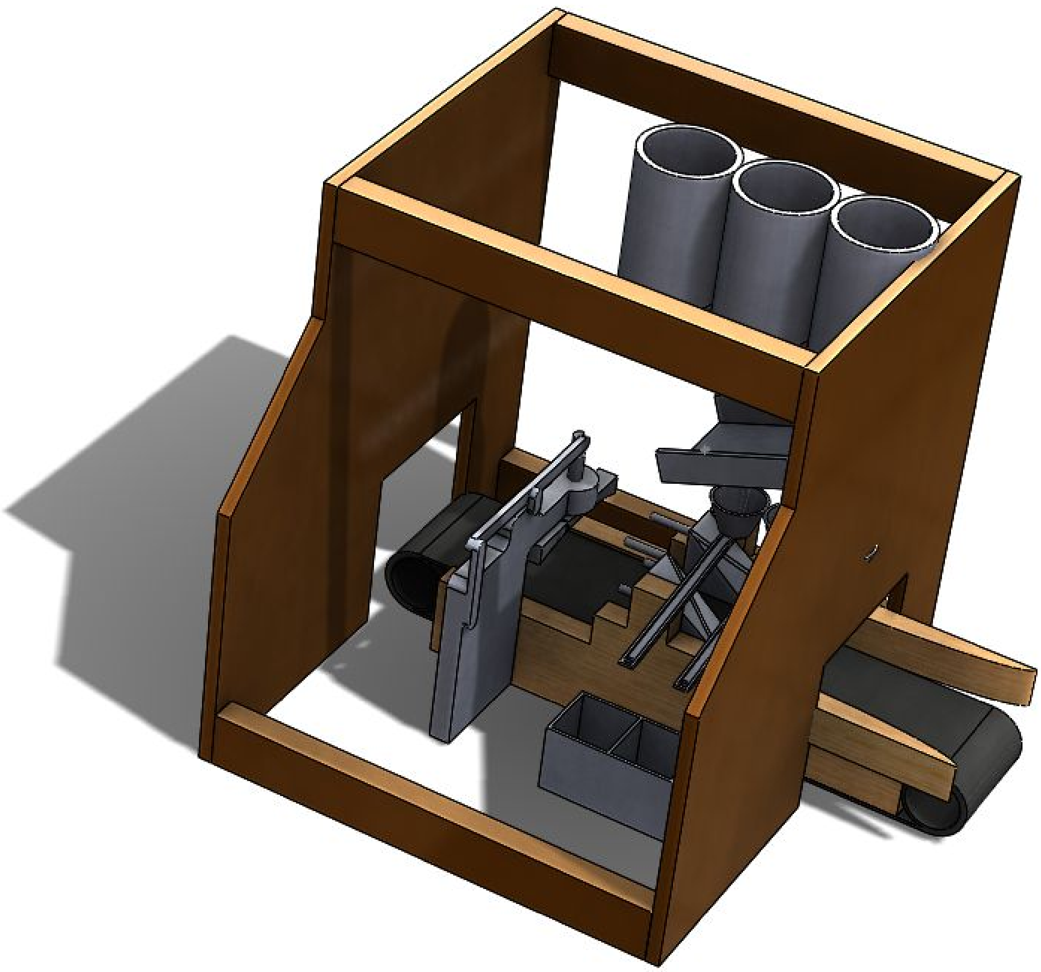
AER201: Engineering Design

The Pill Packaging Machine



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Team 7 | PRA0101 | Teaching Assistant: J. Sarr | Instructor: M. Reza Emami

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Notation and Terminology

- **Machine:**
  - Abbreviation for the pill-boxing machine.

- **User:**
  - Any personnel involved in the operation of the machine; who may perform at least one of the following tasks:
    - Loading / retrieving the pill box
    - Loading / retrieving the pills
    - Entering operation parameters
    - Conducting repair/replacement of components (defined below)
    - Activating the emergency stop button

- **Client:**
  - Any nursing home that desires to purchase, install, and operate the machine.

- **Component:**
  - Any piece of material that is either continuous (not put together by joinery; or the joinery is permanently bound using glue, nails, screws, or solder), or electronic elements that come in a pre-made package that includes all of its subcomponents.
  - Examples: Pill loading compartment, conveyor belt not including motors, motors and actuators, PIC DevBugger board.

- **Subsystem:**
  - A set of interconnected components that perform a specific function that is critical to the machine's operation.

    - Not: “microcontroller”, “circuits and sensors”, or “electromechanical”; a subsystem may involve all three of these roles.
    - Example: pill dispenser subsystem, which is comprised of pill loading compartments, rotating disks with pill slots, axles, and servos operated by PIC18F4620 MCU, and whose purpose is to dispense pills one at a time with precision and reliability.

- **Degree of motion:**
    - A specific type of motion carried out by a component or subsystem, defined by 1. Being rotational or linear, and 2. The plane in which the motion occurs.
    - Example: rotating disk in the xy plane. However, if this disk may also move along the z axis, then two degrees of motion are involved.

- **Error:**
    - Any one misplaced pill (whether in the wrong pill box compartment, or in the wrong reservoir for retrieval)
    - Jamming of the pills or the pillbox
    - Any miscounting of the number of pills
    - Damage of the pills or the pillbox

1. Executive Summary

1.1. Problem

A nursing home requires a solution for autonomously packing three different types of medications into a 14-well pill container. [1] This was identified as a significant

1.2. Solution

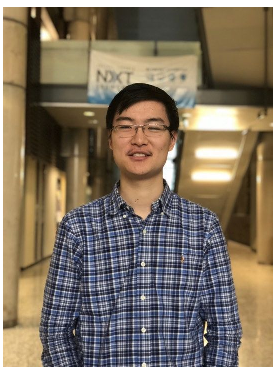
The RFP calls for the design and implementation of a pill-boxing machine. The user deposits three distinctive types of pills into three containers, which, upon the input of a sequence by the caretaker, autonomously packages the pills to those specifications. [1]

1.3. Funding Requirements

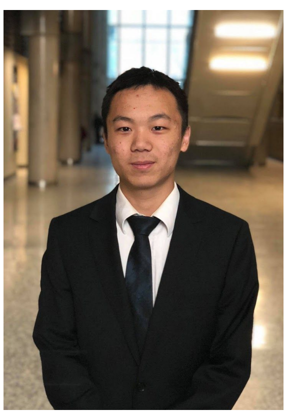
The cost of the machine cannot exceed $230 CAD .[1]

1.4. Team Members and Expertise

Zili Ge - Circuits
I am a second-year engineering science student who is passionate about sensor design, signal processing and electrical engineering. As someone who has worked with biomedical engineers and nursing home caretakers alike throughout my time at the University of Toronto, I am acutely aware of the logistics in medicine delivery. I believe that this is an area that is sorely in need of an improvement, and I wish to be the one who makes that happen.



Lihan (James) Jin - Microcontroller
I am an analytical and detail-oriented person who enjoys being engaged in complex design problems. I strongly believe in quality over quantity, and seek to create solutions that are elegant and robust to address pressing needs in society. With proficient programming experience, my goal in this project is to create an efficient and reliable algorithm as well as an intuitive user interface.



Yuan Hong (Bill) Sun - Electromechanical
Experienced in mechanical and mechatronics design, I enjoy solving multidisciplinary problems through engineering design. Through my expertise, I hope to create a solution that is simple in complexity, user-friendly, safe, reliable, and environmental-friendly. By solving this problem, I hope to make a difference in the community by helping out certain groups of people in need.

2. Problem Definition and Background

2.1. Statement of Need

The Request for Proposal states that a nursing home needs to autonomously package the weekly medications of its residents. Since the repetitive movements of the slow process of manual pill sorting and loading can lead to fatigue-related chronic illness, the entire process should be automated to maximize efficiency and employee safety [1]. In addition, manually sorting and placing the pills into the pillboxes would expose the pills to bacteria on the hands and in the air, which may be harmful to the health of those taking the pills later on; automatic pill-boxing should reduce the chances of bacterial contact, thus, less chance of illness for the patient.

The medication comes in three types (shapes): the spherical-shaped pill, the flat-shaped round pill, and the long pill. There is some variability in mass and size of each type of pills. With the pill boxing machine, the workers at the nursing home would manually enter the prescription into the machine through an interface, load the three different types of pills into specified collectors (assuming the user puts enough of each type of pills to satisfy the prescription), and insert the pillbox into the designated slot. Within 3 minutes, the machine would need to place the appropriate number of each type of pills into the pillbox, and return the pillbox with all the lids closed and locked. The remaining pills would need to be sorted and placed in collection bins where the user can easily retrieve them by type. The display would show the number of each type of pills remaining. For safety purposes, the machine must also have an easily-accessible emergency stop button. [1]

2.2. Stakeholders

1. Nursing homes and nursing home workers: Nursing homes need to provide prescription drugs weekly for some of its residents. The nursing home workers need to organize the pills into pillboxes efficiently and correctly so they can be delivered to the residents.
2. Nursing home residents who take prescription/medication: Some nursing home residents need to take prescription drugs. They need their pills correctly sorted into pillboxes and delivered to them.
3. Design Team: The team desires to satisfy the client requirements for the machine, and hopes to gain design experience and learning from the design and construction of this machine.
4. Professor M. Reza Emami & J. Sarr: The course instructor and teaching assistant desire the design team to demonstrate an understanding of the course material, as well as teamwork and coordination in a thorough design process.

2.3. Goal

The goal is to design and fabricate the proof-of-concept prototype of a machine that can correctly and efficiently package various daily pills in a medication box based on the given instructions from the Request for Proposal.

2.4. Design Values and Objectives

2.4.1. Design Values / High Level Objectives

The design team developed the following set of design values or high level objectives for this machine based on the Request for Proposal and user needs. These high level objectives are listed in the order from the most importance to the least importance:

1. Safety:

   Definition: Protection and prevention from conditions that can cause death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment. (MIL-STD-882E for systems safety)
   Justification: In order to prevent employee exposure to electrical shock, safety must be the utmost priority for this machine. Incorrect circuitry connection during the battery sorting process can cause sparks or flames that would release hazardous chemicals, damage the machine, and possibly injure the operator.

2. Usability and User-friendliness:

   Definition: Little time/effort is needed to set up and calibrate the machine, "the operator needs to provide minimal input to achieve the desired output, and also that the machine minimizes undesired outputs to the human" [6]. In addition, “little time and effort is needed to set up and calibrate the machine, and the machine is modular so that parts can be replaced or repaired easily” [1].

   Justification: In order to allow employees of a variety of skill levels to operate the machine, the machine must be quick and easy to set up, and the interface must be easy to understand and use by the users, and the loading procedure must be simple. In case of a malfunction or repair, the machine is designed in such a way that it is simple to make repairs and replace parts.

3. Manufacturability and Complexity:

   Definition: Little time and effort is required to manufacture the machine to an excellent overall quality, and the machine is designed in a way such that it uses a minimum number of components, with simplistic geometry shapes, and has a simple operation process.

Metrics: The number of actuators/electronic components (motors, servos, solenoids, etc.) required; the total number of components required; the number of modes/dimensions of motion; complexity of the geometry of the parts

Justification: Since the design team has limited time to design and construct the machine, a simpler design / lower complexity would allow for less effort and time spent to make the machine of better quality, and thus, meet the requirements before the deadline.

4. Reliability and Efficiency:

   Definition: The completion of the pill-boxing and sorting task using minimal time possible, and resulting in a minimum amount of errors. [1]

   Justification: The machine must be able to complete the pill-boxing task within the required 3-minute time frame, as given by the Request for Proposal. In addition, since the user needs to organize a large number of pills into pillboxes for the entire nursing home, the process needs to be efficient in order to save time. Less mistakes in the pill organization process would also save time and effort for the user, since they would not need to reorganize the pills manually, and would be more desirable for the patients, who rely on the machine to organize their prescription correctly. [1]

5. Compactness and Portability:

   Definition: The ability to easily lift and transport the machine. [1]

   Justification: In order to allow the client and the engineering team to test the machine is a variety of setting around campus during the design process, the machine must be portable enough to be carried easily. The supply company will also likely have multiple sorting machines, and the machine not occupy excessive space. As specified by the Request for Proposal, the machine must also be less than 6 kg, and fit within a 0.50 x 0.50 x 0.50 m^3 size constraint. [1]

6. Affordability:

   Definition: The price to make and assemble the machine.

   Justification: The total cost of the machine must be under the cost constraint of $230 CAD as specified in the Request for Proposal. The cost must be low enough to make sense economically versus hiring human workers for the client. [1]

7. <u>Reliability:</u>

   Definition: The machine can withstand wear over repeated usage and mechanical stress. It functions consistently in a wide range of operating environments with a low failure rate. [1]

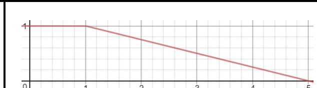
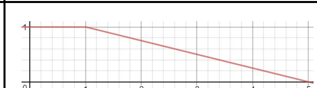
   Justification: The client requires the machine to work reliably over repeated use over time without a malfunction.

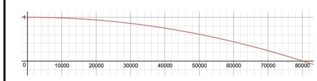
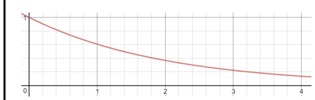
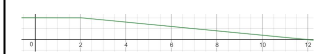
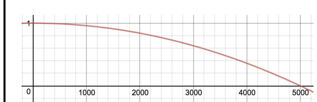
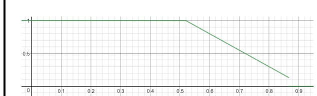
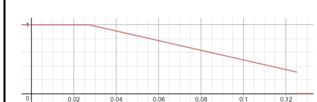
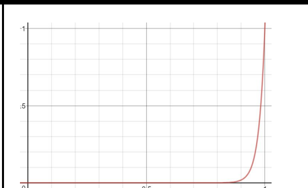
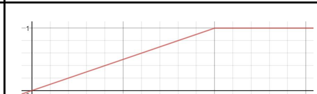
8. <u>Elegance:</u>

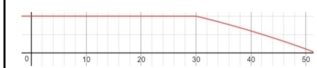
   Definition: "Machine looks elegant, and operates quietly and smoothly with little or no sensible noise or vibration." [1]

   Justification: Since a nursing home should be a quiet environment, the operation of the machine should not disturb the residents. In addition, the appearance of the machine should blend in with the nursing home environment and not be visually distracting/unappealing for its residents. [1]

2.4.2. Quantifiable Objectives and Metrics

Objective	Metric/Parameter	Scale	Unit	Constraints	Utility Function
Safety					
No potentially harmful parts should be exposed (e.g. exposed wires, sharp metals, blades, rotating or fast-moving parts)	Number of exposed parts that may be potentially harmful	Value	1	All harmful components must be concealed from easy access	N/A
Emergency stop button stops machine immediately	Time taken for operation to stop after emergency button is pressed	Value	Seconds	Machine must stop all motion immediately (<2 seconds) [1]	
Usability / User-Friendliness					
User-interface is easy to use	The number of instructions required for the user to operate the interface	Value	1	N/A	
Minimize effort required for loading and retrieval of pill box/pills	Number of instructions that the user requires to load/retrieve the box/pills	Value	1	N/A	

Manufacturability and Complexity					
Minimize the total number of components required	-The number of components in a mechanism / subsystem / the machine divided by its volume -Each electronic part (motor, actuator) is weighed as 5 components	Ratio	$1/m^3$	N/A	
Minimize motions involved in the packaging process	The number of degrees of motion involved for any one component	Value	1	N/A	
Geometry of the design and the parts are simple	Total number of surfaces of all components divided by the number of components	Ratio	1	N/A	
Efficiency					
Minimize the amount of time required to set up the machine (which includes inserting pill box, loading pills, and entering instructions	Total amount of time required to perform the listed tasks	Value	Seconds	Setup time should be less than 1 minute [1]	
Minimize the amount of time required to complete the loading process	Total time required to organize the pills into the pillbox and return the remaining pills	Value	Seconds	Total time for one operation must not exceed 3 minutes [1]	
Compactness and Portability					
Minimize the size of the machine	The length of the main diagonal of the bounding box of the subsystem /machine	Value	Meters	Total dimensions of the machine must not exceed 0.50 x 0.50 x 0.50 m [1]	
Minimize the weight of the machine	Total weight of the machine	Value	kg	Total weight of the machine must not exceed 6 kg [1]	
Affordability					
Minimize the total cost of all components comprising the machine.	Total cost of all components (manufacturing costs are not included)	Value	$ CAD	Total cost of the machine must not exceed $230 CAD [1]	
Reliability					
Minimize the number of errors made	Total number of successful operations over the total number of operations	Ratio	1	Must not make any errors	
Maximize robustness of all subsystems by maximizing tolerance for variability in the dimensions of the box and pills	Maximum possible deviation of the object dealt with by the subsystem from the desired position such that the subsystem will still function	Value	mm	N/A	

	as intended				
Elegance					
Minimize noise pollution from the machine	Maximum level of noise generated during machine operation	Value	Decibels	Maximum noise level must not exceed 50 dB [REF]	

Refer to Appendix A for additional constraints as per the RFP, and Appendix C for the mathematical equation of the utility functions.

2.4.3. Environmental and Operating Conditions

As per the RFP, the machine must operate under the following set of conditions:

- Standard Room temperature (20-22 degrees Celsius)
- A dry environment (no portion of the machine is underwater)
- No interaction with the machine in autonomous run.

3. Background and Survey

3.1. Literature Survey

32 million individuals in the United States alone take three or more pills daily. However, up to 75% of individuals do not adhere strictly to their regimen in some way. [3]

For patient medication, it is vitally important to ensure that pills are taken in the right order and at the appropriate times. This can be a difficult task, especially pertaining to individuals that are on a regimen of multiple medications.

