ME 486 Senior Design

Fall 2016

Final Report

Automated Pill Dispenser

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Executive Summary

The motivation of this project stemmed from the influential problem of patient medication noncompliance -- the undesirable situation arising when individuals do not faithfully consume their prescribed medication as directed. Recent medical research has shown that this pressing issue is prevalent in elderly patients; this is exacerbated by the physical, mental, and logistical limitations common to this aging population. This project assumed patient medication noncompliance to be systematically addressable by the design of a reliable, accurate, and automated pill dispensing system. The guiding principal behind this project was the perception that a convenient and reliable method of pill dispensing would alleviate noncompliance related pitfalls in patient medication regimens. The challenges presented by the mechanical design of this dispensing system, coupled with the implementation of an electronic control system, were deemed to more than adequately fulfill the technical challenge requirements for the 2016-2017 ME 486-87 Senior Design Course.

This project demonstrates the design of an automated pill dispensing system wherein pills of a single variety are poured into a hopper-storage tube, then transported to a collection basin. Pills in the basin are then collected by a quick-detach swappable rotating disk with capture slots to collect pills, which transport the collected single pills to the top of the basin for ejection into a dispensing chute. A magnetically attached rejection wiper, coupled with precise rotation algorithms for the rotating disk, prevents double feeding issues and jams. A light detection and scale system during the ejection process control the amount of pills required for a prescribed medication dose. Supporting structures and features such as an electronics base plate, adjustable tilt basin mechanism, stationary vertical supports, and multiple quick detachment mechanisms were designed to permit ease of use and adaptability of the pill dispensing system for other pill types.

Manufacturing for this project included both 3D-printed as well as purchased stock and specialty parts. Additional processes were applied to parts during the manufacturing process to reach desired tolerances as well as other design specifications. Iterative prototyping was heavily utilized at all stages of design, and heavily coupled both the prototype design and testing stages. Multiple revisions of many subsystem components have been generated and optimized during the construction process. Through consistently making effective engineering decisions, this project was completed on schedule. Though much work has been done by all team members, the contributions made by the group member Alex Medeiros have been profoundly instrumental in the completion of this project.

This project's pill dispenser benefits society by empowering a growing population of elderly individuals to reliably conquer their medication regimens, and in doing so allows these people to enjoy the benefits of their treatments. Likewise, by increasing patient compliance, this project sustainably conserves the resources invested in patient treatment through medication regimens. As future professionals, this project's design team has diligently strived to practice the The Code of Ethics for the National Society of Professional Engineers by following their requirement to say that engineers have the professional obligation to "at all times strive to serve the public interest" [1].

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1 Introduction

1.1 Problem Definitions

This project recognizes the need for a better, economical pill dispensing solution for elderly patients than what is currently available commercially for single-patient applications. The Automated Pill Dispenser Team set out with the intention to take existing industrial pill handling mechanisms, and then modify and scale these technologies down to a form factor and delivery platform that would conveniently accommodate elderly patients in compliantly taking their required pill medication regimens. The final product delivery of the Automatic Pill Dispenser is desired to be small enough, inexpensive, and simply intuitive to make it the obvious choice for elder patients taking multiple medications.

Medication is a fundamental component of everyday life for many elderly patients. The National Highway Traffic Safety Administration says, "90 percent of people 65 or older use at least 1 medication per week; more than 40 percent of this population use 5 or more different medications per week" [2]. At a glance, the most pressing problem for elderly individuals taking medications is the issue of patient non-compliance: complications and obstructions to faithful medication regimens. In his 1995 article published in the Journal of Psychiatry, Dr. Daniel Salzman claims, "estimates of the extent of non-compliance in the elderly vary, ranging from 40% to a high of 75% . . . Forgetting to take a medication is a common problem in older people and is especially likely when an older patient takes several drugs simultaneously" [3]. Memory-related issues such as dementia likely drive elderly patients to forget or altogether abandon their medication regimens, and this problems seems to likely only grow worse with time. A 2005 Lancet Neurology study identifies at the time of the article that "4.3 million people have dementia today, with 4.6 million new cases of dementia every year (one new case every 7 seconds). The number of people affected will double every 20 years to 81.1 million by 2040" [4]. In addition to failures of memory, elder patients also suffer from physical and visual impairments that exacerbate non-compliance. The Center for Disease Control and Prevention says, that for "persons ages 65 or older, 49.7% . . . reported doctor-diagnosed arthritis" [5]. In his 2008 study featured in the Journal of the American Medication Association Dr. Brien Holden remarks that globally, around 1-billion citizens suffer from the disability, and claims that "presbyopia [farsightedness] is common or nearly universal in people older than 65 years" [6]. The Automated Pill Dispenser Project recognized that this collective demographic of aging elder patients would benefit greatly from a systematic solution to address these challenging issues that drive medication treatment non-compliance.

The Automated Pill Dispenser Team desires to resolve the issue of medication non-compliance through the design and construction of an automated pill dispensing (APD) apparatus. This APD system will have three simple focus areas which will each reduce sources of patient noncompliance: minimization of patient mental investment in the regular operation of the device, reduction of manual patient input during operation, and greatly simplified and intuitive user interface mechanisms. The idea of "pour and ignore" will be a guiding principle of this project, such that a patient with memory-related illness be required to extensively remember anything about the APD device after an initial setup. Machine audio-prompts will remind the patient to take required medication doses. The “pour and ignore” principle can be extended further to also encompass the operation of the APD system. After initial setup, the system will run on an automated cycle so that patients suffering from physical ailments such as arthritis will not be taxed to manually operate the APD system on a regular basis. The last guiding project principle, simplified and intuitive patient interfaces, will assist individuals with visual illnesses to simply pour their medication of choice into the APD apparatus, and then perform a one-time setup routine with the easily programmed system interface. The overall idea of “pour and ignore” summarizes the idea that a patient suffering mental, physical, and visual deficient conditions will only be required to perform simple, basic tasks, and that the frequency of this manual operation will be reduced to an absolute minimum.

