Design Document

Needs Assessment

Client/Customer Definition

Relevant attributes of clients:

1. Our target demographic is individuals with dementia. Dementia is a condition that results in a loss of cognitive abilities, such as the ability to think, reason and remember [1]. These disabilities hinder their ability to perform simple tasks in day to day life.
2. The geographic area that our clientbase resides in is Nova Scotia. The number of dementia patients in the province was approximately 16,900 in 2022 [2]. This also means that our product must align with Nova Scotia's health safety laws and dosage amounts of dementia medication as stated in Nova Scotia's 2023 Formulary [3].
3. The economic status of individuals with dementia is low.

Challenges Encountered by Clientbase:

1. Medication conflicts - There exists medication to aid such individuals however their disabilities risk them forgetting to take their medication or worse overdosing on the medication. Our solution intends to fix this issue by making pill taking automatic.
2. Difficulty in maintaining jobs and budgets - Dementia limits the chances of dementia patients of getting or maintaining a job position due to their inability to perform workplace tasks even after accommodations are considered [4]. Furthermore, their spending often exceeds their budget due to them forgetting their budget and re-buying bought items [5]. This impacts our product manufacturing costs as the product must be cheap to be accessible to these individuals.

Competitive Landscape

1. Alzheimer Society InfoKits (Social) - These are customizable brochures that contain national and Nova Scotia specific information relevant to persons with dementia and their caregivers. These brochures are cheap and can aid pill taking by providing information about organizational strategies so that the client is less likely to forget taking their dosage. However, this is not a solution to the potential overdosing that could occur if the client forgets that they have already taken their medication. Furthermore, the brochure cannot help the client in the scenario that they have forgotten to take their medication.
2. Human Caregivers - There is a lot of time put by a loved one or a caretaker into taking care of a dementia patient. While such caretakers can remind the client of taking medication at appropriate times and even aid them to take this medication with

supervision, continuous caretaking can cause conflicts within these caretakers' personal lives. These conflicts are a result of caretakers being unable to partake in their activities or due to caretaking as a profession not being a profitable career.

3. General Automatic Pill Dispensers - There are automatic medical dispensers in the market that satisfy almost all the needs of our clientbase that our product addresses such as medication pill dispensing, automation, and timed functioning. The products do this by implementing a dispenser wheel that rotates pill slots to an opening in the product where these pills can be accessed by the patient. They also consist of a digital screen that provides information on the timing of the subsequent dose that is to be taken. However, most of these products are expensive with respect to the client's economic status and are priced at over 100$ [6][7][8]. Furthermore, these products are not specialized to the needs of dementia patients and therefore do not contain devices like speakers.

Requirement Specifications

Functional:

1) Slot size must accommodate the size of at least one average size pill to accurately dispense the specified quantity of medication. Thus each pill container must be 22.20 +/- 0.46mm long and 12.96 +/- 0.46mm wide [7].
2) Integrated speakers must play an audible and sufficiently noticeable tone when it is time for medication. Specifically, this solution will reference the average sound level of an alarm clock, 80 +/- 5dB [8].
3) Production cost must remain relatively low to accommodate the socioeconomic status of individuals suffering from dementia. Such patients are often forced into situations where financially providing for themselves becomes systematically more difficult due to a decreasing ability to work. As a usable metric, the total cost of this solution must remain below the cost associated with remunerating caregivers who would otherwise be performing the same role. Using $\frac{1}{6}\, hours/day/person$ and Nova Scotia minimum wage, $14.50/hour [9], that this cost should not exceed $882/year.
4) Microcontroller must be sufficiently fast to run the machine appropriately. This means that the microcontroller must process data at least at a rate of 8Mhz.
5) Medication is released at programmed time.
6) Rotating mechanism may rotate continuously and is not physically inhibited at any point.

Technicals:

1) Pill container must be airtight in order to prevent the degradation of the medication. This will be measured via the strength of the seal created between the lid and the rest of the container [10].
2) Need a plug to connect to the power supply. Running on battery will be inefficient due to the embedded clock running at all times. The average AA battery stores 2850mAh [11],

meaning a change in batteries would be required too often for this mechanism to be effective in keeping time.