Our prototype is designed to address this concern. The process of pill sorting is streamlined through automation, freeing up more time for nurses and personal support workers.

In addition, the area of pill administration has been identified as an area for further optimization. It was found that up to 40% of pills are wrongly administered in a clinical setting. Out of this 40%, half of all errors occurred during drug administration, with the most common mistake being that the pill is taken too early or too late. By sorting into discrete time steps, this prototype makes it easier for healthcare workers to properly sort the pills by the time in which they should be taken. For patients on a time-sensitive pill regimen, this is of vital importance. [4] [5]

3.2. Market Survey

A market survey was conducted, and it was found that products exist on both sides of the scale of our proposed solution in terms of size and ability. On one end of the spectrum, there has been efforts to develop automated pill dispensing mechanisms in homes. An example would be the startup Pillo [6][7], which addresses the individual or family segment of the market of automated pill dispensing. On the other end of the spectrum in terms of automation is pill packing facilities in pharmaceutical machines, which experience high throughput and is integrated into the manufacturing process.

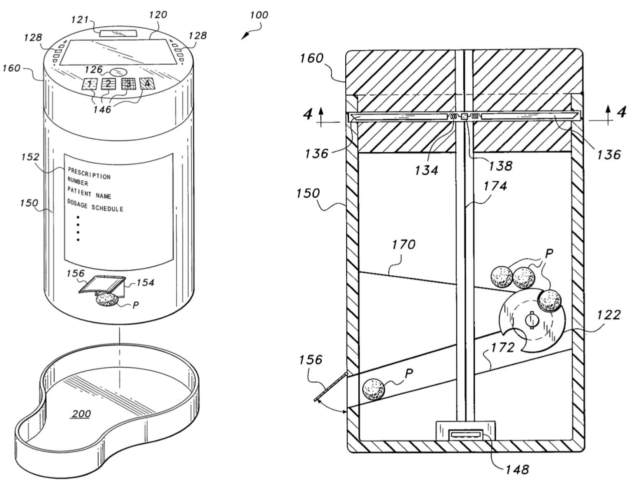
However, neither of these categories can satisfy the purpose of organizing multiple prescriptions into pill boxes for a nursing home, given the requirements defined by the Request for Proposal.

First, both of these existing solutions are too expensive and exceed the cost constraint of CAD $230. The personal home-use automatic pill dispensing robot (Pillo) has a listed retail price of USD $449 (CAD $554). Large industrial-purposed pill packing machines can cost thousands of dollars.

Second, even though personalized dispensers like Pillo are well within the size constraint, large industrial pill-packing machines are far too great in size to be implemented at a nursing home setting.

We believe that our solution exists on an intermediary level between these two niches, which addresses pill packaging on a scale in between home and industrial applications.

3.3. Patent Survey



The US 7359765 B2 patent [], shown in the figures above, is an electronic pill dispenser. This device, like the Pillo, serves to remind patients when they need to take medication, and prevents accidental overdoses by controlling the number of pills dispensed each time. Although the function of this device is different from that of the requested pill-boxing machine, it gave inspiration for a mechanism that can consistently dispense one pill at a time. As shown in Fig. _, the pills are caught by a wheel with slots, and precisely one pill can be released by turning the wheel 180 degrees. This design lead to many of the brainstormed ideas that involve rotating disks/wheels with holes tailored to a specific type of pill, including the selected design, as will be discussed in section 4.2.3.

4. Conceptualization

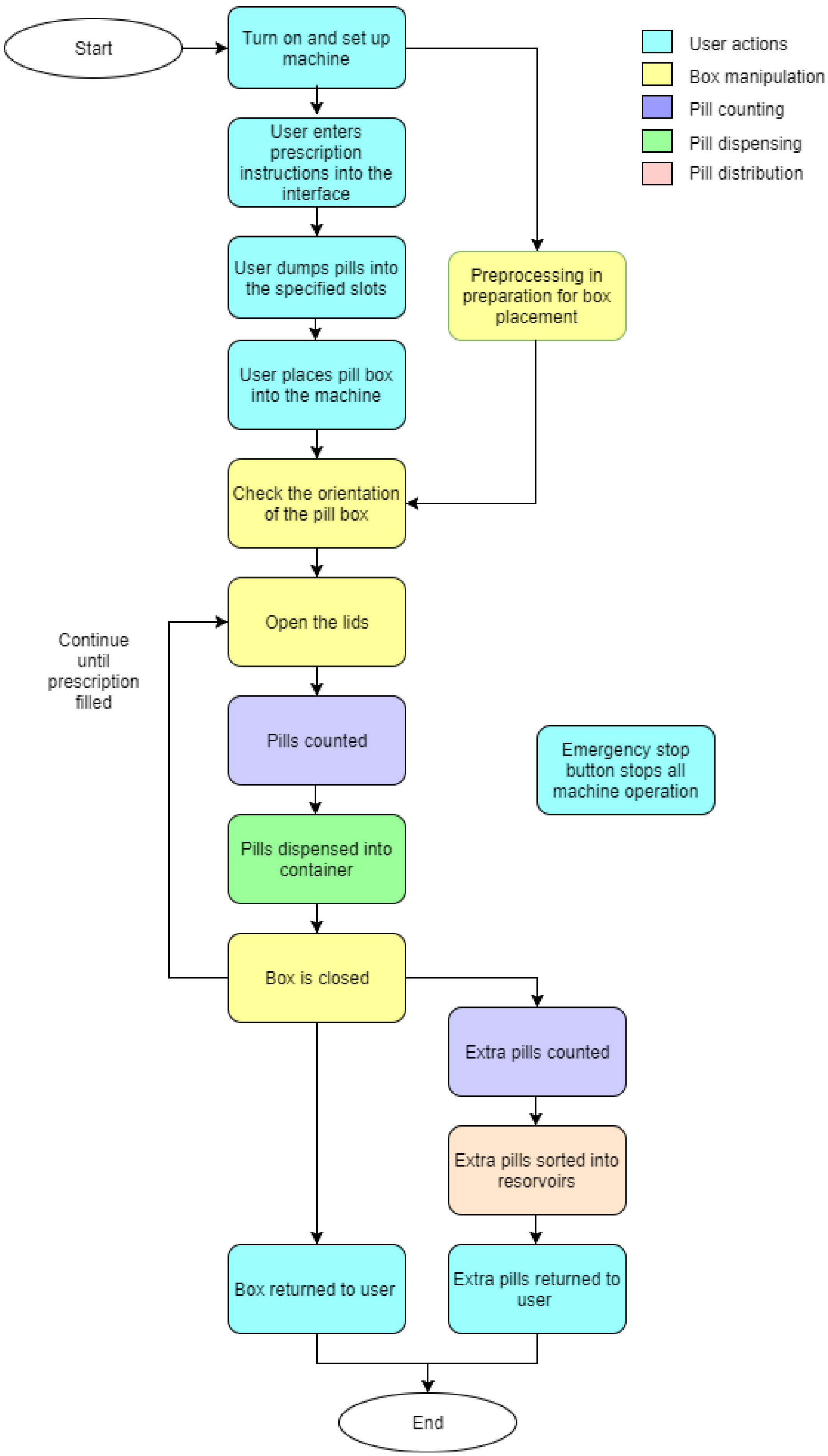
4.1. Overview of Design Process

The design process begins with a definition of the required operational procedure of the machine. A flowchart (Section 4.1.1) is used to model this process. 4 sub-functions were identified, each of which is addressed by a respective subsystem. Section 4.2 discusses the process of designing these subsystems and various mechanisms within them. Because the subsystems differ in the functions that they address, the design objectives listed in Table 2.4.2 will have varying importances with respect to each. For instance, the objective of robustness is critical to the ‘Box Manipulation’ subsystem as it must have tolerance for the range of possible positions that the user will initially place the box, while minimizing error in the number of pills dispensed is more relevant to the ‘Pill Dispenser’ subsystem. Section 4 serves to elucidate the process undertaken by the design team to arrive at the final design. The design process of each subsystem begins with a discussion of relevant objectives and metrics, followed by idea generation through brainstorming and research. The solution space is then condensed through utility-based decision-making and AHP. Detailed specifications of the mechanisms will be discussed in Section 5.

4.1.1. Proposed Operational Flowchart

The following operational flowchart was devised based on the requirements and functions that the machine must perform as outlined in the Request for Proposal.

Proposed Machine Operation Process



4.1.2. Functional Decomposition

From the proposed operational process flowchart above, the main functionalities of the machine were identified as the following:

- Box manipulation
- Pill counting
- Pill dispensing
- Pill distribution

Note: User actions (or user interface) is discussed in Section 5

Box manipulation consists of the process of determining the orientation (direction) of the pillbox, opening the lids for pill dispensing, positioning the pillbox with the precision required to dispense the pills into their respective containers, in addition to the process of closing the lid post dispensing. The box must be accessible to the operator upon completion.

Pill counting is an autonomous process whereby the quantity of pills the user inputs into the machine is determined, with excess pills dispensed into an easily accessible location.

Pill dispensing is the process that begins as soon as the user dispenses the pills into the collector bins, and the pills then drop down one at a time into the pill distribution mechanism.

Pill distribution is a combination of all the processes involved in guiding the pills into different areas after they are dropped down from the dispenser. This includes different compartments of the pillbox, as well as the three collection reservoirs for extra pills.

4.2. Prototyping & Functional Testing

4.2.1. Box Manipulation

4.2.1.1. Box Movement

The machine must be precise enough to dispense pills into each individual container, in addition to being robust to uncertainties involved with the user. This includes robustness to the orientation of the box in addition to the collection area. It therefore becomes necessary to manipulate either the positioning of the box itself or the dispenser.

Additionally, the following factors were given strong consideration, which corroborates with the AHP analysis.

Degrees of motion

A heuristic adapted by the design team is to reduce the degrees of motion necessary for dispensing. A binary system (i.e. a motor only needs to switch between two positions) is preferred to a continuous solution to reduce complexity. Physical constraining mechanisms are given precedence over increasing degrees of motion using motors and actuators, as this was considered to be more cost effective and reduces complexity. One degree of motion for a particular mechanism reduces the minimum number of motors, actuators and moving components to one.

Size

Mechanisms for box manipulation opens up the possibility of moving the box to various areas of the machine for processing. As the box itself has a length of 19 cm, or 38% of the length of the machine, a naive approach may see the mechanism quickly exceed design constraints.

Reliability

Box manipulation involves the action of opening the lids of each individual container so pills can be dispensed while maintaining the structural integrity of the container itself, in addition to closing each lid after the pills have been dispensed. As this process involves working with containers on the order of ~(insert dimensions here), the small margin of error increases the likelihood of a misplacement, or, if the system is mechanical, damaging the box.

The following is an AHP analysis to determine the relative importance of criteria relevant to the Box Manipulation subsystem:

	Criterion	Comment	Weights	Rk
1	Criterion 1	Geometry	3.2%	7
2	Criterion 2	Degrees of motion	20.1%	2
3	Criterion 3	# of components	18.1%	3
4	Criterion 4	Time	10.9%	4
5	Criterion 5	Size	5.9%	6
6	Criterion 6	Minimize effort	8.6%	5
7	Criterion 7	Robustness	33.3%	1

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8	0	0	normalized principal Eigenvector
	1	2	3	4	5	6	7	8	9	10	
1	1	1/6	1/4	1/4	1/2	1/4	1/5	-	-	-	3.17%
2	6	1	3	1	2	4	1/3	-	-	-	20.08%
3	4	1/3	1	3	5	4	1/3	-	-	-	18.05%
4	4	1	1/3	1	1	3	1/5	-	-	-	10.95%
5	2	1/2	1/5	1	1	1/4	1/4	-	-	-	5.88%
6	4	1/4	1/4	1/3	4	1	1/3	-	-	-	8.59%
7	5	3	3	5	4	3	1	-	-	-	33.28%

Consistency index: 13%

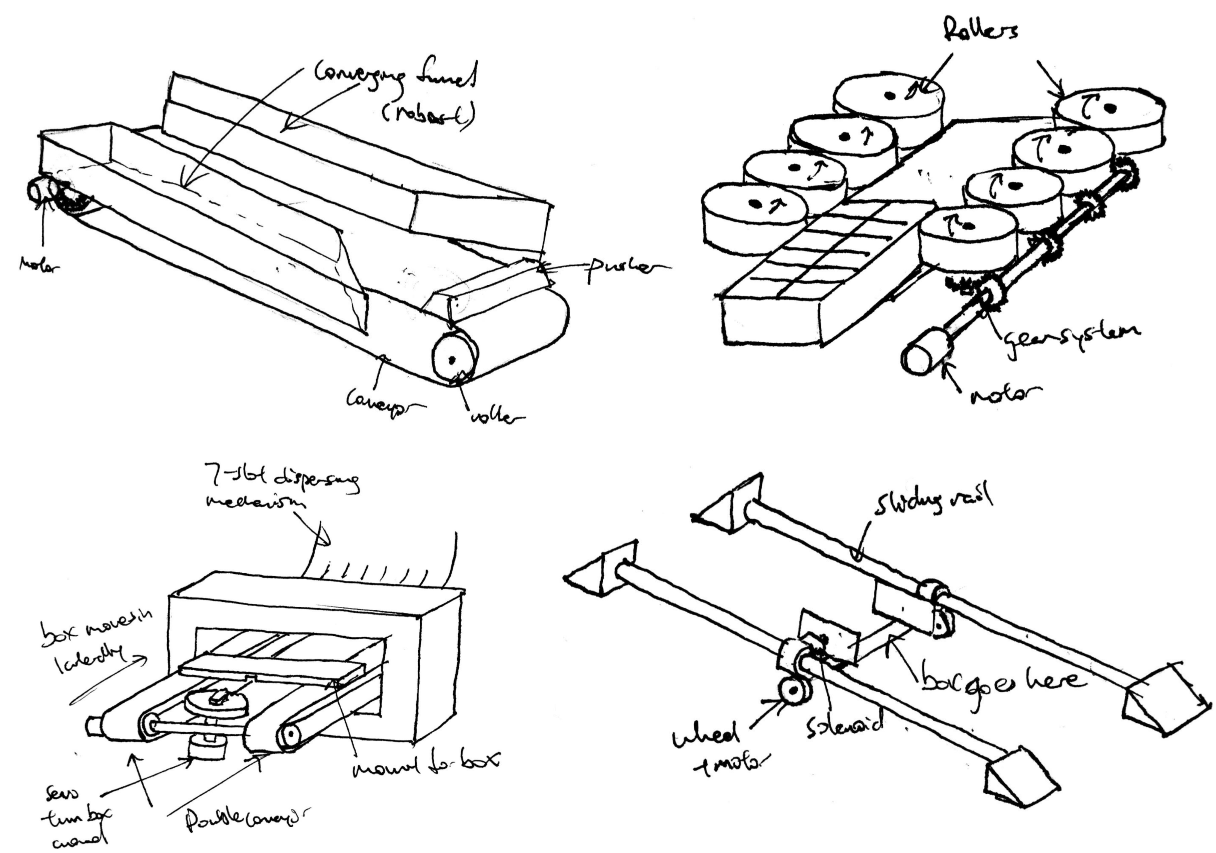
		Criteria		more important ?	Scale
i	j	A	B	A or B	(1-9)
1	2	Criterion 1	Criterion 2	B	6
1	3		Criterion 3	B	4
1	4		Criterion 4	B	4
1	5		Criterion 5	B	2
1	6		Criterion 6	B	4
1	7		Criterion 7	B	5
1	8		Criterion 8		
2	3	Criterion 2	Criterion 3	A	3
2	4		Criterion 4	B	1
2	5		Criterion 5	A	2
2	6		Criterion 6	A	4
2	7		Criterion 7	B	3
2	8		Criterion 8		
3	4	Criterion 3	Criterion 4	A	3
3	5		Criterion 5	A	5
3	6		Criterion 6	A	4
3	7		Criterion 7	B	3
3	8		Criterion 8		
4	5	Criterion 4	Criterion 5	B	1
4	6		Criterion 6	A	3
4	7		Criterion 7	B	5
4	8		Criterion 8		
5	6	Criterion 5	Criterion 6	B	4
5	7		Criterion 7	B	4
5	8		Criterion 8		
6	7	Criterion 6	Criterion 7	B	3
6	8		Criterion 8		

Note that, due to the high cost and complexity associated with actuators, one actuator counts as five components in our analysis as a normalization factor.

In addition, other normalization factors were used for time, size and volume. As each subcomponent is not expected to be the size or expected to account for the entire operational time budget of the machine, an estimate for the percentage of the total size and time required for each subcomponent as a function of the entire machine is found. The raw utility values for each individual subcomponent is then divided by this scaling factor in order to calculate for the effective utility value.

Placement	Design #1		Design #2		Design #3		Design #4		**Weights**		**Scaling Factors**	
	Normalizec	Utility	Normalizec	Utility	Normalizec	Utility	Normalizec	Utility				
Design	**Single Conveyor Belt**		**Rollers**		**Track**		**Lateral**				Time	0.2
Metrics											Size	0.85
Geometry	2.88	0.91	3.10	0.89	2.67	0.93	3.07	0.89	0.03		Volume	1
Degrees of motior	1.00	0.61	1.00	0.61	1.00	0.61	2.00	0.37	0.20			
# of Components	1600.00	0.90	2500.00	0.75	3833.33	0.41	5416.67	0.00	0.18			
Time	1.88	0.69	1.88	0.69	1.88	0.69	2.71	0.32	0.11			
Size	0.59	0.82	0.59	0.82	0.56	0.89	0.44	1.00	0.06			
Minimize effort	1.00	1.00	2.00	0.75	2.00	0.75	2.00	0.75	0.09			
Robustness	10.00	1.00	5.00	0.50	2.00	0.20	10.00	1.00	0.33			
Weighted sum		**0.86**		**0.64**		**0.48**		**0.59**				

Sketches of Designs (1 to 4 in clockwise order):



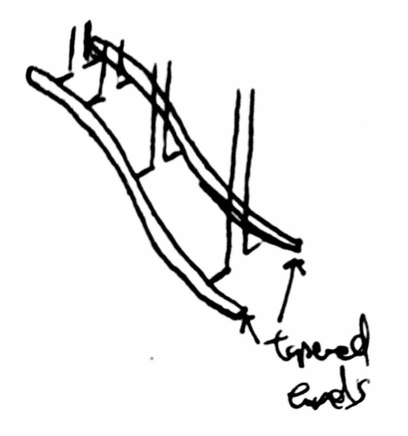
From the AHP and utility-based analysis, it was determined that the single conveyor belt design with a pusher block would be strongly preferred for the box movement system. Its relative ease of construction and good reliability potential is desired by the design team.