1.2 Existing Solutions

Figure 1: Gridded Pill Dispenser [7]

Currently, there is no completely automated pill dispenser solution available for an at-home patient. The best pill dispensers on the market require a caretaker or third party to manually prepare the pills by placing them into scheduled dosages within receptacles. This process is labor intensive, and can easily result in operator error. The classic plastic pill dispenser has a 1-week treatment manually prepared, labeled Sunday through Saturday with AM and PM designations Figure 1. This type of pill dispenser is shown in Figure 1 to emphasize the catastrophic tiny flap lids that are not conducive to patients with arthritis. In addition, these individual compartments make it cumbersome to change medication dosage on the fly.

Figure 2: Philips Pill Dispenser [8]

At the high end of the market is the Philips Medication Dispensing Service. This dispenser Figure 2 is shown to emphasize the use of its more accommodating dispensed pill-cup design. This is an user-automated medication dispenser that spits out medications in pre-packaged cups. Although this may be one of the best dispenser options for elderly patients, it still requires a caretaker to package the cups with proper dosages. This system does not easily allow for any changes in pill dosages. As an additional drawback, this unit costs $100/month.

1.3 Scope and Limitations

This project limited its scope to the dispensing of orally consumed medicines in pill form. Two pill form factors were selected: a birth-control tablet and fiber-gel capsule. The Automated Pill Dispenser Project did not desire to sort pills from one another, but rather capture and dispense a specified quantity of pills of a single variety for each separated dispenser. Therefore, the scope of this project covered the design of a method of capturing one pill from many identical pills.

The design team focused on the mechanical design and construction of the dispensing system, and purchased electronic sensors, motors, and other electrical components as needed. Prior to the onset of this project, one APD team member was already familiarized with electronic boards and corresponding embedded system programming. This team member provided expertise in the wiring of different boards, motors, sensors, and interfaces together, but did not attempt independant fabrication of any of these parts. The challenge of electrical system integration into the project was seen as a required task to overcome, but was not of the highest emphasis of importance. Instead, the roles and functions provided by these electrical components as parts of the larger mechanical pill dispensing system was of primary focus. Of major importance was the design of the mechanical systems, support structures, design, and testing processes.

As previously mentioned, mechanical design was limited to two separate pill types. The mechanical requirements of the dispensing system involved designing a pill feeding system consisting of a hopper feeder and chute. Next, the design required the hopper system to be integrated into a pill basin with a rotating pill capture wheel, which worked in cooperation with a rejection brush. The construction of all structural components, as of present time, has been limited in scope to those that can be rapidly prototyped through 3D printing additive manufacturing processes. Therefore, tolerances of the system design has been reasonably interpreted in terms of those which can be achieved within the scope of possibility of the project team's 3D printer using various plastics.

2 Methodology

2.1 Analysis of the Problem

While implementing the design for the APD, there are three main objectives that must be addressed: how the pills are fed, how the pills are detected, and how the pills are dispensed. By answering these three main objectives, the problem of non-compliance is minimized.

Beginning with the objective of how to feed the pills into the proposed APD design, the main motto of "pour and ignore" once again pops up. On the exterior of the APD, there is a designated pill bowl which the user can pour an entire medication bottle into. This accepting bowl is attached to a hopper, which feeds the pills through individual sorting mechanisms. No longer does the user or a third party need to trouble themselves with the manual strain of opening and closing pill bottles repetitively. Now, the pestering prescription bottles only need to be pried open once, and the APD will do the rest, helping such patients with crippling arthritis.

Pills which await the individual sorting mechanisms are now faced with the next objective of detecting the pills so that they may be easily distributed. To fulfill this objective, one must determine how to select one from the many. This goal of selecting one pill from the many is answered by designing a wiper and programming a sensor. The wiper is the part which guarantees that only one pill enters the pill slot while ensuring other pills do not enter the slot in such a way that will disturb the function of the sorting mechanism. The light sensor functions as an additional detector to promise that a pill has gone through the sorting mechanism. With these two components, one pill can surely be selected from the many. The APD's sorting mechanism relieves its user of the mental confusions that accompany pills by reducing the error which could occur. This error, whether forgetting to take a dosage or mixing two different prescription, is lessened and mitigates non-compliance.

The third objective, how the pills are dispensed, is now the only objective to be addressed. This may be accomplished by the chute, which catches the pills once they are carried through the individual sorting mechanisms. This chute connects all the different sorting mechanisms that handle different pills. Pills, after traveling down the chute, are dispensed into a medication cup which allows the user to ingest the correct dosage at once. This method of delivery reduces visual impairment by decreasing confusion which might arise from pills of similar size and color. Alongside the easily accessed medication cup, there is a reminder that will alert its user when the correct time to ingest the dosage is upon them. Opportunities for patient non-compliance are now lessened through the APD's easy dispensing system.

It can be seen that the APD's design goals of how pills are fed, detected, and dispensed ultimately point towards the goal of lowering preventable non-compliance. Arthritis, dementia, and visual impairments which people suffer from are taken into consideration in the APD's design implementation and improvement. With these objectives that are handled through the APD, there are also conditions which the APD must abide by.