3) Power input must not exceed 30 W
    a) Use C++ as opposed to alternative languages such as Python in order to reduce power consumption
        i) ex/ interpreter must do less work to process c++ code
4) Must have a simple design such that the medicine wheel is easily disassemblable. This is so that a caretaker could apply lubricant to the motor of the machine which could have difficulty moving due to constant functioning.

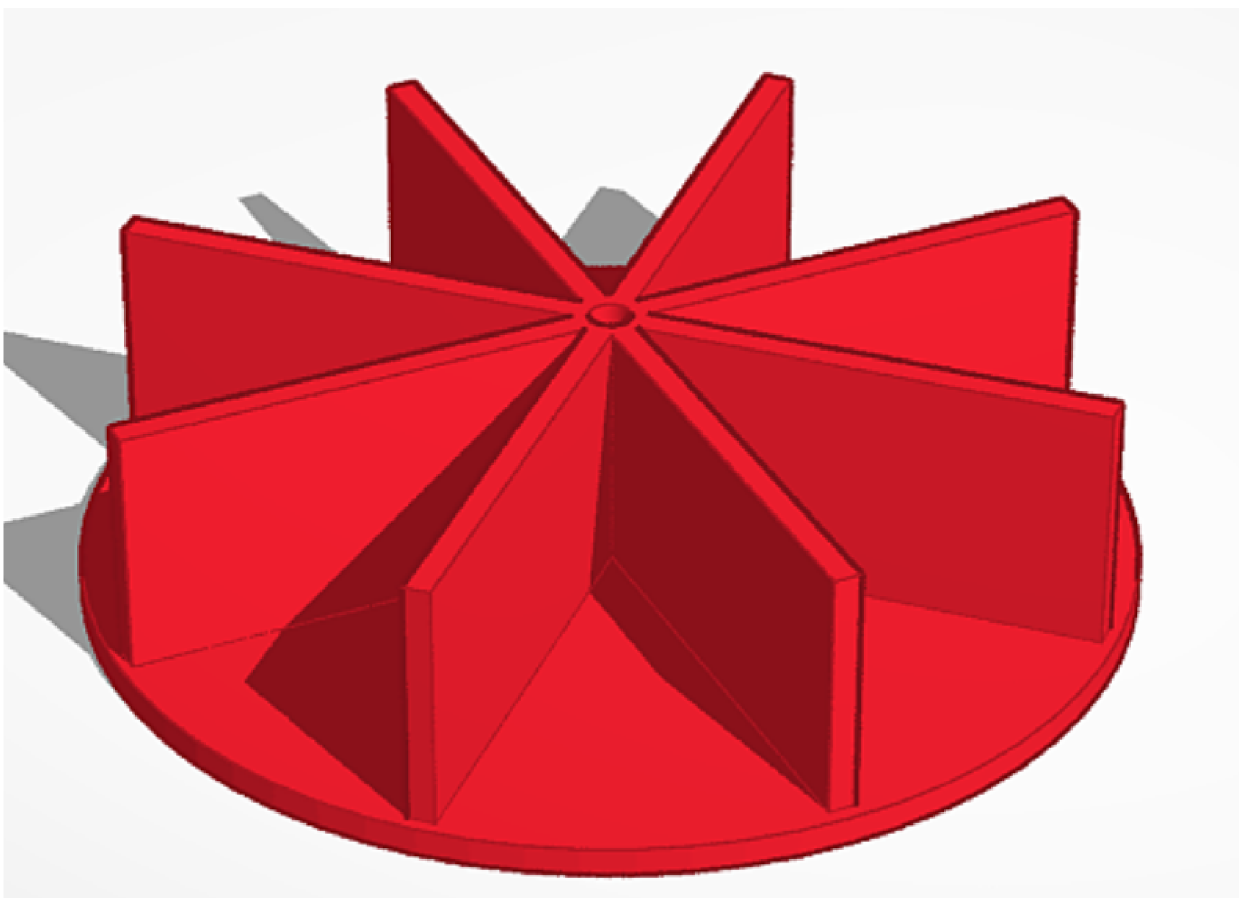
Analysis

Design

Note: The design uses the design of user chrisweedonart from instructables.com as a template [].