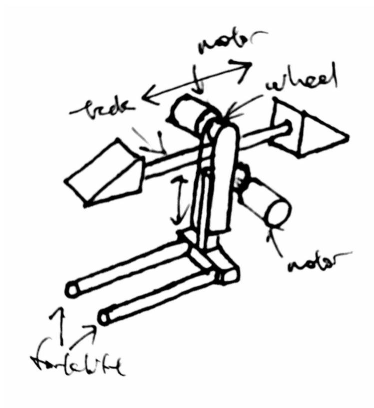
4.2.1.2. Opening the Lids

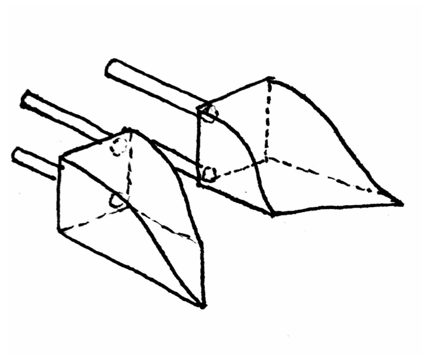
As per the RFP, the user would clip open all the lids of the pillbox and leave it in a rest position before placing it inside the machine for processing. At rest position, there would be a small gap ,~5 mm at the widest, between the lid and the box structure where a mechanism can reach inside and open the lid. Using the same set of criteria from above ,excluding “minimize [user] effort” as the process is autonomous.

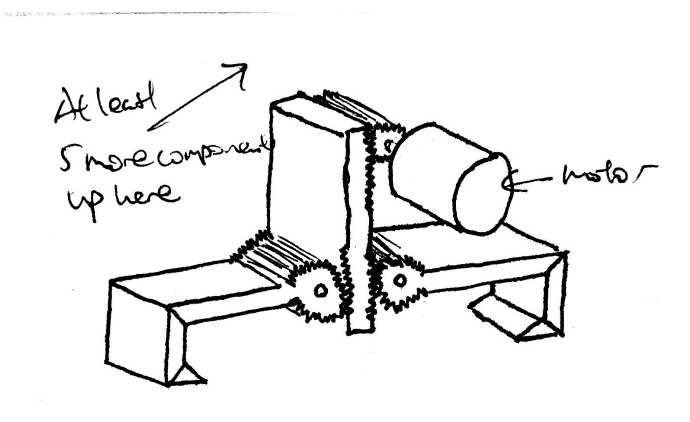
Opening the Lids	Design #1		Design #2		Design #3		Design #4		Design #5			**Weights**		**Scaling Factors**	
	Normalizec	Utility	Normalizec	Utility	Normalizec	Utility	Normalizec	Utility	Normalizec	Utility					
Design	**Double Rod**		**Forklift**		**Double Wedge**		**Double Actuator**		**Claw**					Time	0.05
Metrics														Size	0.25
Geometry	1.80	1.00	Complex	0.00	3.00	0.90	3.67	0.83	Complex	0.00		0.03		Volume	3.00
Degrees of motior	0.00	1.00	2.00	0.37	0.00	1.00	2.00	0.37	2.00	0.37		0.20			
# of Components	4629.63	0.14	8333.33	0.00	4166.67	0.31	2962.96	0.65	4861.11	0.05		0.18			
Time	0.00	1.00	1.67	0.77	0.00	1.00	0.50	1.00	7.00	0.00		0.11			
Size	0.84	0.20	0.88	0.00	0.64	0.69	1.09	0.00	0.70	0.54		0.06			
Robustness	3.00	0.30	3.00	0.30	3.00	0.30	2.00	0.20	10.00	1.00		0.33			
Weighted sum		**0.52**		**0.28**		**0.58**		**0.43**		**0.49**					

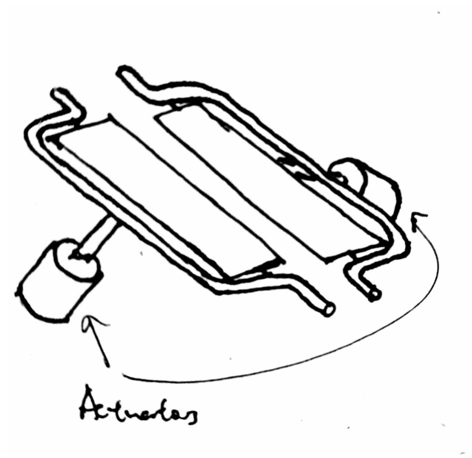
Sketches of Designs (1 to 5 in clockwise order):











From the utility-based analysis, it was found that the double wedge design was somewhat preferred for opening the lids of the pillbox. It was quite simple to construct. From the testing of a mostly functional prototype of the double wedge design, it was found that the box can slide underneath the wedge with relatively ease while the lids are opened. This design also integrates well with the component that drops the pills into the pillbox (discussed in Section 4.2.2).

4.2.1.3. Closing the Lids

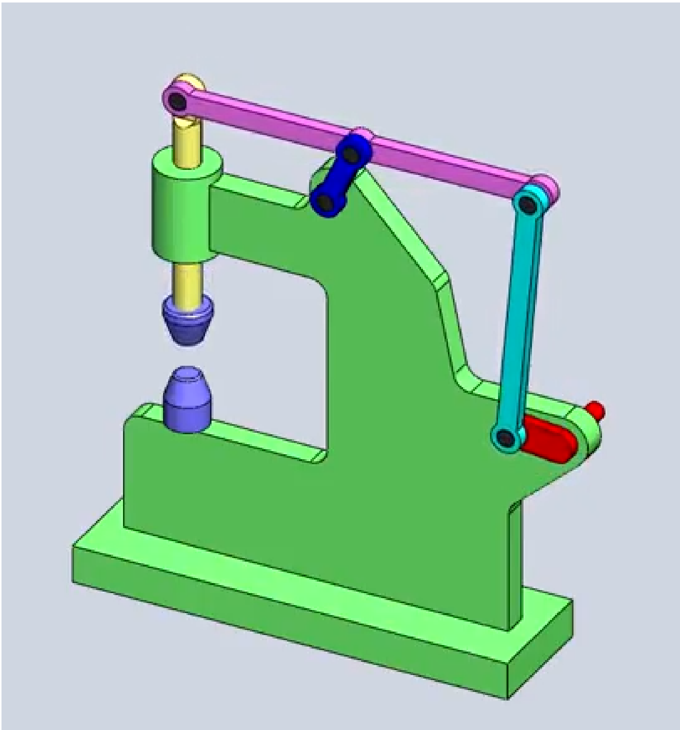
As per the RFP, the lids of the pillbox needs to be closed and locked in place when it is returned to the user. Intuitively, this action would require a force compressing down onto the lids as the pillbox moves forward on the conveyor belt.

From testing out several different designs (including a roller, a flat plate, a block of wood, and pressers), however, it was found that the lid closing mechanism requires the application of not only force, but force in a specific location and direction. A pressure force that possesses a purely vertical component (press) was found to be unfeasibly large due to the snapping mechanism of the lid, while forces that act purely in the horizontal direction (rollers) were found to press on and damage the lid (figure on right). Through the use of a Newton meter for force analysis, it was found that directional or impulsive force application is more effective. Methods for increasing the effective applied force include:

- Dropping a mass onto the lid applies a sharp impulse, which snaps the lid closed even with a relatively small mass and drop height
- Due to the lids opening from the centroid of the pillbox, it was found that applying force towards the outer edge of the lid increases the moment arm, hence increasing torque and reducing the amount of force required
- Decreasing the contact surface area increases local pressure, which is more effective in closing the lid than a larger contact surface area, and
- A block with a larger second moment of area is more effective than a thin plate, as less energy goes into elastic deformation and buckling.

Therefore, designs such as a single roller, a flat plate, and a plain wooden block that apply only downwards force are ruled out. A block with a more precisely manufactured shape is needed to provide both downwards compression, as well as a horizontal force, and limit the contact surface area. An actuator is also required to provide linear downwards motion and impulse.

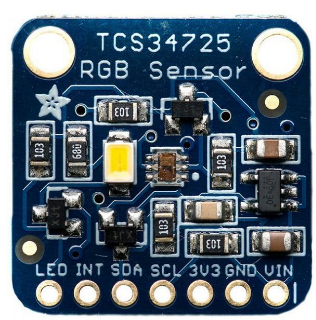
Upon research of possible designs online, one particular design was considered (figure below). It involved a set of bars that move to transfer motion from a motor, and a piece that presses straight down. However, instead of using a round presser piece, the piece would be precisely manufactured to clamp down the lids from both sides, providing both vertical and horizontal force. Although this structure is relatively complex, it was deemed to be more reliable.



4.2.1.4. Checking Box Orientation

There exists the need to differentiate between the two orientations of the box, assuming that the user places the box on the conveyor and does not check which side it is on. The only physical differentiating features between the two sides are the lid colors in addition to the text on the board. Reading text requires OCR, which involves a camera, and this was deemed to be beyond our budget.

An RGB color sensor (shown on right figure) could then used, as this provides the necessary degree of sensitivity at an acceptable price range to detect the color of the lid and hence the orientation of the box.

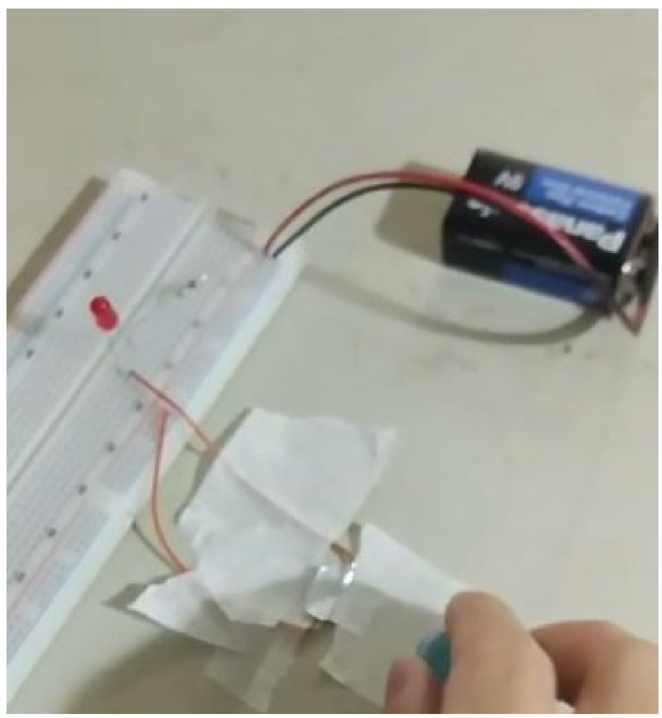


4.2.2. Pill Counting

As per the RFP, the machine needs to count the remaining number of pills for each of the three types of pills. At first, the following options were considered.

Design	Description
Pressure sensor	A small spring-loaded plate, with two wires on each side. Upon a detection event, the plate elastically deform due to the contact with the pill and completes the circuit, sending a signal to the microcontroller. This design is inexpensive and easy to manufacture; however, it needs a larger mass in order to trigger.
Light sensor	A LED with a photodiode. A passing pill lowers transmittance to the photodiode, creating a detectable dip in light intensity which can then be used as a detection event. This sensor has low latency, but has a higher cost and is not robust against external influences (for example, flipping the light switch could potentially trigger the sensor).
Force sensor	The force sensor interfaces with the PIC board by sending force values, in newtons. By thresholding this value it becomes possible to detect an event. It is more sensitive than the pressure sensor, but is more expensive to implement and solutions need to be implemented, be it hardware or software, to debounce the signal.

As per constraint o [Appendix A], there cannot be any errors (i.e. counting the wrong number of pills).



A pressure sensor was then prototyped with aluminum acting as the plate, with two wires on each side. This sensor achieved satisfactory performance, detecting each individual event despite the low fidelity. This sensor was found to be unable to detect the ellipsoid pills rolling on a flat surface; this was remedied by dropping the pills from a height. The sensor was ultimately chosen due to its accuracy. It is also vastly more cost-effective and simple compared to the other designs; the cost for 2 wires and a strip of aluminum is negligible.

4.2.3. Pill Dispensing

As per the RFP, there can be three separate compartments for the user to dispense three different types of pills. The pills then drop down one at a time from the compartments to the pill distribution system to be loaded into the pillbox (one pill at a time ensures that the right number of pills are loaded).

Although the three compartments can have a similar outline and structure, since the three types of pills greatly differ in shape and size, the specifications of each compartment may be different.

From testing out several prototypes of systems that control pill dropping (including basic funnels, linear actuator pushing the pills into a slot, cylinder with rotating base with slot, rotating catchers), it was found that:

- Basic funnel-shaped dispensers without further modification are prone to jamming as the pills pile together.
- Simply pushing and dropping the pills through a slit is unreliable, because if the slit is too large, several pills may fit through at once; and on the other hand, if the slit is too small, jamming could be an issue.
- Using a rotating catcher (the catcher has slots that can only fit one pill at a time, and is powered by a motor) would be difficult for the long pill, since it does not always enter the catcher at the same orientation. Building additional slider ramps would increase complexity and consume too much space inside the machine.
- Attaching viberators to the dispenser to prevent jamming would create too much noise; and the vibration may destabilize the parts.

For these reasons, designs such as the basic funnel, boxes with a pusher and slit, and the rotating catcher were disregarded.

The remaining designs were evaluated using an AHP-ranked metrics system, and a utility-based analysis. Some of these designs drew inspiration from personal design projects on Youtube. [9][10][11][12]

	Criterion	Comment	Weights	Rk
1	Criterion 1	# of Components	18.9%	2
2	Criterion 2	Geometry	13.5%	3
3	Criterion 3	Error Rate	62.3%	1
4	Criterion 4	Size	5.3%	4

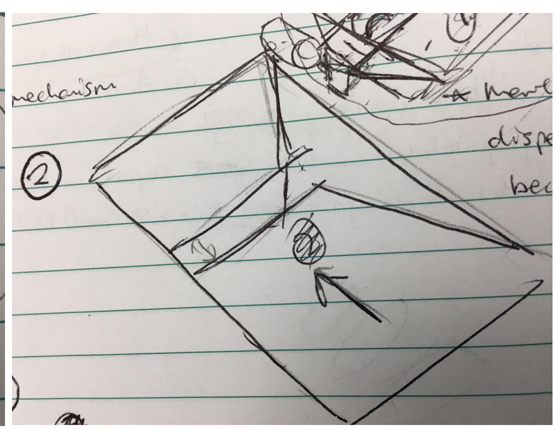
Matrix		Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8	0	0	normalized principal Eigenvector
		1	2	3	4	5	6	7	8	9	10	
Criterion 1	1	-	2	1/5	4	-	-	-	-	-	-	18.95%
Criterion 2	2	1/2	-	1/5	4	-	-	-	-	-	-	13.48%
Criterion 3	3	5	5	-	7	-	-	-	-	-	-	62.26%
Criterion 4	4	1/4	1/4	1/7	-	-	-	-	-	-	-	5.31%

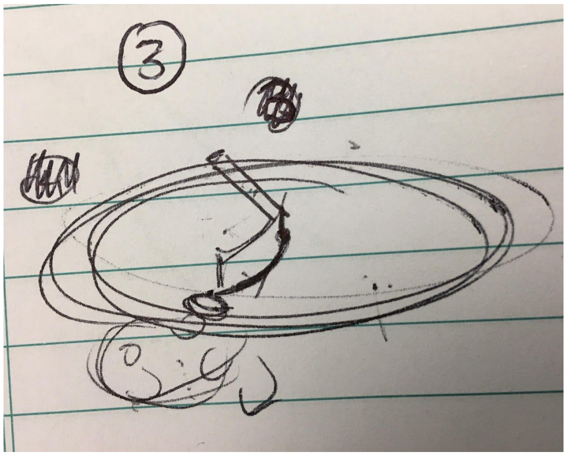
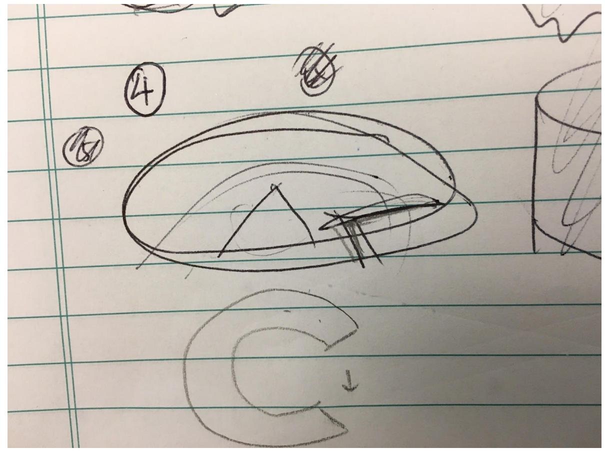
-Consistency ratio: 8%

	Design #1		Design #2		Design #3		Design #4		Weights	Scaling Factors	
	Normalized	Utility	Normalized	Utility	Normalized	Utility	Normalized	Utility			
Design										Size	0.3
Metrics											
Geometry	3.45	0.85	High	0.00	2.00	1.00	3.00	0.90	0.19		
# of Components	2500.00	0.75	5833.33	0.00	10000.00	0.00	4000.00	0.36	0.13		
Success Rate	0.95	0.14	0.87	0.01	0.98	0.45	1.00	1.00	0.62		
Size	0.62	0.75	0.67	0.63	0.53	0.97	0.53	0.97	0.05		
Weighted sum		**0.39**		**0.04**		**0.52**		**0.89**			

*One motor was discounted since all designs have at least one.