2.2 Initial Conditions and Specifications

To successfully implement the desired reliable function of the APD system, many prototypes will likely need to be constructed. Each of these updated designs will assist to fine-tune aspects from its predecessors. As each prototype is created, it must work towards the following conditions:

1. To dispense pills such that no more than 1 pill per 100 pills dispensed is either lost or damaged.
2. To function with no acceptable tolerance for counting errors.
3. To capture and dispense a single lone pill within a five-minute cycle for 85% of trials.
4. To accommodate the transportation and dispensing of two predefined pill sizes: a 200mg fiber gel capsule, and a generically sized birth control pill tablet.

To test the quality of prototype design against these objectives, the following test methods will be performed as follows. For no less than 5 trials of 100 pills capture cycles, the number of lost or damaged pills will be confirmed through visual inspection of the pill during its journey through the dispenser prototype. In this way, "lost pills" can still be recorded to ensure design tolerance is met. This test method allows reliable record keeping of pill damage, loss within the mechanism, and any counting errors taking place via the detection sensor. Because the APD prototype must meet the previously tolerance criteria for two separate and different pill sizes, the test method shall be carried out separately for each of the two pill types.

For the overall APD system, there will be separate sorting units. With regards to the prototype, there will be two different sorting units, one for each pill type selected for testing. These individual sorting units will connect to share a common dispensing chute and electronic control system. For each sorting unit, the mechanism will not exceed a 100 cm^2 footprint. No constraining vertical dimension limitation will be required. There shall be no overall maximum footprint requirement of the networked distribution system, as the total size of the apparatus is dependent on the number of modular bins attached, which is contingent upon the number of medications to used.

3 Design Standards

3.1 Engineering Standards and Codes

For the Automated Pill Dispenser, two standards which we have considered helpful to our project are ASTM E2500 and ASME Y14.5M-1994. The standards contained within ASME Y14.5M-1994 relate directly to dimensions and tolerances used to construct and present the rendered prototype drawings. Near the end of the design phase of the project, our concentration emphasis shifted from performance-enhancing prototype changes, and focused on polishing up our design. During this final stage of refined presentation, the tolerance and dimensioning requirements of ASME Y14.5M-1994 were enforced to ensure that the presentation of our design will met this professional industry standard.

The essential nature of our automated pill dispenser is to dispense pharmaceutical medication faithfully and safely. Therefore, review was undertaken of the standards contained within ASTM E2500 (Standard Guide for Specification, Design, and Verification of Pharmaceutical and Biopharmaceutical Manufacturing Systems and Equipment). These standards emphasize aspects of design review (ASTM E2500-7.1), change management (ASTM E2500-8.4), and risk management (ASTM E2500-8.2). Rather than a collection of standardized tests to be carried out on our dispenser design, this collection of standards delivers guidelines for design, manufacture, and performance of our pharmaceutical dispensing product. By complying (**as practically as possible**) with ASTM E2500-7 and E2500-8, our design will therefore also be consistent with prescribed practices in The International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use (ICH) for ICH Q8, ICH Q9, ICH Q10, and ICH Q11.

As multiple revisions of the APD prototype were created, it was important to be consistent. To help with consistency, the standard ASME Y14.5M (Dimensioning and Tolerancing) allowed for the Inventor drawings to be uniform. Specifics of this standard include how rounded ends (ASME Y14.5M - 1.8.4), slotted holes (ASME Y14.5M - 1.8.10, 1.9.6), and repetitive features (ASME Y14.5M - 1.9, 1.9.5, 1.9.5.1) should be read within the Inventor drawings. Due to the goal of dispensing pills, the disks that are 3D printed have radial symmetry. The holes that are meant to transport the pills through a sorting unit are dimensioned accordingly. Also, while keeping in mind the dimensions of pills, it is important that the tolerance is not too high so that the margin of error remains low. Once the most optimal tolerance for specific pill disk were found, ASME Y14.5M - 5.2 (positional tolerancing) guided us on how to label the Inventor drawings.

4 Manufacturing

The manufacturing and fabrication processes used in the scope of this project were heavily dependant on rapid prototyping techniques. Many of the parts and features manifested in this project's prototype designs were created specifically for a 3D-printing process. AutoDesk Inventor Professional 3D-CAD software was used to produce multidimensional designs for concept renders and printable prototypes. These prototype designs were then sliced into gCode by the Simplify 3D software package before being printed on a D-Bot Core-XY 3D Printer. This project's 3D-printing facilities consisted primarily of a printing unit with a *300 mm x 200 mm x 325 mm* printing volume. The Simplify 3D software, when desired, allowed estimation of part printing times, quantities of printing plastic used, and equivalent cash worth of printing materials utilized. After parts were printed, they would be tested intensively to determine functional and tolerance fits. This processes, incorporating re-design and optimization was repeated ad nauseam on subsystem components a successful prototype resulted, at which point the part would be ready for integration with the larger system. Then, the design, testing, and optimization process would begin again for this larger, connected system.

Printed parts would often require dimensions for the incorporation of stock manufacturing components. After parts were printed, if required, they would be subjected to post-print fabrication and assembly procedures. Stock parts were heavily utilized as a cost-effective means to providing additional functionality that could not be easily obtained by the 3D-printing process. These cheap parts consisted of fasteners such as threaded inserts, screws, bolts, as well as spacers such as washers. Additional common parts included neodymium magnets, wires, resistors, solder, and other similar items. During the span of this project, special manufacturing processes were at certain times also required. These tasks consist of grinding, sanding, tapping, hot glue-gunning, and similar processes employed as needed. The incorporation of both stock parts, as well as these more intensive processing techniques added to the challenging intellectual complexity of the project, as well as degree of rigor required for the project to be successful.