Top Down View:

Figure 1: *Dispensar Wheel*

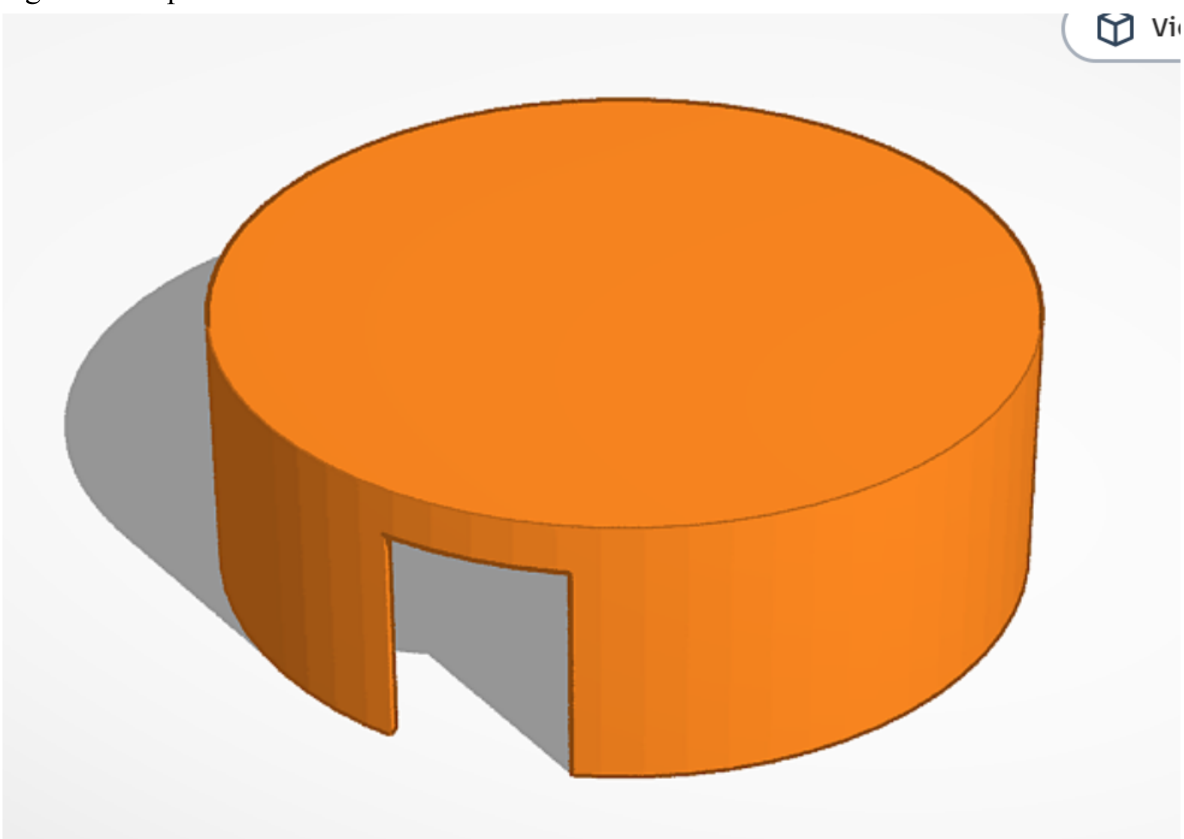


Seen above:

- 3D printed Circular dispenser wheel of radius [insert length] , for smooth rotation. Consists of a circular hollow base that does not rotate and contains the STM board and connected hardware. Depth of the base is approximately considered to be 3 cm .
- The hollow base also has a retractable protrusion out of the medical dispenser. This is so that the pill slot door on the dispenser lid can be locked (see figure 4)
- Circular slot in center to connect to motor rotation shaft. Note that the slot is as wide as the shaft on the purchased DC motor, measured in mm.
- 7 divisions (medicinal slots) of the main circle to serve as the individual pill containers.