Design 1: Slot with rotating collector
Design 2: Simple slot
Design 3: Disk with rotating strip
Design 4: Cylinder with rotating disk with a slot and an opening



In the end, it was determined that the cylindrical dispenser with a motor-driven rotating base, which has a slit cut in the base to only allow for one pill to be dropped each time, would be used for the pill dispensing mechanism (Design 4). It has a significant edge over the other designs on its reliability.

4.2.4. Pill Distribution

Based on the definition of this subsystem, the pill distribution subsystem has two components: the component which guides the pills into the correct pillbox compartment, and the component that guides the remaining pills into the collection reservoir (although the two parts can be combined).

Since pill distribution is the part that determines the overall functionality and reliability of the machine, both the error rate and the running time are important parameters.

The following designs were mostly reference designs from existing projects, with some modifications (such as the removable plate in Design 4).

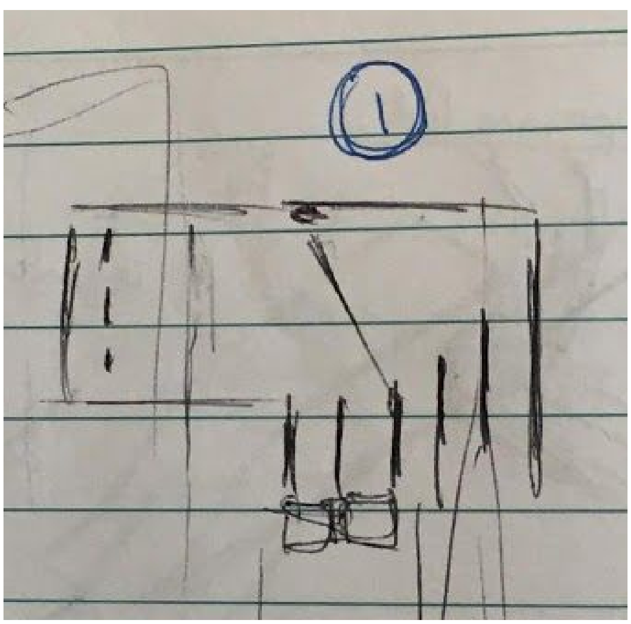
	Criterion	Comment	Weights	Rk
1	Criterion 1	# of Components	12.3%	3
2	Criterion 2	Geometry	11.3%	4
3	Criterion 3	Error Rate	36.5%	1
4	Criterion 4	Size	3.9%	6
5	Criterion 5	Degrees of Motions	9.7%	5
6	Criterion 6	Time	26.3%	2

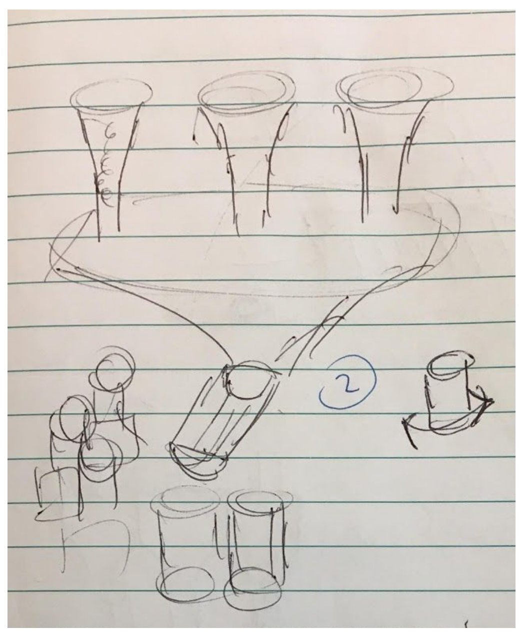
Matrix		Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8	0	0	normalized principal Eigenvector
		1	2	3	4	5	6	7	8	9	10	
Criterion 1	1	-	2	1/4	4	1	1/3	-	-	-	-	12.27%
Criterion 2	2	1/2	-	1/4	5	2	1/4	-	-	-	-	11.32%
Criterion 3	3	4	4	-	6	4	1 1/2	-	-	-	-	36.48%
Criterion 4	4	1/4	1/5	1/6	-	1/3	1/4	-	-	-	-	3.94%
Criterion 5	5	1	1/2	1/4	3	-	1/2	-	-	-	-	9.67%
Criterion 6	6	3	4	2/3	4	2	-	-	-	-	-	26.31%

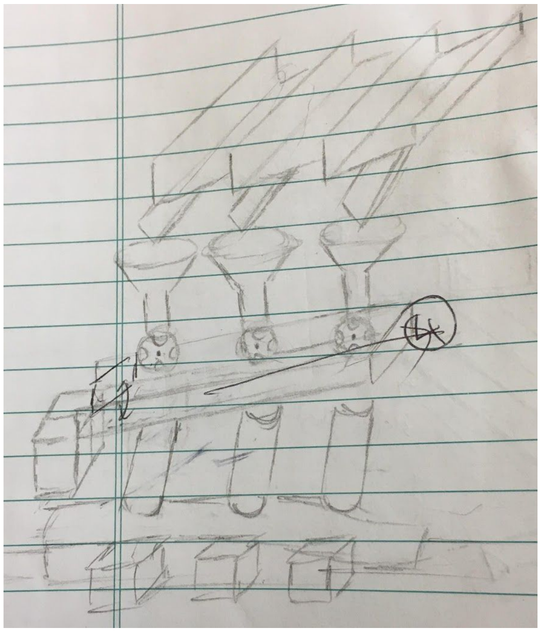
Consistency ratio: 6%

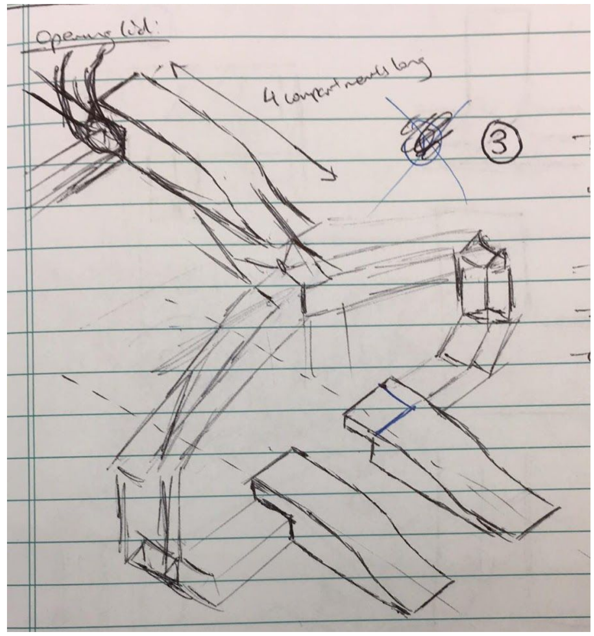
	Design #1		Design #2		Design #3		Design #4		Weights	Scaling Factors	
	Normalized	Utility	Normalized	Utility	Normalized	Utility	Normalized	Utility			
Design										Size	0.5
Metrics										Time	0.65
# of Components	1111.11	0.95	2777.78	0.69	2720.00	0.70	2166.67	0.81	0.12		
Geometry	4.00	0.80	3.80	0.82	8.55	0.35	high	0.00	0.11		
Success Rate	0.92	0.04	0.90	0.02	0.99	0.67	0.99	0.67	0.36		
Size	0.81	0.28	0.73	0.47	0.81	0.27	0.75	0.43	0.04		
Degree of Motions	1.00	0.61	1.00	0.61	4.00	0.14	2.00	0.37	0.10		
Time	2.56	0.39	2.05	0.61	1.79	0.72	1.79	0.72	0.26		
Weighted sum		**0.39**		**0.42**		**0.58**		**0.59**			

Design 1: 5-channels with rotating barrier
Design 2: Rotating tube
Design 3: Side loading into the pillbox
Design 4: "Pinball mechanism" and movable base plate









From the AHP and utility-based analysis, the “pinball mechanism” design was chosen since it has a slightly higher edge on reliability over the other designs.

4.3. Structures and Materials

4.3.1. Material Selection

When selecting materials for the structural frame and the components, several factors were considered. The material must be light, but durable, and does not easily deform (material data sheets were referred to). It must also be cheap and easily acquired.

First, plywood was considered for the outer frame. Even though aluminum sheets (0.025”) are somewhat more durable, they tend to deform more easily over time compared to plywood. To decrease the weight as much as possible while still providing sufficient support for the structure, ¼” plywood was used for the outer boards of the structure. For the cross beam, wooden sections of 1” x 2” were readily available for very low prices, and were thus considered.

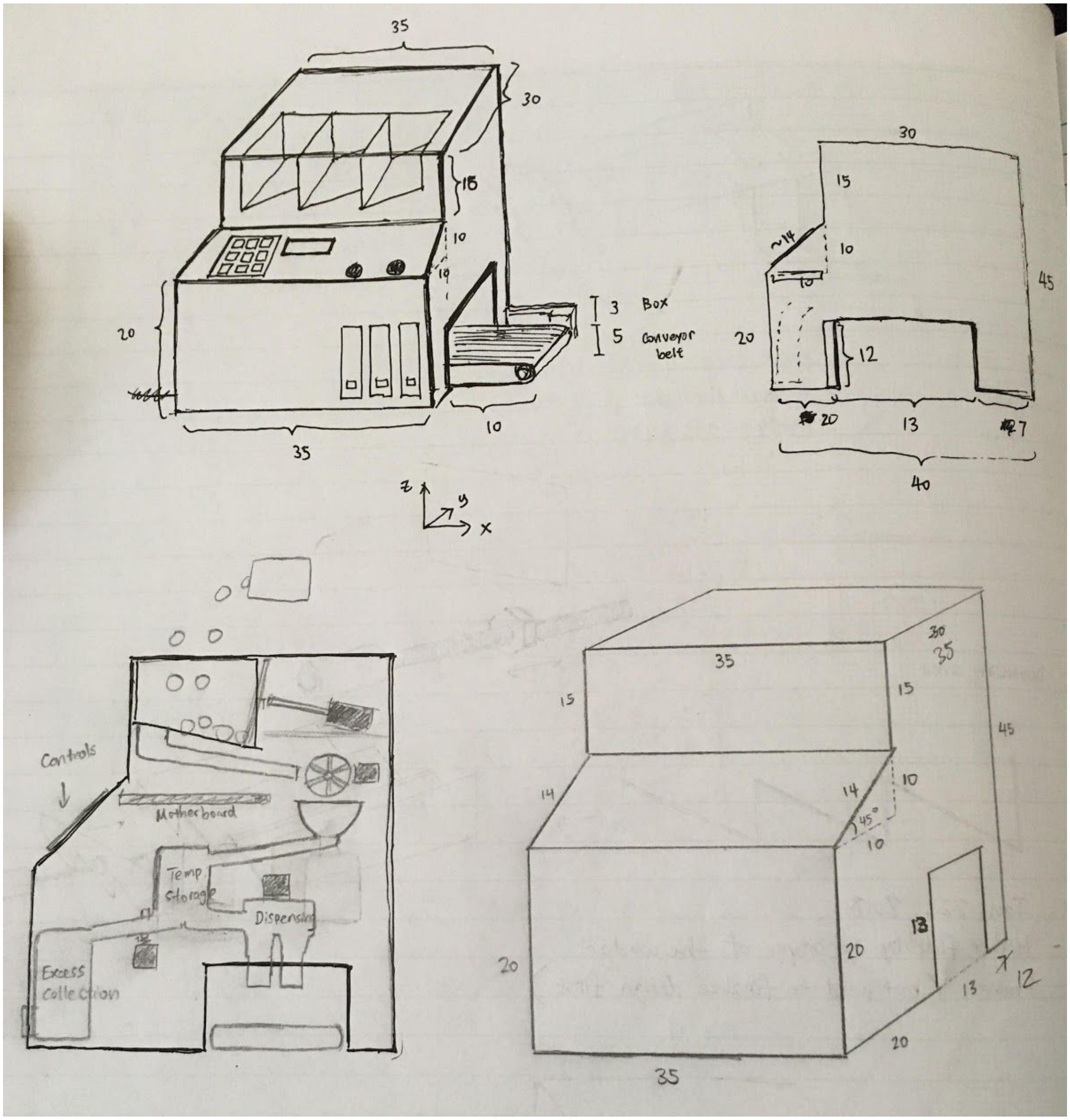
Second, for components such as the cylindrical dispensers, the “pinball mechanism”, and the various funnels and channels inside the machine, the material needs to take up little space (minimal thickness) as space is quite limited. Also, it needs to be easily malleable in order for components of different shapes to be made with little effort. For this purpose, aluminum sheets (0.025”) were considered. Although one disadvantage would be that aluminum could deform, but this was not a major concern since pill handling does not involve large forces (largest torque in the pill handling process is 1.5 kg*cm or 14.7 N*cm). Even so, bracings can be easily manufactured and installed to prevent significant deformation.

Third, for the structure of the conveyor belt, wood of varying thickness (1”, 2”) was needed to build the structure and support the conveyor belt itself. For the belt itself, since typical conveyor belt materials like Polyester Nylon fabric were found to be difficult to obtain, a substitute was considered. After experimenting with various types of fabrics, it was found that cotton-based fabric had the least amount of deformation per force (about 3% per 14 lbs force), and relatively little friction with a wooden surface. To generate enough friction to turn the conveyor belt, the rollers at each end were coated with sandpaper tape (A more detailed description is in Section 5.4.1).

4.3.2. Frame and Structure

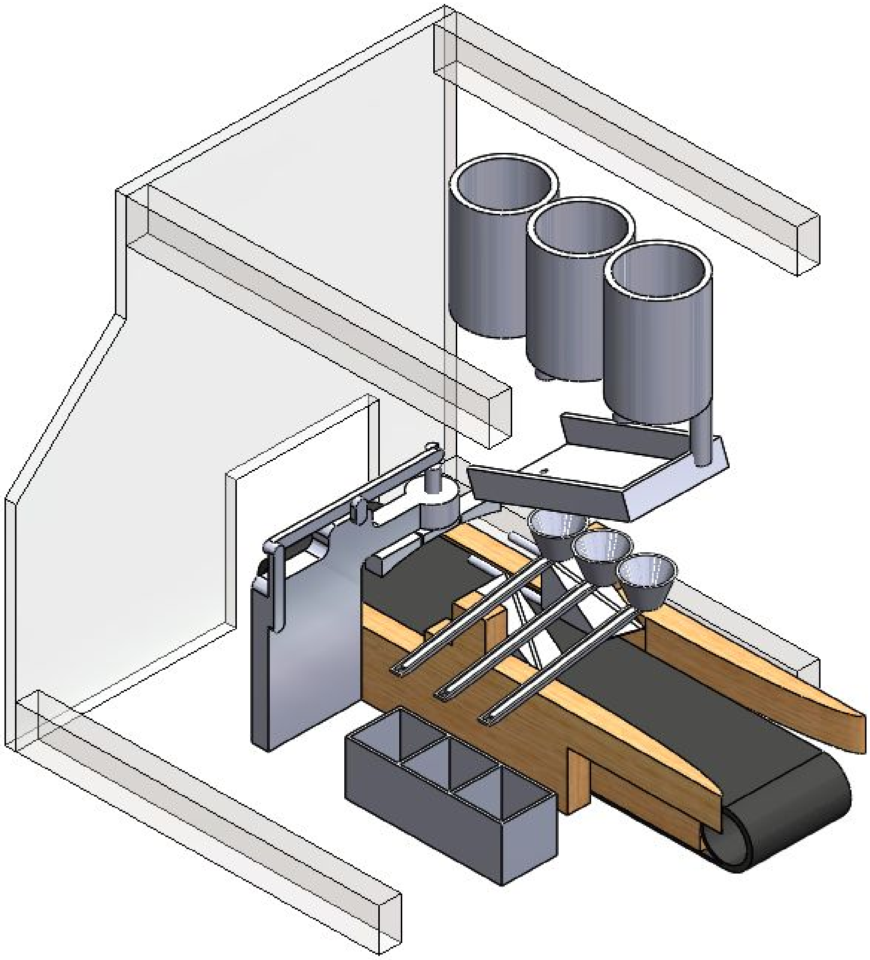
The outer frame was designed on the basis of the inner structure details, such that the frame would enclose and support the inner components.

Although a simple design like a cube or a cylinder can be used for the frame, usability was a major factor in designing the frame shape. For instance, to minimize dynamic body movement and rotation by the user, the pill dispenser and collection bins, as well as the controls, are located at convenient locations on the front of the machine. Also the slanted edge, which mounts all the controls, make it easier for the user to operate the machine. (A more detailed description is in Section 5.3). A rough schematic of the frame is shown below.