The mechanical components of this project were controlled via an electronic control loop. A prototype printed circuit board was used as a socket to attach the Teensy 3.5 development board. This board allowed for control of the motor as well as reading light sensor inputs. Within the span of this project, both an electronic control board system, as well as the type of motor used, were swapped out in favor of alternative components. Though these alternative electrical systems increased performance in regards to physical space savings, computative capability, and other physical performance characteristics, the corresponding integration processes were both physically and intellectually intensive, as it forced this project's design team to expand their expertise and knowledge into the cross-disciplinary roles of electrical engineering.

5 Design Concepts

5.1 Proof of Concept, Revision 0

5.1.1 Design Synthesis and Testing

Could a small plastic wheel select one pill from a group of many identical pills? This idea lead to the rotating wheel design first seen in Figure 3, which successfully proved this idea had merit. Agitators were placed on the wheel to prevent pills from clustering too closely together. Furthermore, it was noticed that the tilt angle of the basin had strong influence on the ability of the capture wheels effectiveness. This observation led to the design within the revision prototype for an adjustable angle to the mounting mechanism, such that the optimum tilt angle for each each of the two pill types could be determined.


Figure 3: Revision 0

5.1.2 Manufacturing

The initial design used three 3D printed parts: the motor mount basin combination unit, the base, and the wheel. The wheel initially was found to need a greater tolerance around its edge. The slot for the pill needed to be enlarged so that the pill could easily slide through the this slot. Holes were tapped for mounting the stepper motor to the motor mount basin combination unit. Sanding was done in addition to reducing the diameter of the disk so that the disk could spin freely inside the basin.

5.1.3 Testing and Solutions

Pills did not initially fit into the slots, so new disks were printed with higher tolerances, allowing the pill to smoothly fall and easily seat in the hole. Another problem that was noted was the thickness of the disk, which caused pills to have the tendency of staying firmly seated in the hole, and not exiting after passing over the ejection slot. To solve this issue, the rotating disk was made thinner.

5.2 Refinement of Initial Design, Revision 1 (Fiber Pill)

5.2.1 Design Synthesis

An electronics base plate was designed to mount the electronic control system, as seen in Figure 4. An on-hand Arduino Uno Redboard and dual L298N H-bridge stepper motor driver were installed. The main initial control parameter of interest was stepper motor's rotational speed, which was modulated by an analog potentiometer signal.

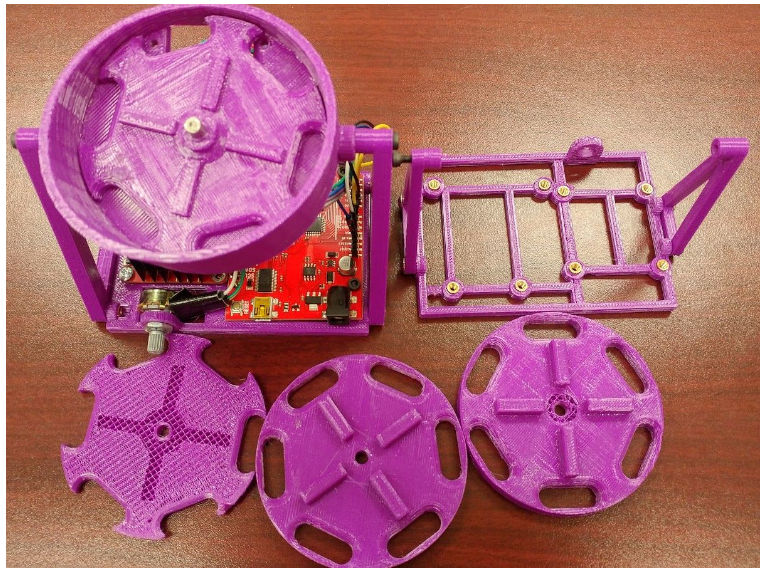

Figure 4: Revision 1

The pill basin shape was redesigned to accommodate a resized pill disk, and also conserve plastic around its upper edges. This new basin was mounted between two vertical supports, and rested above the base plate frame. To increase single-pill capture rates, the new and enlarged pill slot was moved to the edge of the disk, which was now made to be both thinner, and more tightly friction-fit to the stepper motor.

5.2.2 Manufacturing

This was the first time threaded brass inserts were used to attach the electronics to the base with M3 screw. M3 screws were used to pivot around the center of the basin mount.

5.2.3 Testing and Solutions

The increased pill-hole size created double-feeding problems, which caused jams during pill ejections. In response, the rejection mechanism concept converged onto the design of a sweeper brush. This brush was intended to sweep incorrectly aligned pills out of the pill slot. Other design problems took precedence over the sweeper brush design. The size of the disk agitators were reduced to increase reliability of the fills falling back into the basin without clustering up in-between the agitators. Also, a new, thicker base unit permitted better spacing of the electronics. Lastly, the transition to continuous rotational servo motors was initiated to overcome over-vibration of the stepper motor units, which caused pills to tumble from their slots prematurely.

5.3 Quick Detach Mechanism, Revision 1

5.3.1 Design Synthesis

The need was recognized for a quick release design that would accommodate the servo motor and also the pill needs of users. This required a mechanism that would be both easy to print and simple enough for the user to operate during disk changes.

Figure 5: Quick Detach Prints

5.3.2 Manufacturing

The initial mechanism chosen was two M3 screws that use the machine head as a locking mechanism when rotating the disk.

5.3.3 Testing and Solutions

A total of six quick release geometry revisions were tested to best provide consistent locking fit. Figure 5 shows the revisions from left to right on the bottom row, from first to last revisions respectively. A small base piece was used to test the fits of each of the six revisions. This piece was made bigger to provide a better leverage angle. An intermediate version of the quick release was implemented in this revision of the pill dispenser. After consistent performance failure due to the insufficient servo motor holding torque, the pursuit of an alternative, magnetic quick release concept was suggested.