  Each slot sector should have an angle of $51.4^{\circ} \pm 0.5^{\circ}$ measured from the center of the circular wheel.
- Pills contained (red and green)

Side View:
Figure 2: Dispensar Wheel Lid

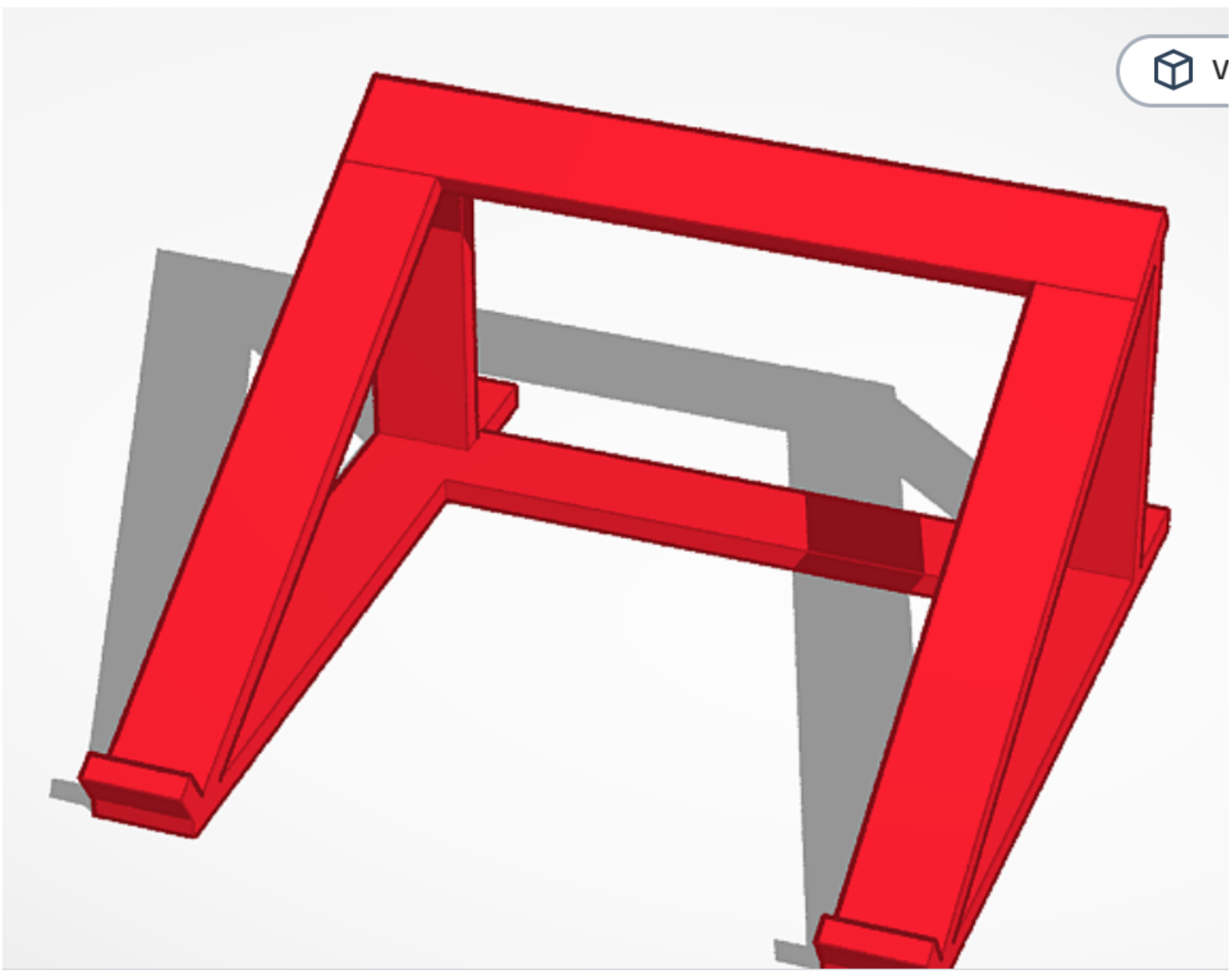


Seen above:

- Removable lid for entire mechanism
  - Removing lid allows access to individual pill slots for refilling purposes

- Circular lid must have a radius equal to the radius of the dispenser wheel, also measured in cm. The height of the lid structure must be the height of the wheel slot walls.
- Lid must have a door hatch with a height slightly greater than that of the slot walls and the arc length of the slot sector.
- Gap allows for pill to dispense through

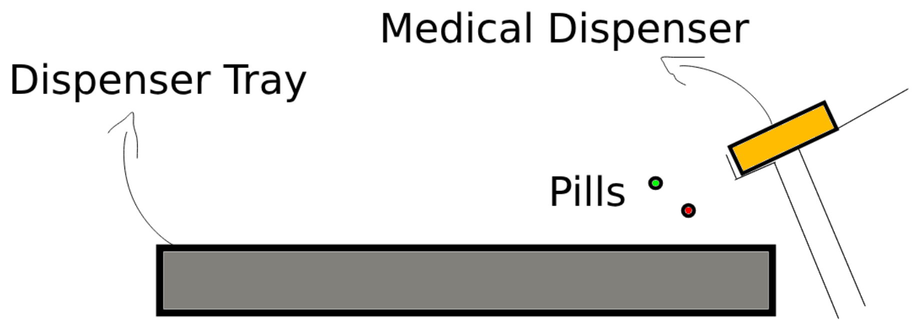
Figure 3: Pill Stand



Seen above:

- Elevates contraption such that pills will fall due to gravity

Figure 5: Full view of product

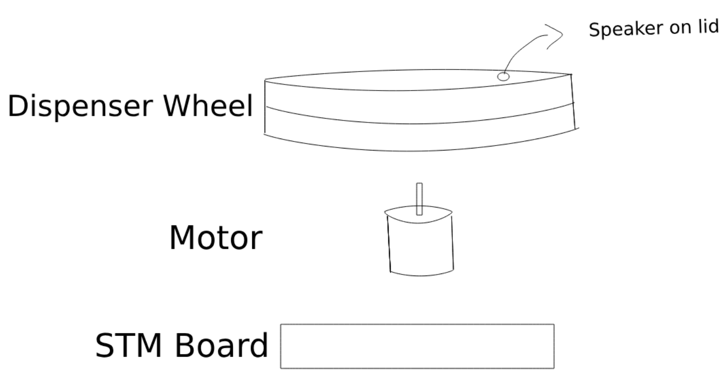


Seen above:

- Dispenser tray used for pill collection and display
- Pills (red and green)

Interior view:

Figure 6: Interior Structure



Seen above:

- Position of motor and STM board
  - Connected in vertical series

- Speaker is at the bottom of the medical dispenser near the STM board.

Scientific or Mathematical Principles

Italics text will be used for annotations regarding how each formula is used and why certain decisions were made.

Power Required:

Power equation used to identify energy required to operate motor [15]

$P = \frac{W}{t} = \frac{Fd}{t}$, $d = \frac{circumference}{7} = \frac{2\pi R}{7}$, let R represent the radius of the entire rotating body.

$P = \frac{2F_a \pi R}{7t}$, $\tau = rF_a$, let r represent radius of the motor's shaft

$F_a = \frac{\tau}{r}$

$P = \frac{7\tau\pi R}{7tr}$

Torque:

Used to calculate the torque due to gravity associated with the hatch release

$\tau_g = rF$ [15]

$\tau_g = rF_\perp = rmgsin\,(\theta)sin\,(\phi)$

(r: length of hatch, m: mass of hatch)

Where θ is the angular displacement of the dispenser and ϕ is the incline angle to the horizontal of the stand.