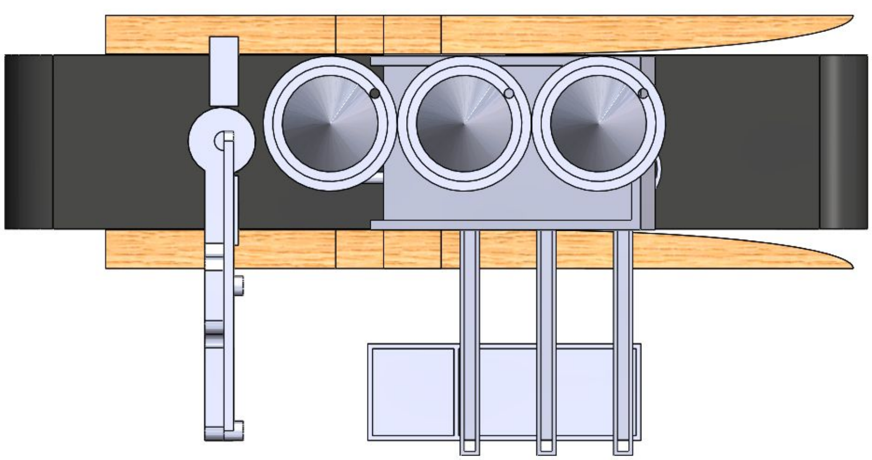

35
30
15
10
3 Box
5 Conveyor belt
20
35
10
z
y
x
30
15
~14
10
45
20
12
13
7
40
Controls
Motherboard
Temp Storage
Dispensing
Excess Collection
35
15
14
45°
20
13
12
45

5. Specification

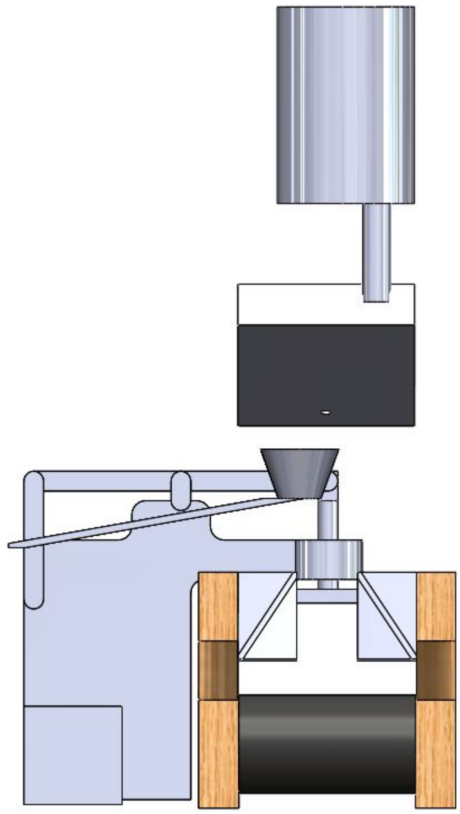
5.1. Machine Views



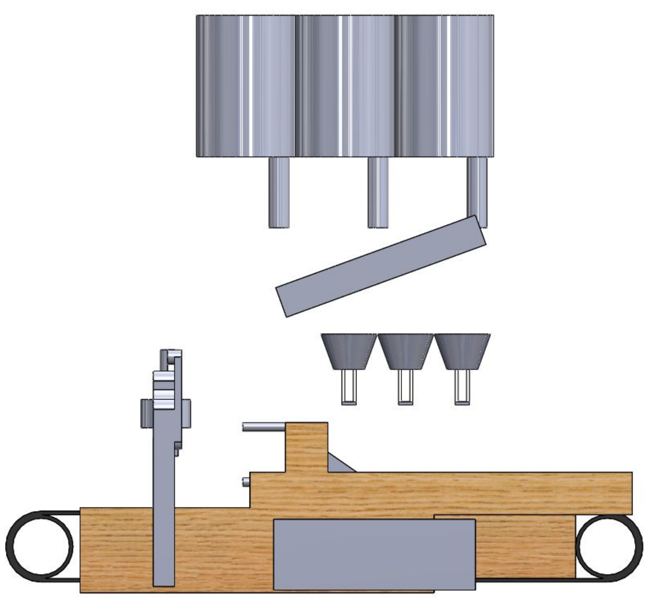
5.1.1. Top View



5.1.2. Front View

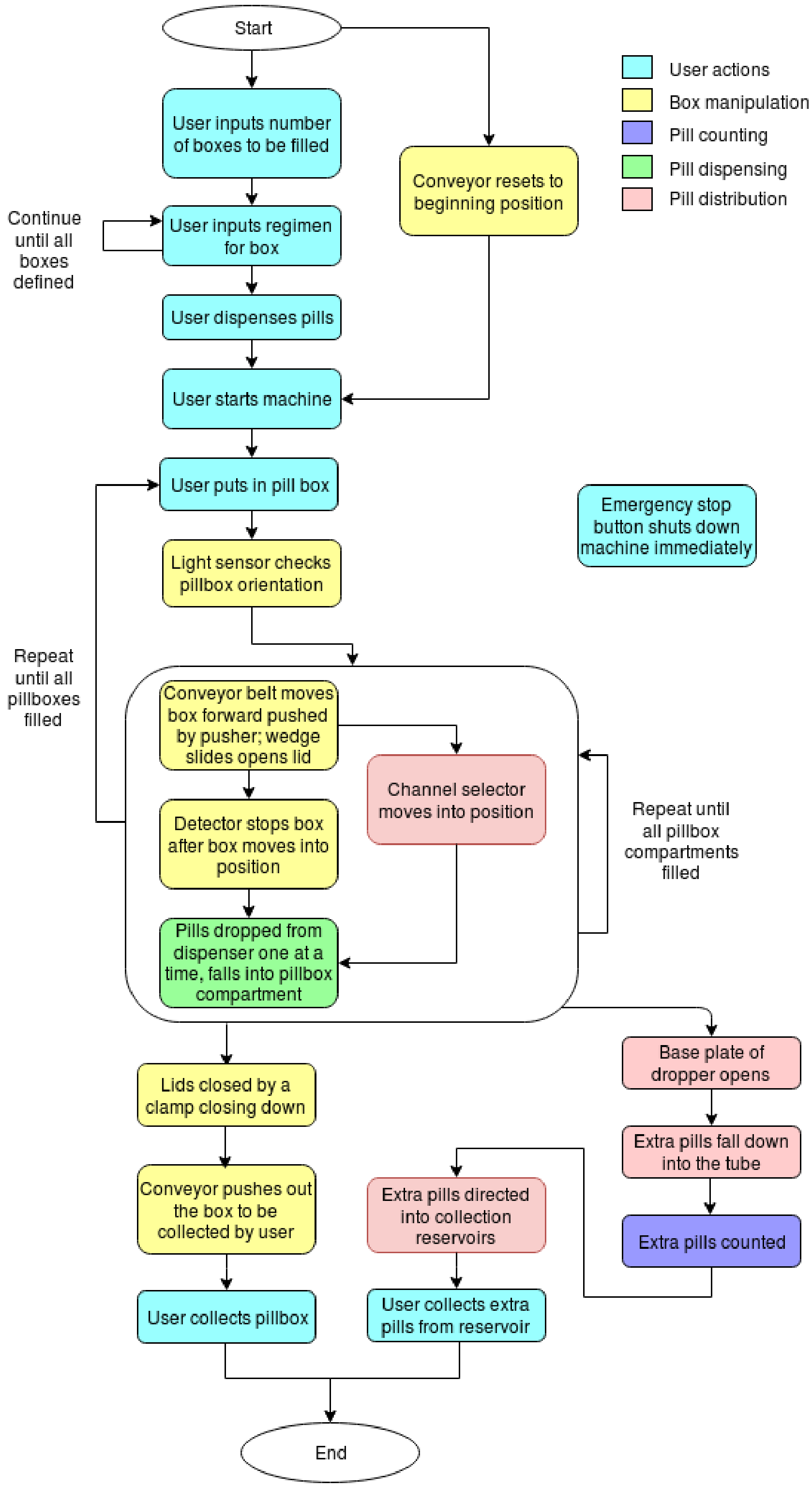


5.1.3. Side View

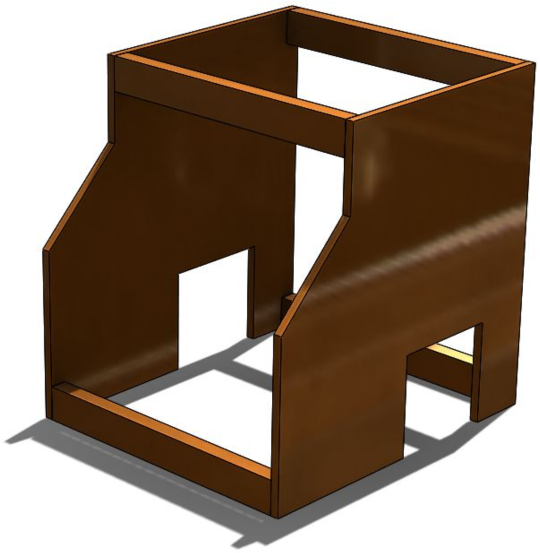


5.2. Machine Work Process

Based on the design of the machine, the functional process is as follows, shown in a flowchart:



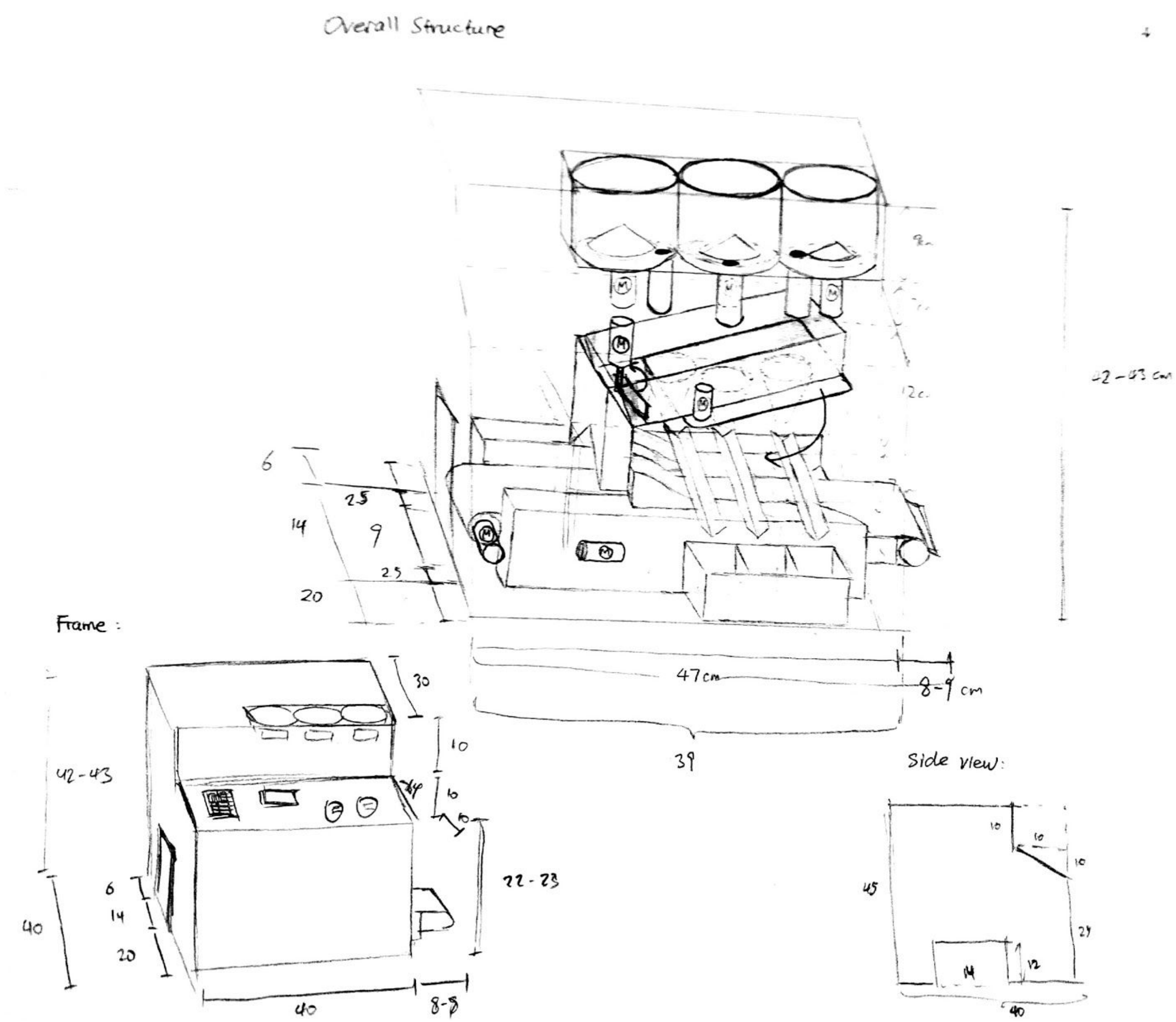
5.3. Frame and Overall Dimensions



The outer frame of the machine consists of two sideboards and 4 cross beams that connect them. There is the option to include a baseboard, a removable top cover, a removable front cover, and a removable back cover, depending on weight and cost requirements. The overall dimensions of the machine are 48 x 40 x 43 cm, while the main frame itself is 40 x 40 x 43 cm. The total projected weight of the machine is about 5.4 kg (see Appendix D for a weight estimation). The estimated total time that the machine takes to complete one operation is just less than 2 minutes (see Appendix E for a time estimation). The total projected cost of the machine is $212 (Section 7).

To ensure that the structure is lightweight, but is sufficiently strong enough to support all the components, the side boards are made out of ¼" plywood. The cross beams are made of 39 cm long, 1"x 2" softwood (pine or fir) sections. The proposed baseboard and other removable covers would also be made out of ¼" plywood.

The figure below shows a general overview of the machine structure, outer frame, and some of its dimensions (in cm).



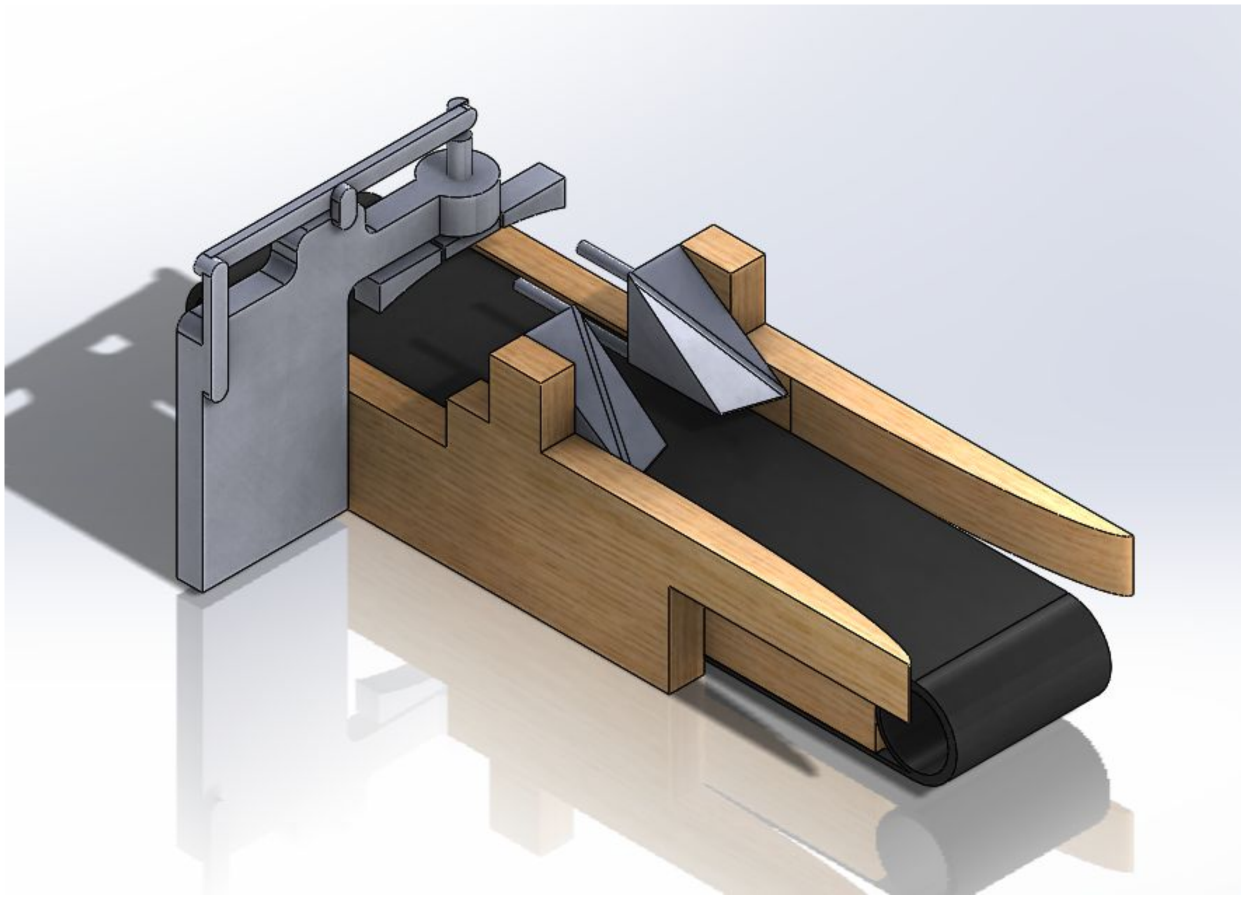
With the exception of pill loading and collection, the user interfaces with the machine through a front panel. The panel, tilted at 45 degrees, contains the keyboard, LED display, on/off switch, and emergency button. Placing the user interface components on an angled surface allows for ease of operation when standing up. Such a design is also feasible since there are more components at the bottom half of the machine than the top half.

To improve the user-friendliness of the machine, all of the user-interface components are conveniently located to allow for minimum effort (body movement) used. The three cylindrical dispensers, where the user drops the three types of pills, are located at the front of the machine, with the opening on the top of the machine. The entrance side of the conveyor belt extends 8 cm out from the machine frame so the user can easily place the pillbox onto it. At the exit side of the conveyor belt, the pillbox should hang off by 8 cm (and extend 8 cm out of the main frame) after it is loaded, which would decrease the effort for the user to retrieve it. In addition, the reservoir for collecting the extra pills are located at the front of the machine at the bottom.