5.4 Mini Pill Basin, Revision 2

5.4.1 Design Synthesis

In order to meet a smaller footprint for the end device, the size of the pill disk needed to be reduced substantially. This would mean a smaller diameter disk and less pill slots than other versions.

Figure 6: Mini Pill Basin

5.4.2 Testing and Solution

As seen in Figure 6, the small size of the wheel did not allow for proper movement of the pills inside of the basin. The wheel was too small for the pills to stack as they had in previous versions.

The mini pill basin concept was not used further, and was completely abandoned as a viable design. The size of the pill disk was reduced by 10mm in the next revision of the unit.

5.5 Sweeper Arm and Light Sensor, Revision 3 (Fiber Pills)


Figure 7: Sweeper Arm Revision (*Left* Old wiper, *Right* New wiper)

5.5.1 Design Synthesis

A magnetically detachable wiper brush of softer rubbery plastic was implemented to reject pills that were double fed into the pill slot. The wiper started out as a small shape and progressed into a larger shape. Magnets allowed the wiper to be detachable. For the pill disk to be removable, the wiper brush needed to be easily detachable. The change of the wiper design can be seen from the first design on the left (initial design) and right (revised design) of Figure 7.

A new servo mounting bracket allowed the pill dispenser tilt angle to be adjusted on the fly for any pill geometry. The continuous rotation servo motor was swapped in and fitted with the the quick detach mechanism shown in Figure 7. The main circuit board was upgraded to the Teensy 3.5 microcontroller to accommodate a wider array of future interface options, and plentiful input-output capabilities. A dosage verification electronic control system was installed that consisted of a light sensor and LED bulb.

5.5.2 Manufacturing

A prototyping copper clad board was used to connect the servos to jumper pins for easier debugging and prototyping. The board also included switches to control power regulation between the 5V needed for the servos and the 5V provided from the USB power source. This heavily involved process required analyzing the pin layout of the Teensy development board and soldering connectors to the copper clad prototype development board. The light sensors and LEDs, used to detect pills being extracted from the basin, were wired to be attached to the prototyping board through pin headers.

5.5.3 Testing and Solutions

Much effort was invested in increasing the reliability of the pill detection control loop This involved manually assessing the light sensor's threshold from verbose readings when a pill fell through the detection slot. Initial detection rates were approximately 0%. The layout and position of the detection system was determined to require relocation testing to increase detection reliability.

Rejection rates of double-feeds increased via the wiper brush, but pills tended to be destroyed in a manner consistent with the scenario shown in the left of Figure 7. Despite iteratively optimized wiper geometry, vertical double-feeds were still an issue, and so forceful vertical grooves were planned to be added into future basin units that would prevent pills from standing vertically upright.

5.6 Magnetic Quick Detach, Shaking, Revision 4 (Fiber and Sugar Pills)

5.6.1 Design Synthesis

The M3-screw quick detach mechanism was improved by its elimination. A new, magnetically attached quick detection mechanism was designed to be operated within a small fraction of a second. This design is shown below in Figure 8. Per Design Standard ASTM E2500, the APD device's quick detach mechanism needs to minimize every preventable source of system and patient error (over-complication). To increase simplicity, prevent double feeds, and eliminate pill damage, the wiper brushes were eliminated in favor of programming the electrical basin motors to shake the capture wheels back and forth via short rotations.

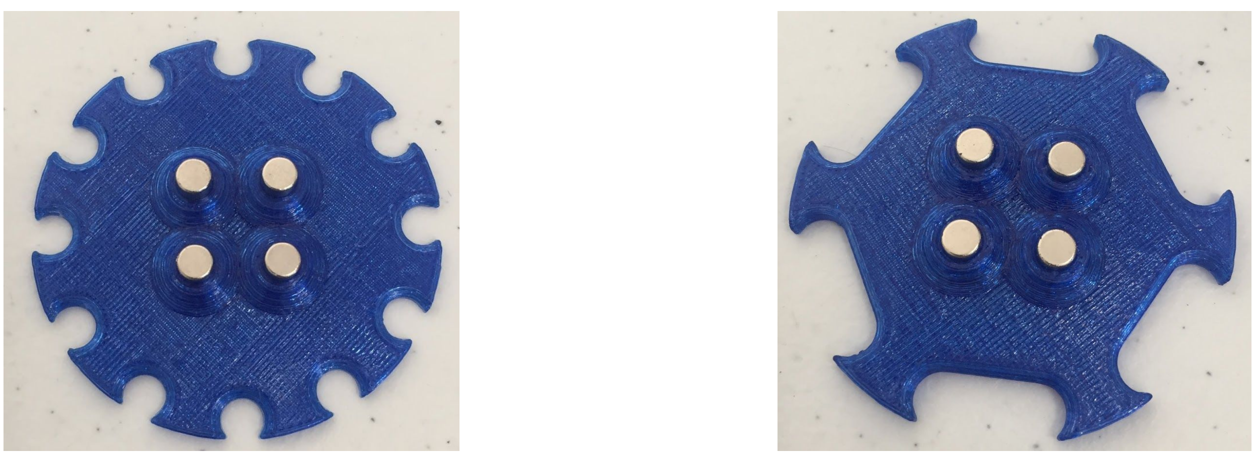

Figure 8: Magnetic Quick Detachment Mechanism

5.6.2 Manufacturing

The new quick detachment mechanism prototype included four inserted magnets. This new attachment mechanism simply sat atop the existing servo motors when glued in place. The shaking feature of the basin wheel was entirely electronic, and therefore required no additional manufacturing. With fewer required parts and virtually no assembly, the shaking design allowed the prototype unit to be utilized both quicker and cheaper than the previous iterations.