Gravity:

Used to find angle needed for pills to fall out of dispenser upon release of hatch

Let θ represent the angle between the platform and the horizontal

$F_{//} = mgsin\phi$, $F_f = \mu mgcos\phi$ [15]

For pills to fall:

$F_{//} > F_f$

$\therefore mgsin\phi > \mu mgcos\phi$

$\therefore \frac{sin\theta}{cos\theta} > \mu$

$\therefore \mu < tan\theta$

$\therefore arctan\mu < \theta$

Second Fundamental Theorem of Calculus:

$\int_a^b f(t)\, dt = F(b) - F(a)$ [16]

- If the angular velocity of the motor is easier to measure than the relative angular displacements of the wheel, the Second Fundamental Theorem of Calculus can be used to figure out the change in angular displacement required to deliver the dosage to the client when the velocity of the wheel or the angular velocity of the motor are known.

$$\int_a^b \omega(t)\, dt = \theta(b) - \theta(a)$$

Application:

Note that the change in time, Δt, is measured experimentally.

$$Fr = \tau$$

$$\Leftrightarrow F = \frac{\tau}{r}$$

$$F_{net} = F - f_s$$

$$\Leftrightarrow a_{net} = \frac{F - f_s}{M+m}$$

$$\Leftrightarrow ma_{net} = \frac{m(F - f_s)}{M+m}$$

$$\Leftrightarrow ma_{net}\Delta t = \frac{m(F - f_s)}{M+m}\Delta t = m\Delta v = mv_f$$ (since velocity is initially 0)

$$-f_s d = -\frac{1}{2}m\Delta v^2 = -\frac{1}{2}m\left(\frac{(F - f_s)}{M+m}\right)^2$$

$$d = \frac{m\left(\frac{(F - f_s)}{M+m}\right)^2}{2f_s} = \frac{m\left(\frac{(F - mg\mu_k)}{M+m}\right)^2}{2mg\mu_k} = \frac{\left(\frac{(F - mg\mu_k)}{M+m}\right)^2}{2g\mu_k}$$

With this distance, the process of retracting and pushing the protrusion will be repeatable as the gear will always hook onto a notch.

Costs

Manufacturing Costs

Used components:

- STM32 board

  Vendor: WStore; 200 University Ave. West, Waterloo, Ontario, Canada
  Manufacturer: STMicroelectronics; 350 Burnhamthorpe Rd W, Mississauga, Ontario, Canada
  $30

- 3D Printing Plastic (main body)