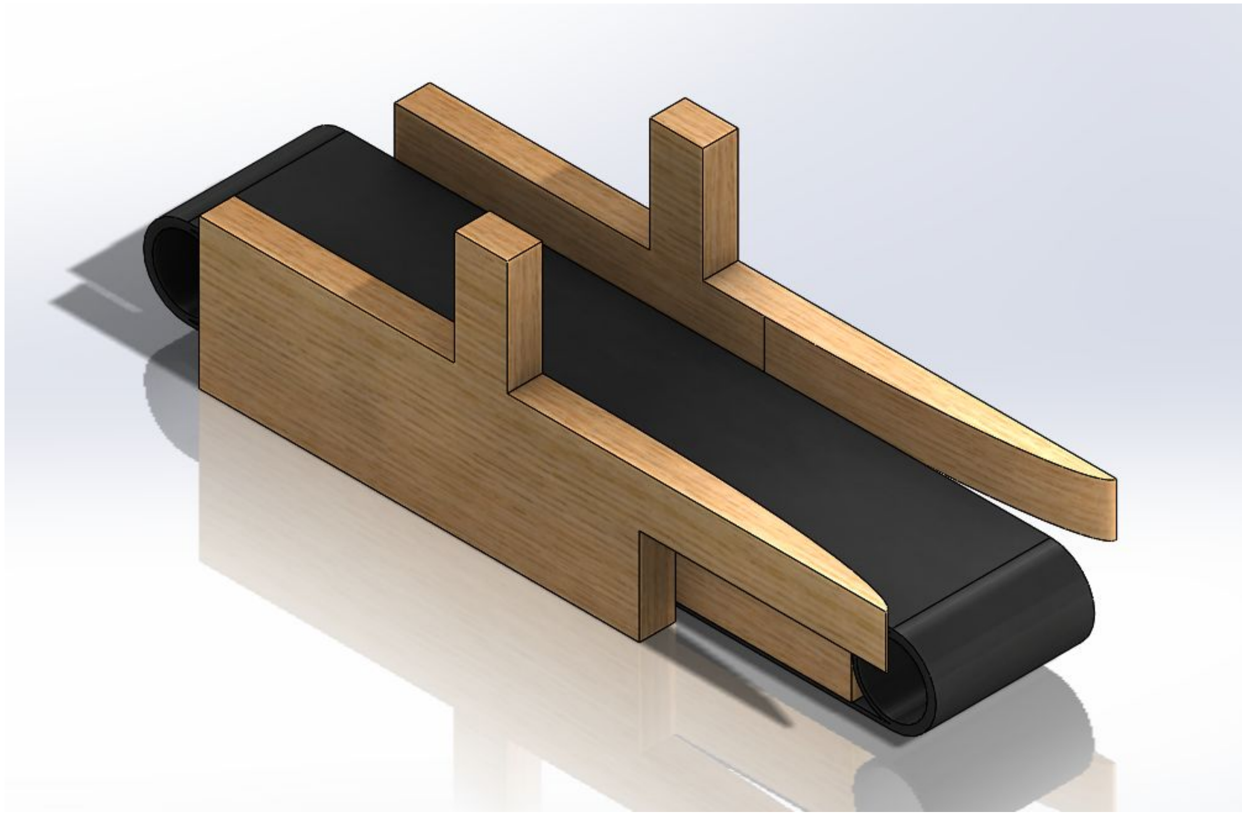
5.4. Subsystem Description and Statement of Work

5.4.1. Electromechanical Subsystems

5.4.1.1. Box Manipulation



- Box placement (Conveyor belt system):

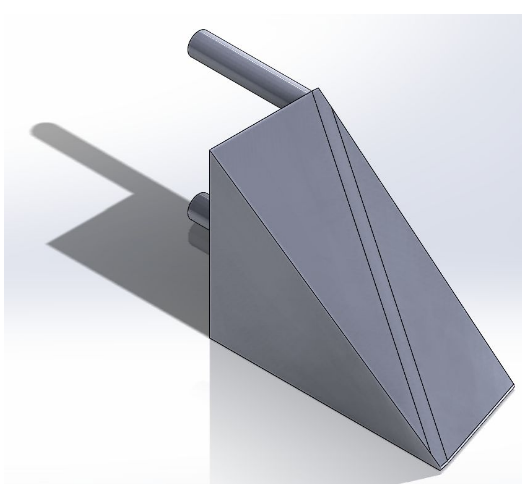


A conveyor belt system is used to move the pillbox relative to the stationary pill dropper. There are two cylinders coated with a rough material that hold a roll of cotton-based fabric in tension. There is a motor on one end of the conveyor that spins a roller, which transmits torque to the other roller through tension. A block of wood sits under the conveyor in order to prevent the conveyor from drooping.

Component	**Material**	**Justification/Specifications**
Belt	Cotton-based fabric	This material was chosen for its price and properties that make it suitable for a conveyor surface. In testing, the conveyor deformed merely 3% under a load of 49.9 N, indicating a modulus of elasticity of 793 MPa. In addition, It was found that the maximum tension subjected by the fabric is 16 N, way under the limit of the material.
Rollers	PVC Pipe + Traction Tape	The PVC pipe has an inner diameter of 31.75 mm and an outer diameter of 42.16 mm. The traction tape provides additional friction and adds an extra 1mm to the diameter, bringing the total to 43.16 mm.

Motor Attachment	Rubber wheel with D-shaped shaft	The rubber enhances grip, while the D-shaped shaft fits into our motor.
Filler	Softwood	The softwood prevents the conveyor from deforming under load. As the team has more experience with woodworking, the more complex geometry associated with this part in addition to the acceptable price and weight lead to the decision to use wood.
Guide	Softwood	The guide aligns the pillbox to the center of the conveyor. The material selection was done similar to the filler for similar reasons.
Pusher block	Aluminum	A 2 cm by 9 cm block of wood is used for the pusher block; it was found that the force exerted by the wedge counteracts the frictional force between the boc and the conveyor, and hence a pusher was necessary to push the box through the system.

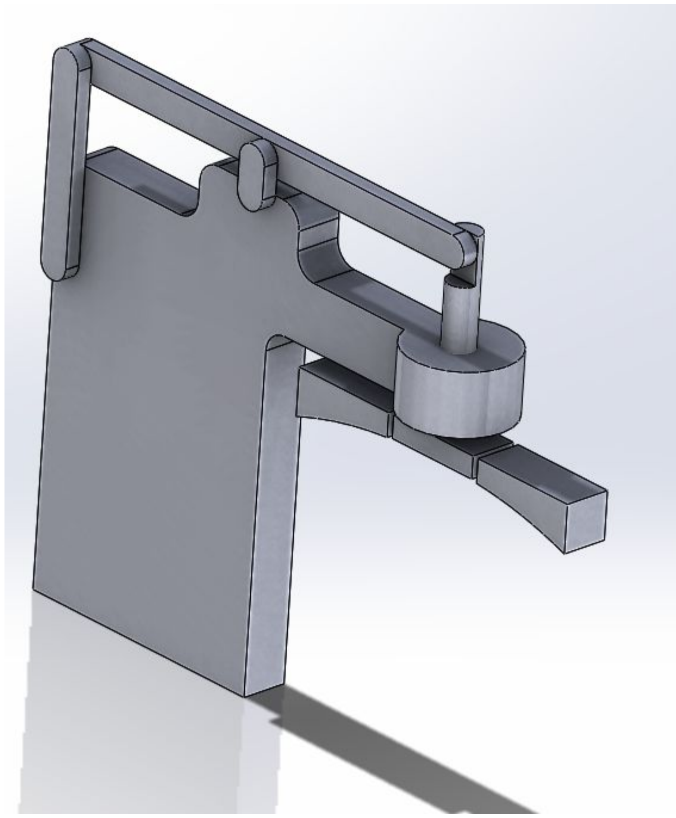
- Lid Opening (Wedge):




The double wedge is manufactured precisely to easily fit under the opened edge of the pillbox lid and slide open the pillbox lids with minimal friction. The maximum pushing force measured from testing the prototype (figure on the right) was 0.61 lbs, or 2.7 N. To counteract that force, a pusher block was installed on the conveyor belt to provide extra pushing force in addition to the friction of the conveyor belt itself.

This force value was taken account into the calculation of the torque required by the motor to drive the conveyor belt, with a factor of safety of 2.

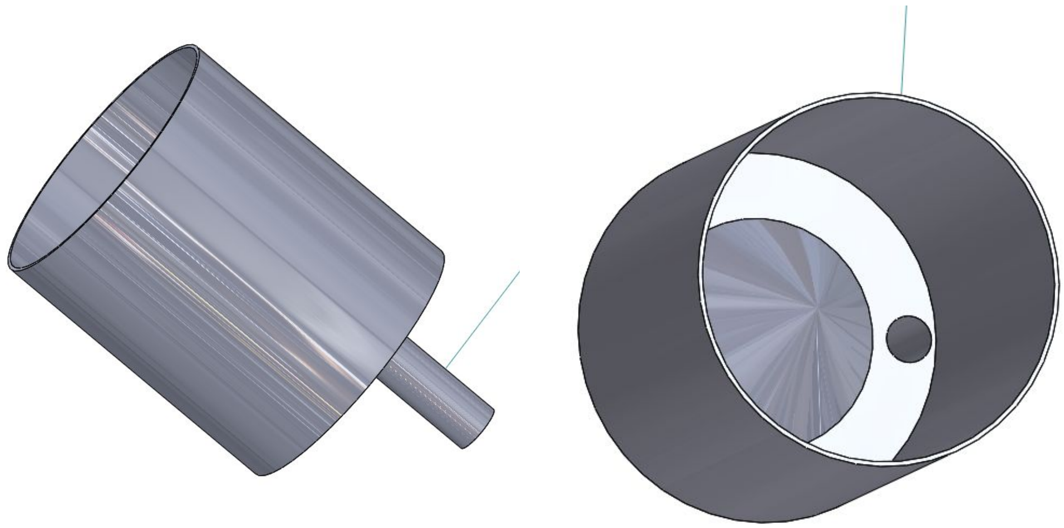
- Lid Closing:



By exploiting some of the force reduction measures discussed in Section 4.2.1.3, a mechanism was designed in order to push down the lid. The height requirement meant that there needs to be lateral motion up to 3 centimeters, with a force of 4.5 N. The mechanical mechanism mentioned in Section 4.2.1.3 effectively converts rotational motion to lateral motion. The pressure geometry consists of two tapered wedges attached to the center piece through springs. This consistently applies force to the outer edge of the lids even as they close, taking advantage of the moment arm. In addition, the wide shape and sharp sides decreases surface area and increases the second moment of area, increasing the pressure and reducing deformation.

The required torque supplied by the motor was calculated to be 0.7 kg*cm, which is well within the specifications of the ZGA25RP DC motor, at 2.9 kg*cm.

5.4.1.2. Pill Dispensing



The pill dispensing subsystem would include three cylindrical dispensers, one for the user to dispense each type of pill (sphere, flat bottom, long). The dispensers are 8 cm in diameter, 9 cm deep, which are large enough to hold at least 45 pills each.

At the bottom of the cylinder is a rotating disk of 1 cm thick, which has a slit cut into it that could only fit one pill at a time. The bottom plate of the cylinder has an opening, such that when the slit rotates onto the opening each time, one pill would drop down. The motor and disk would rotate continuously until either the power is cut, or when enough pills have been dispensed into the pillbox.

In addition, a cone shaped barrier on top of the rotating disk allows for pills to roll down into the lower area easily and prevents jamming.

From testing of a prototype, it was found that, with a factor of safety of 1.5x applied, that:
- A minimum of 1.5 kg*cm of torque is needed for the motor for the spherical pill (0.7 lbs of force for r = 3.75 cm)
- A minimum 1.2 kg*cm of torque is needed for the motor for the flat bottom pill, and
- A minimum 0.5 kg*cm of torque is needed for the motor for the long pill

The following motors are then considered:
- 1 ZGA25RP DC motor (torque 2.9 kg*cm) for the spherical pills
- 2 TGP01S-A130 DC motors (torque 1.2 kg*cm) for the flat bottom and long pills

5.4.1.3. Pill Distribution

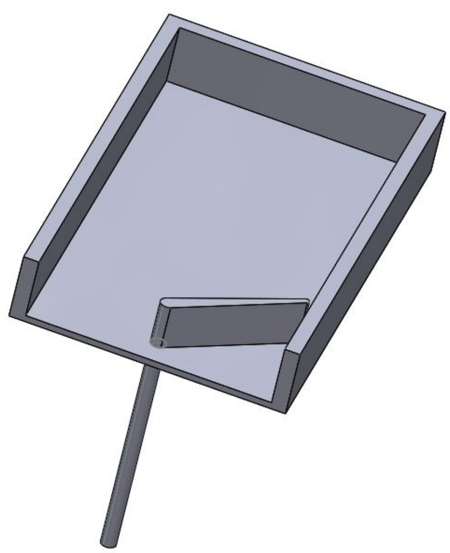
- **Main Channel:**

The main channel is made out of an aluminum structure, with a thin (¼”) plywood base to prevent deforming when pills are dropped. Testing showed that when the pills are dropped, the plywood plate does not deform significantly (<= 2 mm).

The channel is angled down at 20 degrees to allow the pills to slide down after they are dropped from the dispenser. Testing results showed that at 20 degrees, there is sufficient gravity for all three types of pills to slide down easily after they are dropped.

The channel walls are 5 cm high to prevent pills from bouncing out.

- **Channel Switching Mechanism (“Pinball Mechanism”):**



Similar to the mechanism inside a pinball machine, a half-rotating metal strip (3 x 6 cm) controlled by a servo motor switches the channel that guides the pills down into the left or right compartment of the pillbox (with a 2-slot pill dispensing design, i.e. two compartments are filled each time before the conveyor belt moves forward and the next two compartments are filled)

For the motor, the action requires relatively precise angle control to move between two states (so only one channel is opened each time for dispensing and there are no gaps), and it requires very little torque since the metal strip is light. The specifications of the FS-90 model is sufficient (torque of 1.5 kg*cm).

- **Rotating Base Plate:**

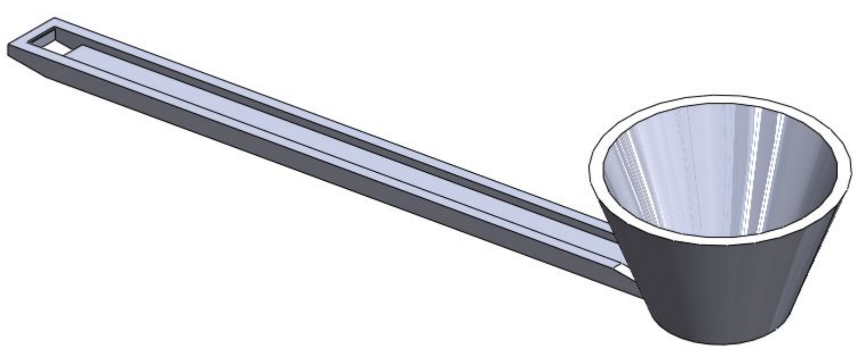
To allow for the remaining pills inside the dispenser cylinders to drop directly into the collection reservoir after the pill box is filled completely, a section of the base plate (10 x 15 cm) needs to be opened. This is done by rotating that section of the base plate by 90 degrees using a stepper/servo motor.

As mentioned above, to prevent the base plate from deforming, the top aluminum surface is attached to a ¼” thick plywood base. At rest position (when the plate is inside the main channel), wedges (1 cm wide) extend out from two sides of the channel wall to provide support. The other two sides do not have wedges, since it would obstruct the plate rotation.

The rotation would be provided by a stepper/servo motor, bolted to a corner of the plate. Calculations showed that the motor requires a minimum torque of 0.5 kg*cm. Also, it must have a relatively precise angle control since the plate can only be rotated 90 degrees (more would result in the plate hitting other components, less would obstruct the fall of the pills). For this purpose, a 180-degree stopper servo motor can be used. The FS-90 model has a maximum torque of 1.5 kg*cm and 90-degree angle control.

- **Collection Reservoir and Channel:**

Right under the section of base plate that can be opened, are the opening of three funnels leading to the collection reservoirs for the extra pills. Each of the three openings is aligned exactly with the tubes above from where the pills drop down from the dispenser.



The funnels are made from aluminum sheets, and each one is connected to a v-shaped channel where the pills can slide down into the collection reservoir. Jamming would not be an issue since the pill dispenser above only drops one pill at a time.

5.4.1.4. Summary of Components Required

List of all actuators required:

Model Name	**Torque**	**Shaft**	**RPM**	**Quantity**	**Weight**	**Cost**
120:1 25D Metal Gear Motor	7.9 kg*cm	D shaped, 4 mm	50	1	90 g	$15.99
TGP01S-A130 DC Motor	1.2 kg*cm	Gear shaft	130	2	10 g x 2 = 20 g	$5 each
ZGA25RP DC Motor	2.9 kg*cm	D shaped, 4 mm	60	2	86 g x 2 = 152 g	$9 each
FEETECH FS90 Servo Motor	1.5 kg*cm	Gear shaft	130	2	9 g x 2 = 18 g	$5.25 each

A number of the same motor models are used since repeatability decreases the complexity of construction and wiring, and would also perform more consistently when a same voltage and current is loaded.