5.6.3 Testing and Solution

When testing the birth control sugar tablets, the large magnets prevented the disks from sitting low enough in the basin structure, and caused the pills to be lodged under the disks. Lack of satisfactory magnetic strength also led to pills becoming stuck under the disks while in operation. Tests at different shaking speeds and basin angles revealed the electronic shaking method to provide a better alternative to the rejection brush mechanism. Basin grooves were changed from new vertical alignments into a horizontal configuration, which helped prevent double feeds.

A new disk detachment design was used that consisted of four-supporting-spindles, two-threaded-thumbscrew, and an integrated-handle. This new design is shown to the right in Figure 9. Though this new and finalized design took approximately 6-seconds longer to operate, its performance was significantly more reliable, and prevented pills becoming stuck or lost under the disks.

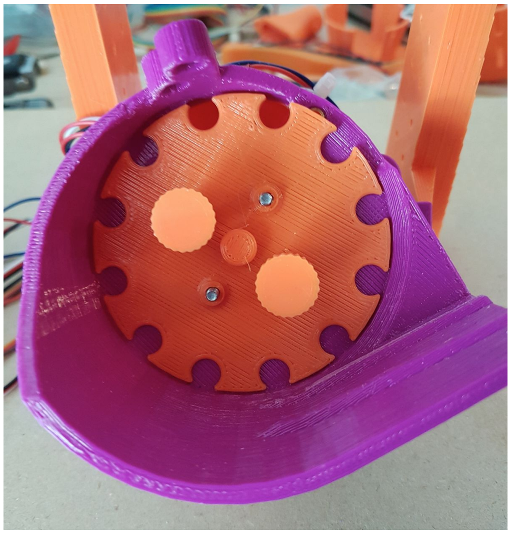

Figure 9: Final Quick Detach

5.7 Current Design: Buttons, Ejection Chute, Revision 5

5.7.1 Design Synthesis and Manufacturing

In accordance with the proposed objectives, a simple user interface was required to easily engage with and accommodate user pill dosage requirements. Faithful dosage verification was expected to be achieved via a digital scale. A suitable touch screen interface module and separate digital scale were purchased and installed.

Figure 10: Button Panel

5.7.2 Testing and Solution

The initial touch screen interface was no sooner installed before its implementation was abandoned. The touch screen component was unsuccessfully trialed, and swapped out in favor of an oversized arcade button system. The buttons array provided ease of use for individuals with mobility disabilities, and similar core functionality, as seen in Figure 10.

The sensitivity on the purchased digital scale should have detected sugar pills, yet this was found not to be the case. Purchasing a pharmaceutical grade scale was found unfeasible; therefore this scale design concept was withdrawn.

Returning to the primary pill detection method, it was determined that sugar pill detection by the light sensor suffered because the pills ejection path of travel was inconsistent, and therefore were not always over the light sensor. Despite trying many different sensor locations, orientations, diffusivities of incident light, sensor sensitivity settings, pill feeding rates, painted acrylic colors within the detection chambers, and even multiple sensor modules, detection of the sugar pills had only improved from 0% up to approximately 70%, which was far below the required 100%. An additional chute chamber was installed on the prototype as shown below in Figure 11, and reliably constrains the sugar pills path of travel to be in front of the sensor. The chute was designed to be compatible for both the fiber-gel capsule and sugar pill types without any adjustment. This project is very pleased to report that detection of these troublesome tiny sugar pills has increased to 99.5%, and the fiber-gel capsules has increased to 99.9% when using this enhanced drop chute design. The final design of this system, complete with the button panel, is shown below in Figure 12, and includes a vertically stacked mounting rack, which contains holes for the addition of possible future performance enhancing attachments.

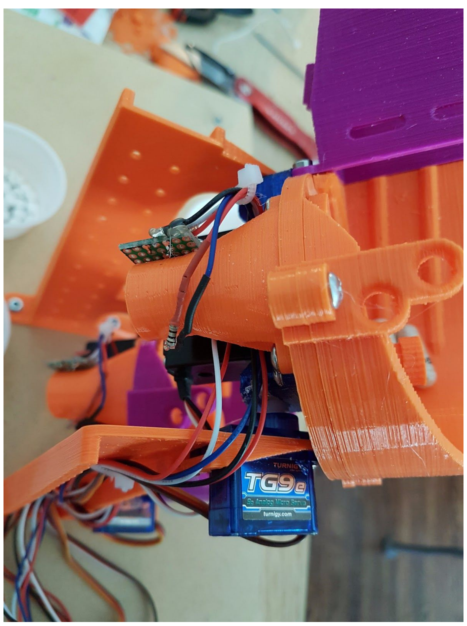

Figure 11: Light Sensor


Figure 12: Final Design

5.8 Current Results

So far, the APD has gone through 5 major revisions from the original design. To fulfill the initial conditions set for the APD, the revisions have been geared toward making the best product before taking quantitative trials. With each revision, no matter how big or small, the APD's workability has increased, and the complexity --failure tendency-- of the system has been minimized. The normalized cost each pill dispenser unit approximately $50 and is broken down below in Table 1. This $50 amount is far below the nearest competing product, the $60/month Philips Lifeline Medication Dispensing Service, which also requires an initial $895 startup [9].