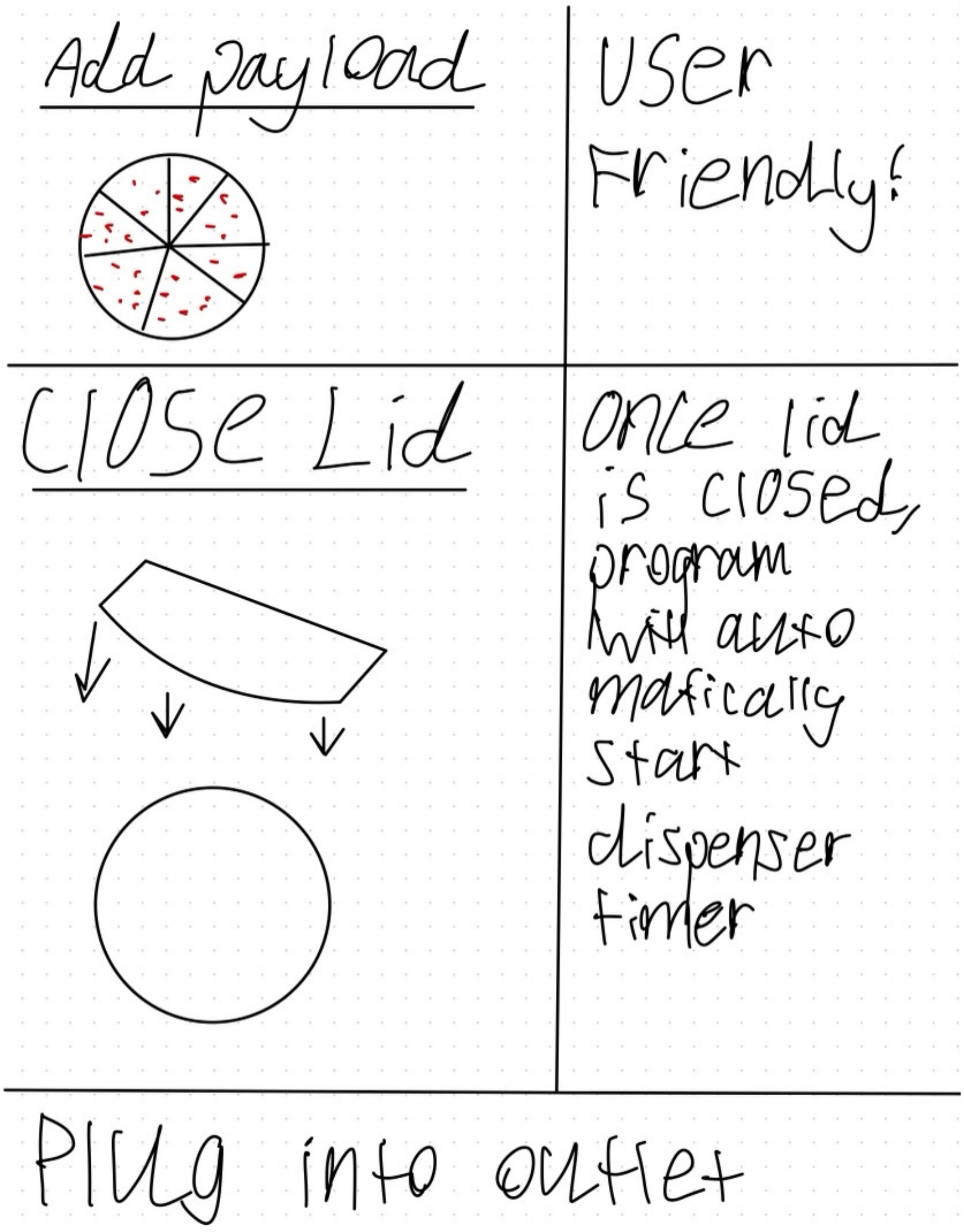
  Vendor and Manufacturer *(Designed and 3D printed by us, printed at…)*: WATiMake, University of Waterloo; 200 University Ave. West, Waterloo, Ontario, Canada
  $15

All of the following components were purchased from the same vendor:
DigiKey; Thief River Falls, Minnesota, United States

- 2xStepper motor (ROB-10551)
  - SparkFun Electronics; Boulder, Colorado, United States
  - $14
- Speaker (SP-1504)
  - Soberton Inc.; Minneapolis, United States
  - $3.17

Implementation Costs

Manual:



Risks

Energy Analysis

Reference standard for the AC power adapter: UL

Adapter:

	WAU24-1000 AC/AC WALL MNT ADAPTER 24V 1A *Triad Magnetics*	221 In Stock 395 Factory	1 : $26.71000 Box	WAU24	Box	Active	North America	Wall Mount	Fixed Blade	120VAC	24VAC	1A	24 W

Approval Agency
cUL, UL

Baseline Power level: 24W

Gravitational Potential Energy:
Let d be the distance of the base of the dispenser from the from the bottom of the slope, θ be the angle of the incline, and m_{total} be the total mass of the pills in the medicinal slot that is to be released.

$$U = mgh = m_{total} g d sin\theta$$

Our product does not have any significant energy storage except gravitational potential energy. This is due to the simplistic design of the product and the lack of springs, capacitors and other objects that store potential energy.

Furthermore, the circular shape of the dispenser wheel allows there to be little contact, reducing the risks of energy conversions.

Since the power output of the adapter is below 30W, the design meets the power requirements of the project.