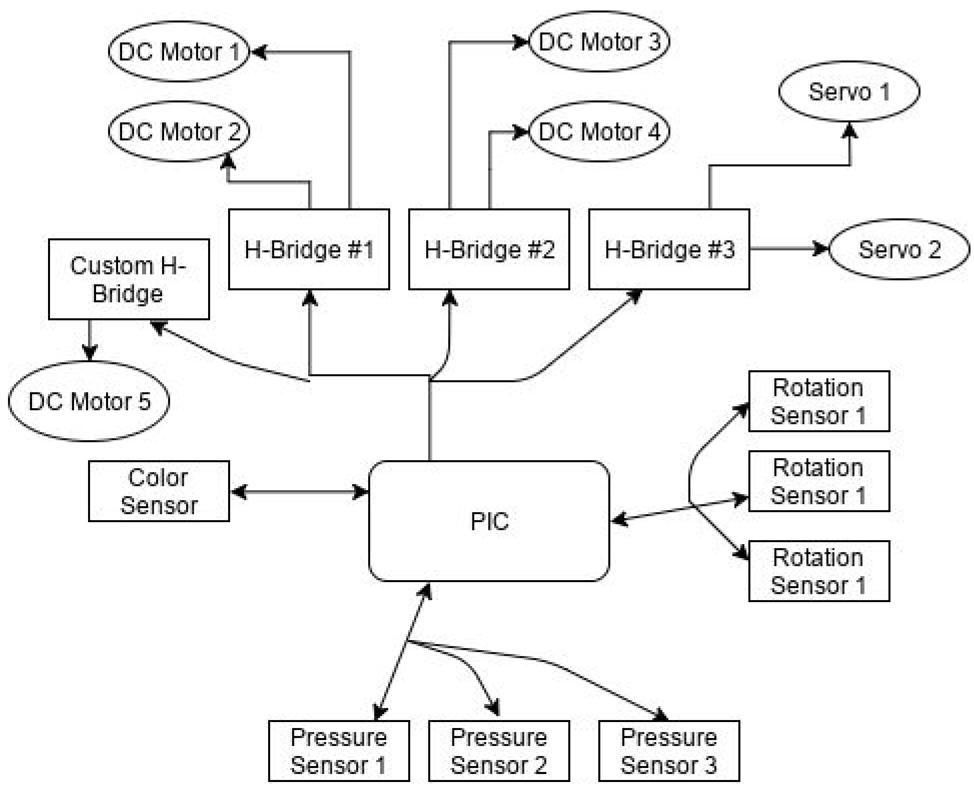
List of all other materials/parts required:

Material / Part	**Quantity**	**Weight**	**Unit Cost**	**Total Cost**
0.025” Aluminum sheet	0.19 m^2	326 g	$26.29 / m^2	$5.00
V-shaped aluminum channel	0.45 m	60 g	$1.41 / m	$0.64
¼” Plywood	0.38 m^2	1100 g	$10.76 / m^2	$4.09
1” x 2” Wood	1.95 m	760 g	$0.52 / m	$1.02
1” x 4” Wood	0.80 m	700 g	$0.91 / m	$0.73
2” x 4” Wood	0.38 m	670 g	$1.44 / m	$0.55
Cotton fabric (conveyor belt)	0.09 m^2	30 g	$11.06 / m^2	$1.00
1 ¼” PVC piping	0.20 m	630 g	$6.07 / m	$1.22

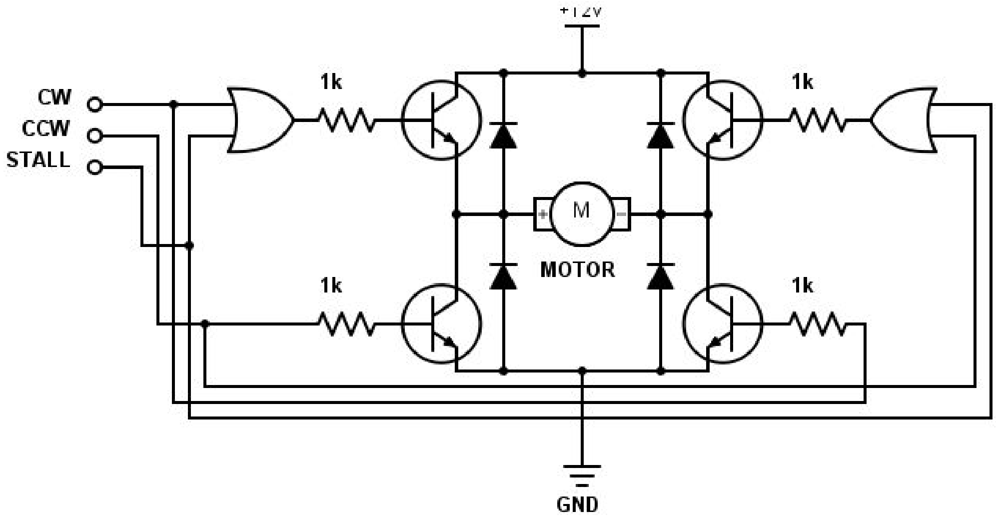
Gear shaft motor attachment	1	9 g	$5.30	$5.30
Bolts, nuts, screws, etc.	---	100 g	---	$5.00
Other misc. materials	---	50 g	---	$2.50

5.4.2. Circuits & Sensors

The circuits in this machine operates on a hub-like structure. Both the input and output is maintained between the sensors and the PIC, while the PIC passes signals to the H bridges, which, in turn, drive the motors.



5.4.2.1. DC Motor Driver



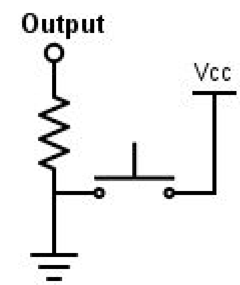
Specifications:

Component	Count
TIP147 Transistor	2
TIP142 Transistor	2
74HC08	1
1k Resistor	4
Diode	4

The motor needs to be able to move forwards and backwards, as well as react immediately to a signal. This requires stall, forwards and backwards functionality. This driver board is one-hot encoded. The diodes prevents current from to the motor from flowing back to the power supply.

5.4.2.2. Mechanical Sensor

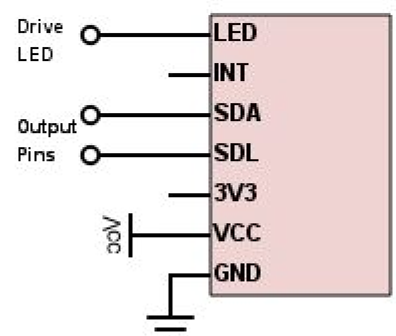
The mechanical sensors will be used to detect pills as they move into the collection areas. The pressure plate will be custom-built. The sensor will require nothing from the power supply, as it is a passive component. A 1kΩ resistor prevents a short circuit across the output pin.



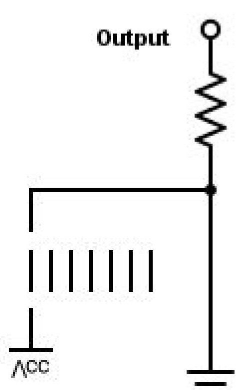
This design is used again for the rotating pill dispensing mechanism and the lid closing mechanism for the DC motors to detect where they complete a 360 degree rotation, with the modification that the pressure plate is replaced with a length of wire.

5.4.2.3. Colour Sensor

The box orientation is determined by a TCS 34725 color sensor. The sensor uses I2C protocol to provide RGB intensity values of what is directly below it. The signal is sent to the microcontroller to be thresholded. The LED is switched on directly after the conveyor starts moving, then turns off when the threshold values are reached, signifying either a blue or a purple detection corresponding to the side of the pillbox.



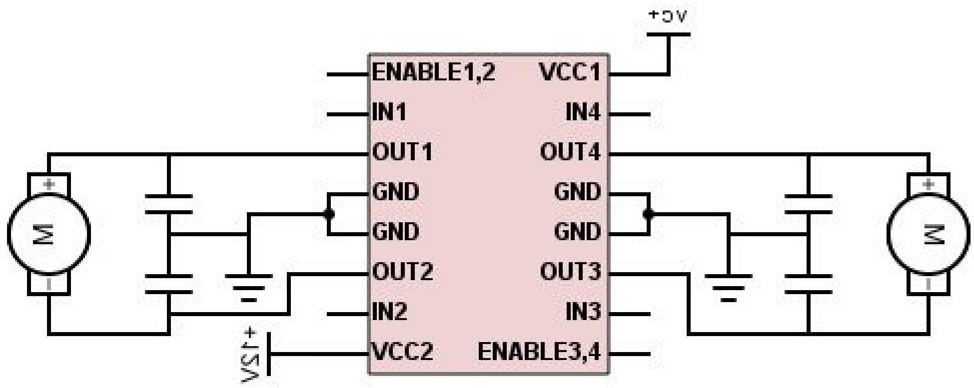
5.4.2.4. Conveyor Position Sensor



This is the sensor for the detection of position of the DC motor. There will be 7 conductive strips on the conveyor, with 2 wires on each side of the conveyor. As the pusher mechanism aligns the pillbox on the conveyor, the position of the pillbox can be accurately found by spacing the strips of conductive wire at varying intervals along the belt.

When the conductive strip makes contact with two conductive leads placed on each side of the conveyor on the wooden guide, the circuit will be complete and send a logic high to the microcontroller, which will in turn alert the PIC board that the conveyor has reached a certain position. This generates an interrupt, sending a signal to stall the motor. This is calibrated such that the conveyor will stop with the dispensing mechanism over the appropriate bin. As there are seven bins, there are seven strips. The PIC board keeps track of the amount of bins filled by incrementing a counter.

5.4.2.5. DC Motor Driver



The DC motors are driven by H-bridges. The H-Bridge of choice is the L293, chosen for its power rating and the ability for it to drive two DC motors simultaneously at 0.6A each. The 4 1μF capacitors act to smooth any current spikes caused by the large inductive load. Pieces of aluminum will be attached to the ground pins in order to act as a heat sink. Although the inputs and outputs are unique to each motor, the enable bits will be connected to a rail and therefore connect to its own pin.

5.4.2.6 Power Supply

A Sodial B011KF056C power supply will be used in this design. It outputs 12V at 10 amps, which is definitely enough power; every motor requires less than one amp, and there is only 7 motors. This power supply was chosen for its low cost and weight.

5.4.3. Microcontroller

Coordination of the actions in the pill packaging process will be carried out by a PIC18F4620 Microcontroller Unit (MCU). The MCU is mounted to a PIC DevBugger development board, which contains a module that programs the controller, a keypad to allow the user to enter instructions, and an LCD screen that communicates with user through prompts and progress status/history. This subsystem receives input from sensors and in turn sends signals to actuators that control movement of the pills / pill box. The microcontroller has two modes of operation: a Standby Mode in which it displays information about the previous run and waits to receive user input, and a Packaging mode where it uses signals to control the packaging process. These modes are further described in the proceeding sections.

5.4.3.1. Standby Mode

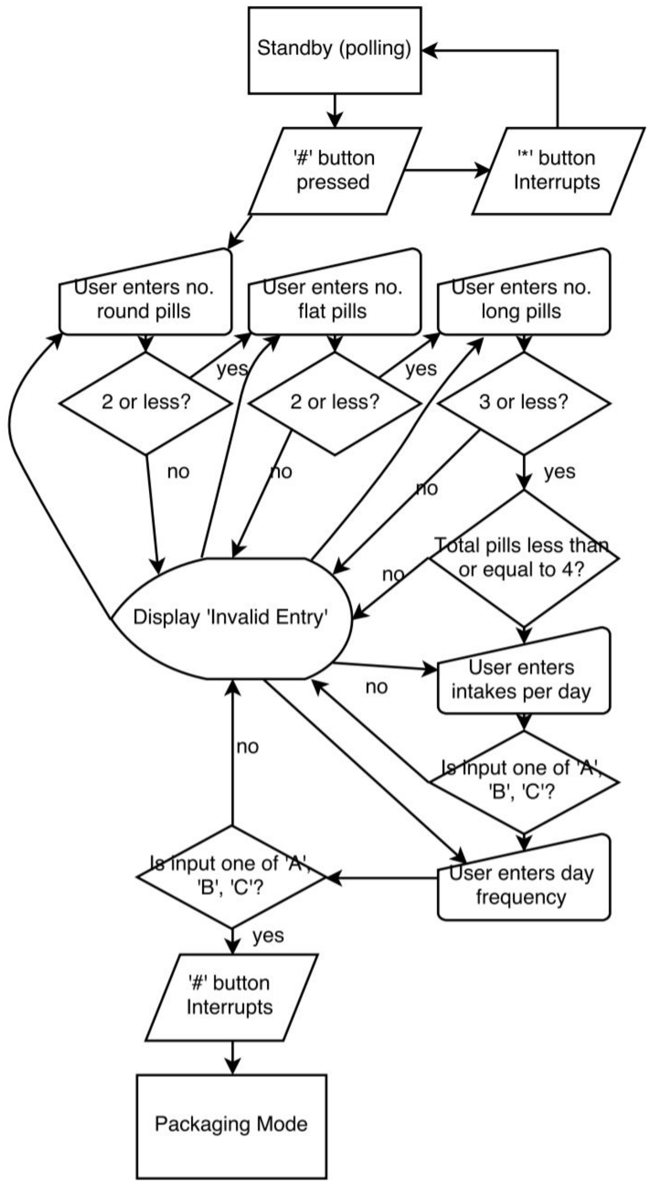
When in standby mode, the MCU uses polling to detect pressing of the "Begin" ('#') button, which occurs after the empty pill box and pills have been placed in appropriate locations. The machine then prompts the user to enter the number of round pills in the prescription, and if an appropriate input (0, 1, or 2, according to the RFP []) is received, it proceeds to prompt the user for the numbers of flat and long pills. After this, the user is required to enter the number of medical intakes per day. The options are:

- 'A': Morning only,
- 'B': Afternoon only, and
- 'C': Both morning and afternoon.

Finally, the machine asks the user for the days of the week on which the patient must take their prescription. The appropriate input options are:

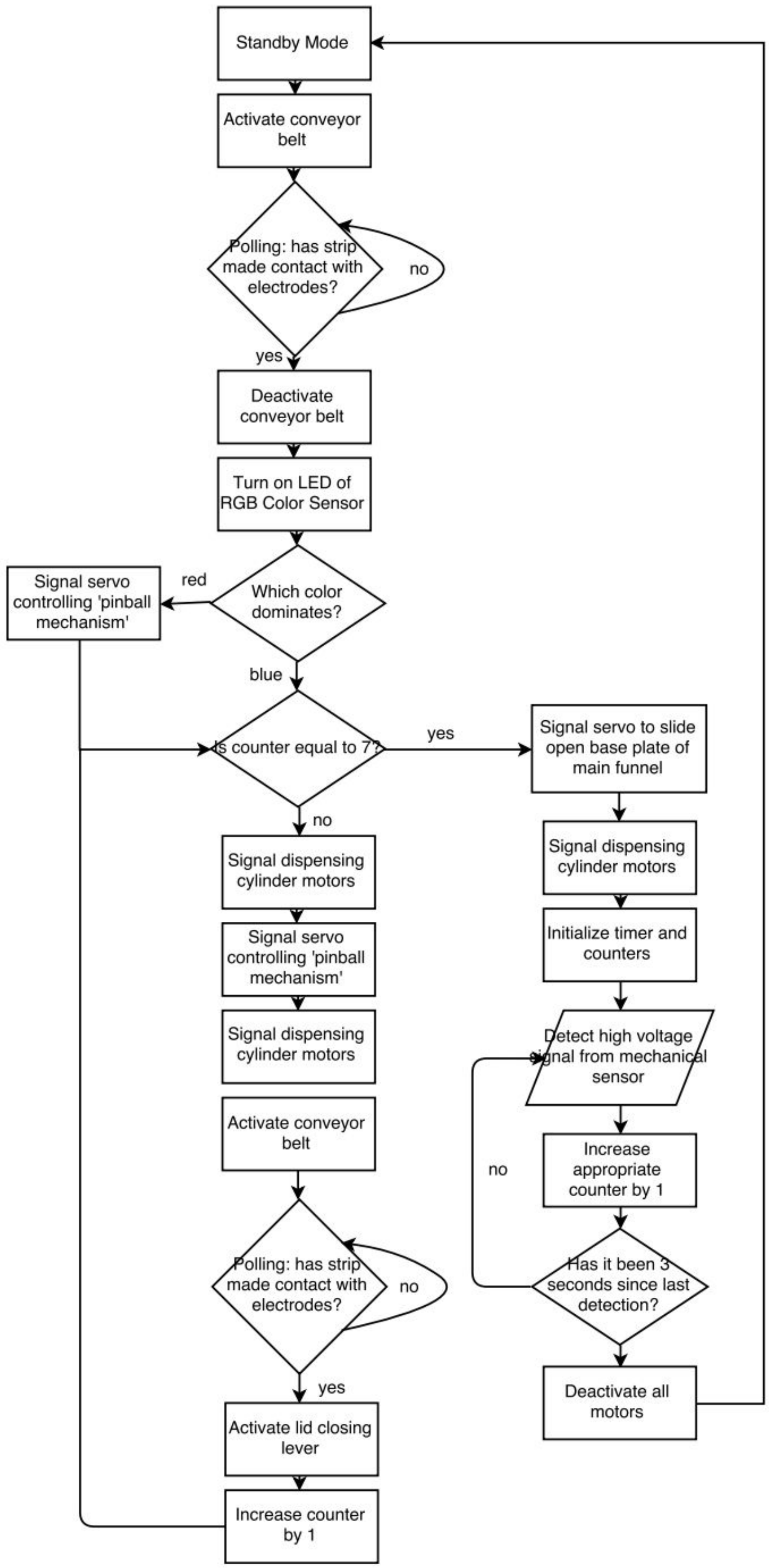
- 'A': Everyday,
- 'B': Every other day starting Sunday, and
- 'C': Every other day starting Monday.