Table 1: Manufacturing Cost

Item	Price
2 Switches	1
6 Buttons	6
2 Plastic Quantities	10
Metal Parts	2
Panel & Rack	10
Teensy 3.5	29
2 Rotation Motors	28
Servo Tilt Motors	6
2 Light Sensors	2
2 Bearings	2
Total For 2 Dispensing Units	**96**
Per Dispensing Unit	**48**

6.1 Objectives Completed

From the initial condition set for the APD's sorting units, three conditions have been completely fulfilled: 1) each sorting unit mechanism will not exceed an 100 cm^2 footprint, 2) two predefined pill sizes are accounted for by the use of two separate rotating disks, and 3) pills are detected as they leave the pill basin. Not only is the current prototype of an individual sorting mechanism less than 100 cm^2, but it currently maintains a footprint of 85.5 cm^2. As for the predetermined pills, two separate pill disks have been 3D printed and successfully tested for both pill types. The light sensor included in the final prototype design detects fiber gel pills with a 99.9% detection rate, and the birth control sugar pills at a 99.5% detection rate.

The rest of the initial conditions are defined under the category of quantitative testing. As proposed, the initial specifications for the APD include: 4) dispensing pills such that no more than 1 pill per 100 pills dispensed is either lost or damaged, 5) functioning with no counting errors, and 6) capturing and dispensing a single lone pill within a five minute cycle for 85% of trials, and 7) these specifications must be held accordingly for 5 separate trials of 100 pill capture cycles. As previously mentioned, for the sugar pill type, the final APD prototype system has a detection rate of 99.5% rather than 100%. The design team proudly maintains that this is a phenomenal demonstration of the engineering work that went into the APD system design. Because the initial design concept called for two detection stages, involving an additional weight sensor, the fact that such high detection accuracy could be achieved without the additional weight detection stage is noticeably remarkable. All other quantitative specification requirements for the prototype system have been achieved in gross excess. Single pill captures times were observed to be far quicker than the required 5-minutes, and so no data was recorded. Pills were flung out of the APD system (lost) at a rate of two-per-thousand for the fiber pills and one-per-thousand for the sugar pills. No pills were observed to be damaged during any one of the thousand pill trials. In summary, the design specifications of this project were far exceeded beyond those reasonably intended.

6.2 Unfulfilled Objectives

As previously mentioned, an extra 0.5% sugarpill detection rate, and an additional 0.1% fiber pill detection rate is technically required to meet all proposed design requirements. These enhancements would be trivially achieved with the addition of a proper weight-sensing scale. Though not specifically required in the design described in the proposed specifications, the installation of a touch screen would be utilized in a production-ready system. Here, the use of such a device was not called out specifically in the proposed specifications, and therefore, given the success of the included arcade-button panel, falls outside the predetermined scope of this project as it applies to this course.

7 Conclusion

The motivation of this project stemmed from the influential problem of patient noncompliance. This plaguing issue was assumed to be systematically addressable by the design of a reliable, accurate, and automated pill dispensing system. The guiding principal behind this project was the perception that a convenient and reliable method of pill dispensing would alleviate noncompliance related pitfalls in patient medication regimens. Though no formal or informal scientific studies were undertaken to validate the following claim, it seems principally sound that the success of this project has benefited the environment, society, and the engineering profession as a whole.

Our successful pill dispenser can benefit members of society who are required to consume pill-form medications. Though younger, physically and mentally capable individuals might not grapple to faithfully fulfill their medication, there is a sizable and increasingly growing population of elderly patients who struggle to comply with their medication treatments. Our pill dispenser assists these disadvantaged members of society by granting them personal achievement to overcome the obstacles preventing them from taking their medication, such as presbyopia, arthritis, and memory illnesses. Users of this project's pill dispenser would likely find greater personal achievement in themselves from the medicinal benefits they can now enjoy as a result of their faithfully exercised medication regimens.

Medications should be consumed by patients. When the medication regimen of a patient is obediently followed, then the patient is successfully treated by the effective use of their medication. In contrast, medications forgotten by the patient, possibly left sitting in a cabinet, or taken infrequently, will not benefit the patient. These later prospects waste medication and degrade patient quality of life. Our pill dispenser system helps address these probable inefficiencies by increasing patient medication compliance. In doing so, our project sustainably works to conserve the resources that are invested into medications, whether that be human time invested in doctor's visits, resources spent on drug development, or even making effective use of the pills themselves.

In closing, this project's pill dispenser benefits society by empowering a growing population of elderly individuals to faithfully take the medication that dominates their lives, and in doing so allows these people to enjoy the benefits of their treatments. Likewise, by increasing patient compliance, this project sustainably conserves the resources invested in patient treatment through medication regimens. The Code of Ethics for the National Society of Professional Engineers says that engineers have the professional obligation to "at all times strive to serve the public interest" [1]. In benefiting both society and the environment through this academic design and construction project, this design team has fulfilled their professional obligation as eager future participants of the engineering workforce.

8 Appendix

8.1 References

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8.2 Self Evaluations

8.2.1 Evaluation: Jonathan McMahon

Jonathan has worked both individually and collaboratively with other members of this design project to meet project requirements and deadlines. Through weekly to multiple-weekly meetings, Jonathan has met with team members to address design, budget, and deadline concerns. In first bi-weekly period of this semester, Jonathan met with team members Sarah Riopelle and Alex Medeiros four times, with each occasion lasting roughly in excess of three hours. During these meetings, Jonathan assisted discussion regarding in the inclusion of smaller motors, bi-weekly report writing, useful standards, as well as prototype design and behavior. As a group, these meetings allowed Jonathan and his team members to discuss new rotating disk designs, sweeper attachment concepts, and optimum basin tilt-angles. Through brief initial testing, Jonathan's work helped to establish an optimum range of the basin tilt-angle, and propose the idea for a thinner rotating disk design with open ends towards the basin pill entry points.

