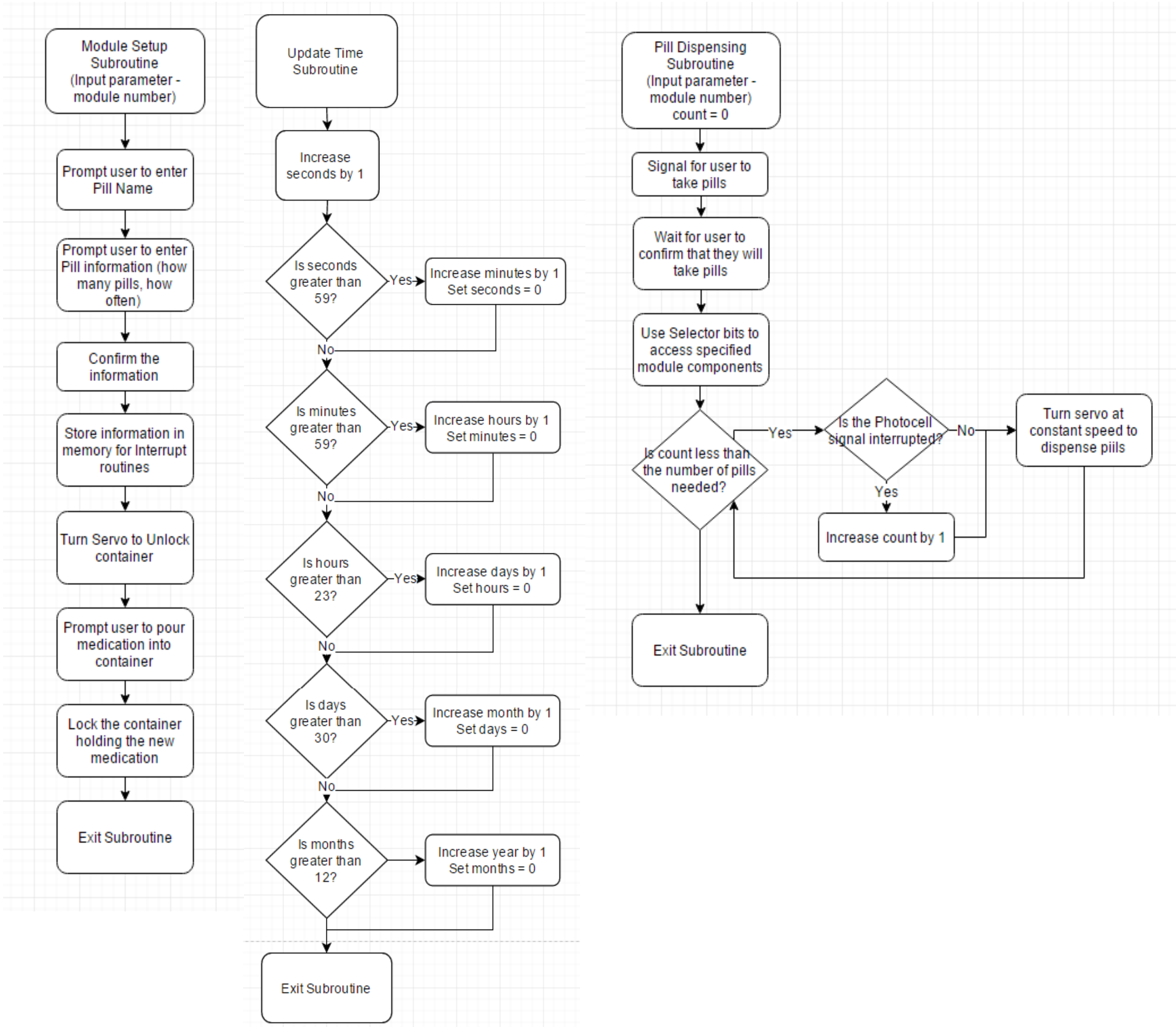


Figure 13: Subroutine flows

Conclusion

The APD build was outlined, and developed using hobby servos, an Arduino, an LCD screen, connectors, CAD design and 3D printed parts. The simple build process allows for a low cost alternative to what is available on the market today using a simple, flexible manufacturing process. APD has the potential to decrease accidental overdoses; while increasing the quality of life of its users and lowering hospital visits and medical costs. Future improvements would include more safety features to prevent the chance of an inaccurate amount of pills being dispensed, as well as increase the amount of dispensing units that could be attached. With continued refinement, the APD for the home could be a real solution to a current healthcare hazard, one that can benefit many people in the near future.

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