Risk Analysis

- Environmental risk: Even in proper use of a product, it will eventually have to be disposed of. At that point, it is the user's responsibility to properly dispose of it. Due to the material of the dispenser being plastic, it poses a threat to the environment.
- Safety risk: Incorrect use of the product may result in improper timings of medication intake. If the individual who refills the dispenser does not fill each separate container, the

mechanism will eventually rotate to an empty slot, resulting in the loss of a single intake event. It is also notable that the individual who fills it is responsible for placing the correct amount of medication in each slot. Failure to do so may result in the patient having an overdose.
- Safety risk: The dispenser should be kept still. If the interior rotation mechanism is jerked it may result in a misalignment of the pill slots. This would cause timing issues and the pills would be improperly dispensed.
- Safety risk: There are numerous ways this design may malfunction. If there is a bug in the design's firmware, the timing of each dispensing event may be impacted. The impacts of such poor timing include missing medication intakes, as well as overdoses on the opposite end. Another possible malfunction is the disconnection of the motor shaft and the rest of the rotating mechanism. Being a mechanical failure, this would likely be the result of a poor design for the interlocking mechanism. This could also happen due to a structural failure related to weak materials being used. In this event, the dispenser will have been catastrophically damaged and became inoperable, resulting in under or overdosage.

Testing and Validation

Test Plan

1) Slot size:

Goal:
- Ensure variety of pill sizes are accommodate by the container sizes

Setup:
- Prepare collection of pills in varying sizes
- Open dispenser to access pill slots
- Place aforementioned pills in each container (one pill at a time) and confirm that all fit

Environment parameters:
- Standard temperature and pressure (STP)

Test inputs:
- Pills of varying sizes, ranging from 20-25mm in increments of 1mm

Measurement standard:
- Number of walls of the container which the pill can touch at the same time

Pass criteria:
- Pill cannot touch two oppositely facing walls at the same time
- Pill can fit through release hatch

2) Audible tone:

Goal:

- Ensure audible tone is sufficiently loud in order to attract the attention of patients at the moment they must take their medication

Setup:

- Perform test in E7 4th floor ECE study room with door closed (minimize background noise)
- Use a sound level measuring application to record sound level.
- Place dispenser (speaker) in center of room to best avoid effects of echo and sound resonance
- Take measurement from near the wall of the room (ie. not directly beside it, allow for some dissipation of energy in sound)

Environmental parameters:

- STP

Test inputs:

- Initiate the tone played by the speaker

Measurement standards:

- Sound level measured in decibels (dB)

Pass criteria:

- Speaker produces sound level of 80 +/-5dB

3) Clock speed

Goal:

- Run code to validate that the processing speed of the STM32 microcontroller is sufficiently fast, as to be able to satisfactorily make use of the dispenser's firmware. This code is publicly available. "It runs, sleeps for a duration specified by the user, and then measures the number of clock cycles and the amount of time that elapsed while it was asleep, then divides the elapsed clock cycles by the elapsed time to get the frequency of the CPU." [13]

Setup:

- Install test code from public repository StackExchange [13] onto the STM32 microcontroller.
- No other programs being run through duration of this test

Environmental parameters:

- STP

Test inputs:

- The cited code measures the number of *clock cycles* and the time elapsed in those clock cycles.

Measurement standards:

- Complete clock cycles (CPU cycles)
- Time elapsed (second)

- Result will be analyzed in MHz

Pass criteria:

- Clock speed of 8MHz

4) Release time

Goal:

- Validate that medication is released from dispenser at the correct time

Setup:

- Load dispenser containers with payloads
- Plug dispenser into wall
- Initiate dispenser cycle (turn on and activate)

Environmental parameters:

- STP

Measurement standards:

- Time taken between dispenser release events (seconds)

Pass criteria:

- Medication dispensed at expected time (ex. Aim for 300s for testing purposes), +/-10s

5) Rotation Mechanism

Goal:

- Validate that the rotation mechanism functions without inhibition
    - all containers are reachable and the mechanism may continuously rotate without barrier

Setup:

- Plug in dispenser and activate
- Create test code to continuously rotate the motor
- Run the aforementioned code for a period 5 minutes

Environmental parameters:

- STP

Measurement standards:

- Number of times the rotation is stopped for any reason other than the end of this test (#collisions)

Pass criteria:

- #collisions by the end of the test is 0

Pre-functioning and Post-functioning

1. Product must first be loaded with the required medication.
2. To avoid complications when refilling the medicine slots, the speaker will sound only when the flap is open.

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