During the second bi-weekly period, Jonathan continued meeting at least weekly with his team members. Special effort was placed on developing a thorough Work Breakdown Structure. This management control structure followed initial work by Sarah, and was then revised by both Sarah and Alex. During this period Jonathan continued practicing his introduction into the AutoDesk Inventor 3D CAD software platform. Jonathan was assigned the hopper-chute subsystem component during WBS design phase, and practiced growing his design skills by working on this simply hopper system. Jonathan used personal funds to acquire printable plastics, an electronic control board, servo motors, arcade, vibrational motors, and switches. Working with Sarah Riopelle, Jonathan worked extensively to generate the bi-weekly reports.

Most recently, Jonathan helped assemble the protyping iterations as they became more complex, such that assembly work could be carried out simultaneously with the design and printing activities of this project. This assembly work involved painting plastics, twisting and crimping wires, installing threaded inserts and other fastener devices. Jonathan has focused his efforts on developing the pill hopper subsystem design, though ultimately the pill hopper system was not implemented because it fell outside the realistic scope of the project. Though the idea was ultimately phased out, Jonathan worked with Alex to converge the design idea concepts of a magnetic quick mounting mechanism for the sweeper brush and basin unit. Jonathan and Alex found a shaking electronic operation that effectively surpassed the sweeper brush concept. Jonathan assisted in troubleshooting the sugar pill detection fiasco, and recognizes that without the persistence of Alex Medeiros the detection rate would have likely not increased to a satisfactory level. Working together, Jonathan and Alex were able to set a sensor threshold, optimum pill ejection rate, sensor orientation and alignment, and determine that painting of the rejection chute was not a viable option to increase pill detection rates.

Last, Jonathan has worked with all team members to generate the Intermediate Report document, as well as the Final Report deliverable. Jonathan attended regular project meetings with Sarah and Alex, and met both during the week as well as weekends when required. Jonathan is grateful for Alex’s patience and incredible personal time investment during this project. Also, Jonathan is thankful for Sarah’s consistent fresh outlook and perspective during this project.

8.2.2 Evaluation: Sarah Riopelle

Sarah has worked with both Alex Medeiros and Jonathan McMahon to complete the design project, the APD. Multiple times a week, the three met up to discuss designs, see the progress in the prototype, as well as working on the reports assignments that are due. For the first bi-weekly report, Sarah met up with Alex and Jonathan four different times, with each team meeting lasting more than three hours. During these meetings, Sarah helped keep the team members on track to finish the weekly assignments for Dr. Sunwoo Kim while also keeping track of the difficulties that were being faced with each prototype iteration. Jonathan and Sarah were able to search for the standards used to guide the progress of the APD to search for the most applicable ones. Individually, Sarah also tested the revision with the stepper motor attached, but realized that the vibrations caused many pills to “skip around” within the basin holding the pills.

During the second bi-weekly period, more meetings came up. The first meeting was with Chip Vaughan, where the three team members gathered input from their senior advisor to see if there was any suggestions. Due to the inconsistent vibrations from the stepper motor at the time, Chip advised the team to make sure that the APD was able reliable enough to make sure no pills double fed because of the vibrations. After meeting with Chip, the three team members then continued their meeting to discuss the Work Breakdown Structure that was due later that week. Sarah began the initial timeline, with Jonathan later formatting the main topics and putting it into Microsoft Project. Afterwards, Sarah and Alex continued to make sure that tasks were lined up to the best of their abilities. Later in this second bi-weekly period, Sarah was assigned the chute delivery system. With Alex’s help on dimensions, the initial idea was born and was left to be designed. Jonathan and Sarah have together finished the bi-weekly reports, incorporating all of Sarah’s notes from the team meetings.

In the third bi-weekly period, Sarah has had to make up times that Jonathan and Alex have met up due to traveling to conferences. Thankfully, the initial set up for the Intermediate Report was already discussed after realizing that the template which was provided did not sufficiently mark the effort and progress that has been made. Alex has been a leader in the designing process of the APD. His experience is valuable to both Sarah and Jonathan for he encourages them both to learn Inventor. Sarah’s experience has grown due to Alex’s teaching in both Inventor and the electronic system, as well as the tutorials through Inventor.

With the video presentation, Sarah has been able to gather photos of the different parts to come together and produce a video that represents what the APD stands for. Alongside gathering photos and putting them in a way that makes sense for those not so familiar with the APD’s purpose, Sarah has also done testing for the final prototype of the APD. After counting over 30 trials of 100 pills distributed, Sarah was able to find the percent error each pill had with the APD. In doing so, it was recognized how different pills of different geometries could possibly fail with the APD. This recognition allowed for the vibration and tilt angle to be adjusted to fit the birth control sugar tablets better. With the change, the error was greatly reduced and the APD objectives were met.

8.2.3 Alex Medeiros

After brainstorming ideas, Alex worked on the CAD drawings for the project. After a completed design revision he would print the design on his 3D printer. This process of adding to the design and making changes to the project was greatly assisted by Sarah and Jonathan. In order for the mechanical components to work, Alex was responsible for programming of the device for prototyping different functionalities. He tried to install a display interface but the concept was not used in the final version.

Maintaining the 3D printer to be in working order for the project continued to be a manufacturing challenge as the printer needed constant tweaking to successfully print. Assembling of the parts printed was mostly done by Alex, with the use of his vast supply of standard components including screws, bolts, washers, and consumable electronics parts. Continuing through the design, Alex soldered the new electrical components for the current revision and crimped the wires for various connectors. With the current revision Alex also completed a new class based programming structure that will prove to be modular as the project continues. He programmed the shaking back and forth into the device allowing for the elimination of the wiper brush.

Continuing to the final product, Alex has worked on designing and printing all of the parts. The installation of all of the electronics and cable management was also completed by Alex. He worked on the fine tuning the movements of the electronics. Most of his time was spent troubleshooting the various problems the light sensor was having. His greatest accomplishment was getting the light sensor working reliably as it was a large part of the original design specification.