An inappropriate input will cause the message 'Invalid Entry' to be displayed on the LCD for 1 second before the user is asked to re-enter the information. After all parameters have been entered and verified to comply with prescription rules given by the RFP [], pressing the "Begin" ('#') button again will begin the packaging process. Activation of the '#' button before complete operating instructions have been entered will generate an interrupt to display 'Incomplete Instructions' on the LCD for 2 seconds. Further, the user wishes to re-enter the prescription at anytime in the process, pressing the "Home" ('*') button generates an interrupt to clear all inputs and brings the controller to the initial state where the '#' button must be pressed to enter information again. The Standby Mode is represented by the flowchart below.



5.4.3.2. Packaging Mode

In the packaging mode, the microcontroller carries out a sequence of instructions to deposit pills into appropriate compartments of the box (according to user input) and to close the lids afterward. The process begins by sending a signal to the DC Motor Driver circuit (section 5.4.2.1), which causes the conveyor belt to turn and moves the box into the machine. As discussed in section 5.4.3.4, the conveyor belt contains 7 conductive strips running across its width whose distances to the back pusher block (section 5.4.1.1) have been calibrated such that when strip X comes into contact with the pair of electrodes on either side of the conveyor, the box will be in the correct location for pills to be deposited into row X. Thus, when the first strip comes into contact with the electrodes, a high voltage signal is sent to the MCU, which responds by stopping the conveyor belt so that row #1 of the box is in position for pills to be deposited into it. Then, the MCU repeats the process of sending signals to the appropriate dispensing cylinder motors to drop pills into the box, signalling the conveyor belt to move until the next strip makes contact with the electrodes, and then signalling the lid-closing lever to snap the lids of the row that has just been filled. A counter is used to keep track of the number of repetitions. After 7 repeats (corresponding to the 7 rows of the box), the process is complete, and the MCU returns to standby mode. A more detailed representation of the Packaging Mode is given by the flowchart below:


Standby Mode
Activate conveyor belt
Polling: has strip made contact with electrodes?
no
yes
Deactivate conveyor belt
Turn on LED of RGB Color Sensor
Which color dominates?
red
Signal servo controlling 'pinball mechanism'
blue
Is counter equal to 7?
yes
Signal servo to slide open base plate of main funnel
Signal dispensing cylinder motors
Initialize timer and counters
Detect high voltage signal from mechanical sensor
Increase appropriate counter by 1
Has it been 3 seconds since last detection?
no
Deactivate all motors
no
Signal dispensing cylinder motors
Signal servo controlling 'pinball mechanism'
Signal dispensing cylinder motors
Activate conveyor belt
Polling: has strip made contact with electrodes?
no
yes
Activate lid closing lever
Increase counter by 1

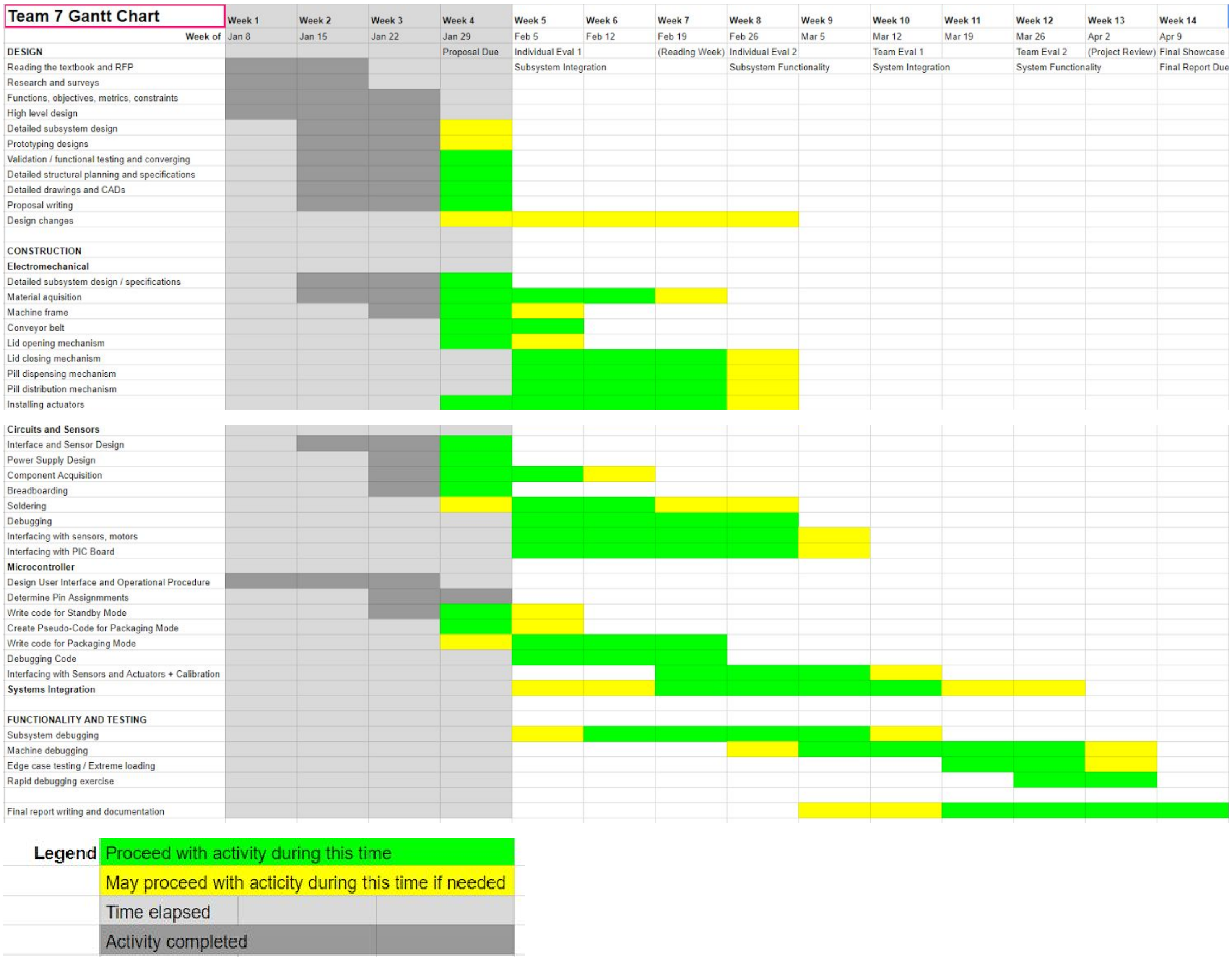
5.4.3.3. Pin Assignments

Pin	Assignment	Component	Pin	Assignment	Component
GND			GND		
KPD	Digital I/O	Enable/Disable Keypad	RC7	Digital I/O	Conveyor Motor Output
RC6	Interrupt	Emergency Stop Button Input	RC5	Digital I/O	Conveyor Motor Output
RC4	SDA	Light sensor	RC3	SCL	Light Sensor
RC2	Digital I/O	Contact Sensor Input	RC1	Digital I/O	Conveyor Motor Output
RC0	Digital I/O	Contact Sensor Input	GND		
RE2	Digital I/O	Contact Sensor Input	VCC	VCC	VCC Rail
RE1	Digital I/O	Contact Sensor Input	RE0	Digital I/O	H-Bridges Enable
RA7	OSC	Main Oscillator	RA6	OSC	Main Oscillator
RA5	Digital I/O	Contact Sensor Input	RA4	Digital I/O	Contact Sensor Input
RA3	Digital I/O	Contact Sensor Input	RA2	Digital I/O	Contact Sensor Input
RA1	Digital I/O	Lid-closing Motor Output	RA0	Digital I/O	Lid-closing Motor Output
RD7	Digital I/O	LCD Data Bit	RD6	Digital I/O	LCD Data Bit
RD5	Digital I/O	LCD Data Bit	RD4	Digital I/O	LCD Data Bit
RD3	Digital I/O	LCD Enable	RD2	Digital I/O	LCD RS
RD1	Digital I/O	Servo Output	RD0	Digital I/O	Servo Output
RB7	Digital I/O	Servo Output	RB6	Digital I/O	Servo Output
RB5	Digital I/O	Dispenser Motor Output	RB4	Digital I/O	Dispenser Motor Output
RB3	Digital I/O	Dispenser Motor Output	RB2	Digital I/O	Dispenser Motor Output

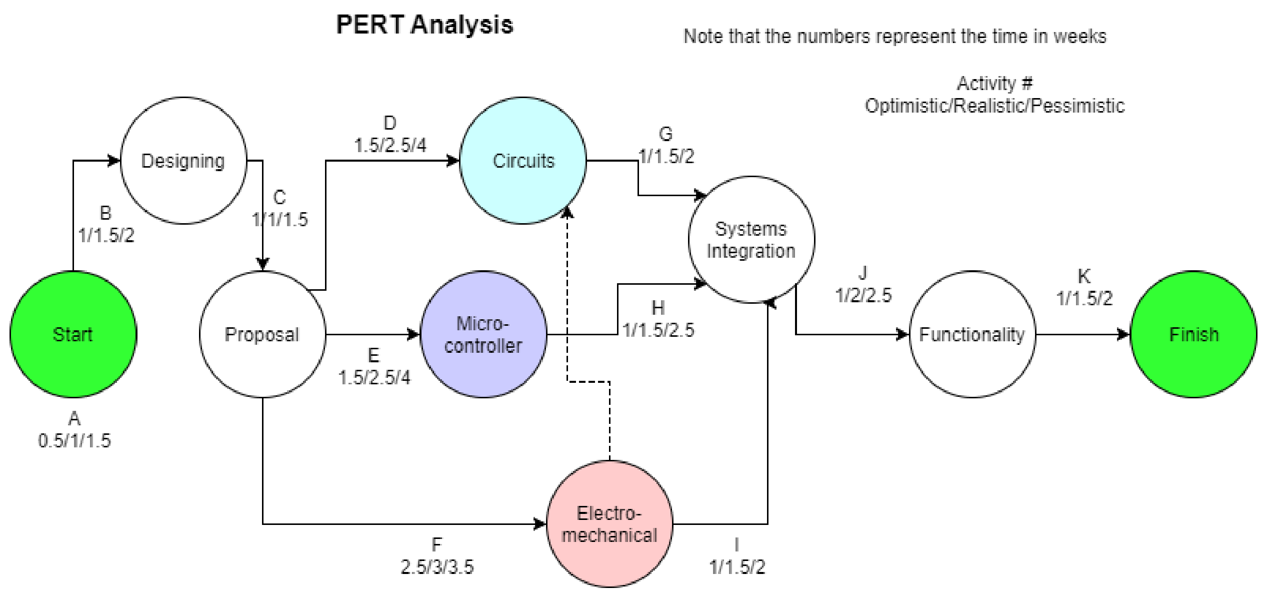
RB1	Digital I/O	Dispenser Motor Output	RB0	Digital I/O	Dispenser Motor Output

6. Project Management

6.1. Gantt Chart



6.2. PERT



Designation	Activity	Activity Duration (Weeks)			Preceded By	Variance	Expected Duration	ES	LS	TF
		Optimistic	Expected	Pessimistic						
A	Research and Design	0.5	1	1.5	-	0.028	1.167	0.000	0.000	0
B	Prototyping, Verification, Validation	1	1.5	2	A	0.028	1.667	1.167	1.167	0
C	Proposal	1	1	1.5	B	0.007	1.083	2.833	2.833	0
D	Circuits Manufacturing	1.5	2.5	4	C	0.174	2.917	3.917	3.917	0
E	Programming	1.5	2.5	4	C	0.174	2.917	3.917	3.917	0
F	Physical Components Fabrication	2.5	3	3.5	C	0.028	3.167	3.917	3.917	0
G	Debugging - Circuits	1	1.5	2	D	0.028	1.667	6.833	7.083	0.25
H	Debugging - Programming	1	1.5	2.5	E	0.063	1.750	6.833	7.000	0.167
I	Electromechanical Functionality	1	1.5	2	F	0.028	1.667	7.083	7.083	0
J	System Integration	1	2	2.5	G,H,I	0.063	2.250	8.750	8.750	0
K	Final Testing/Debugging	1	1.5	2	J	0.028	1.667	11.000	11.000	0
Sum						0.208	12.667			

PERT analysis of the project implies expected completion by the second half of week 12, with a confidence interval of 0.2 weeks. The low variance is ideal, as it signifies that we are fairly confident with our prediction. The critical path is identified as the fabrication and calibration for the electromechanical system.

7. Budgeting

Cost Projection:

Item	**Amount**	**Unit Cost**	**Total Cost**	**Supplier**
PIC microcontroller	1	$50	$50	AER201
Character LCD + Keypad	1	$6	$6	AER201
RTC Chip and coin battery	1	$5	$5	AER201
TCS34725 RGB colour sensor	1	$9	$9	Adafruit
SODIAL DC 12V 10A 120W Power supply	1	$17	$17	(Various)
Wires, resistors, and electrical components	---	---	$25 (est.)	(Various)
Motor driver boards	3 (1 DC (built), 2 HB (OTC))	$5.70 x 2 + $7 (est.)	$18.40 (est.)	(Various)
120:1 Geared DC Motor	1	$16	$16	Creatron
TGP01S-A130 DC Motor	2	$5 each	$10	AER201
ZGA25RP DC Motor	2	$9 each	$18	AER201
FEETECH FS90 Servo Motor	2	$5.25 each	$10.50	Pololu
0.025” Aluminum sheet	0.19 m^2	$26.29 / m^2	$5.00	Rona
V-shaped aluminum channel	0.45 m	$1.41 / m	$0.64	Home Hardware
¼” Plywood	0.38 m^2	$10.76 / m^2	$4.09	Home Depot
1” x 2” Wood	1.95 m	$0.52 / m	$1.02	Home Depot
1” x 4” Wood	0.80 m	$0.91 / m	$0.73	Home Depot
2” x 4” Wood	0.38 m	$1.44 / m	$0.55	Home Depot

Cotton fabric (conveyor belt)	0.09 m^2	$11.06 / m^2	$1.00	G & S Dye
1 ¼" PVC piping	0.20 m	$6.07 / m	$1.22	Home Depot
Gear shaft motor attachment	1	$5.30	$5.30	Creatron
Bolts, nuts, screws, etc.	---	---	$5.00	(Various)
Other misc. materials	---	---	$2.50	(Various)

Total Cost: $211.95

8. Conclusion

In order to address the issue of encouraging the elderly at nursing homes to take their medication on time, it was required that their pills need to be autonomously sorted and organized into pillboxes. Since sorting the pills by hand may contact them with bacteria and other potentially harmful substances. Additionally, it is a time-consuming and error-prone process. Thus, there exists the need for an automatic pill-boxing machine.

The machine design proposed in this report meets all the constraints set forth by the Request for Proposal, in addition to some additional functionalities, such as the ability to fill multiple containers in one operation.

For the design team, the most time-consuming process appears to be constructing and testing the electromechanical components. Integration and debugging of the final design is a bottleneck and requires the completion of all previous activities, and hences serves as a measure of progress for project progression.

It is hoped that this proposal report will lead to a prototype that serves as a proof of concept for a machine that will simplify workflow for medical workers worldwide.

9. Works Cited

[1] University of Toronto, "RFP #1: The Pill Boxing Machine", Toronto, 2018.

[2] A. Protection, "5 Sound levels in decibels: What is a decibel?", *Alpine*, 2018. [Online]. Available: https://www.alpinehearingprotection.com/wiki/5-sound-levels-in-decibels/. [Accessed: 31- Jan- 2018].

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10. Appendices

Appendix A: Constraints as per the RFP
From the Request for Proposal, the following constraints must be applied to the design of the pill boxing machine:

a. The entire prototype (including the reservoirs while containing pills and the box when placed in the machine) shall completely fit within a 0.50 x 0.50 x 0.50 m envelope at all operation times (power cable notwithstanding.)

b. The weight of the machine, including the empty reservoirs, power cable, etc., shall not exceed 6 kg.

c. The total prototype costs shall not exceed $230 CAD before shipment and taxes. For parts purchased in foreign funds, the exchange rate reported by the Central Bank of Canada at the end of business day on January 8th, 2018, will be considered. The manufacturing labour is not considered on top of the material costs in the prototype, unless a part is manufactured using a 3D-printer or CNC machine. In such cases, an additional cost of $5 CAD per manufacturing hour will be assumed. The G-code and
exact manufacturing time for such parts shall be reported.

d. Use of materials such as paper (of any type) or corrugated plastic for fabricating the machine, and non-standard fasteners such as duct tape, masking tape, hot glue, etc., is not acceptable. It is imperative to have the client's explicit consent for other cases similar to the above.

e. The machine can be plugged in the AC, 110V-60Hz, 3-pin outlet. Only one connection cable is allowed.

f. The machine must have an easily-accessible emergency STOP switch that stops all the mechanical moving parts immediately.

g. The machine must be fully autonomous, and no interaction with an external PC or remote control is permitted during the operation. The operation must begin by pressing a <start> button on a keypad.

h. No installation or instrumentation is allowed in addition to what is devised within the machine.

i. The locations for supplying pills and the box and also the pickup location of the box must be clearly specified in the machine.

j. Loading pills and the box, delivering the packed box, and retrieving the remaining pills must be convenient to the operator with no need for disassembling any part of the machine.

k. The time required for loading the pieces into the machine, entering the operator's instructions on the keypad, and starting the operation shall not exceed 1 minute. The number of supplied pills must remain undetermined during the loading period, i.e., machine must not pre-count the pills before the operation begins.

l. Each operation is considered "complete" when the correct type/number of pills are dispensed into all compartments, remaining pills are returned to their reservoirs, and the display shows a message indicating the completion of the process.

m. At the end of each operation, the machine display must be on prompt to show the following information per operator's request: operation time, number of remaining pills in each reservoir, and a summary of the instruction parameters.

n. The machine user interface for both operation and information retrieval shall be self-explanatory, and provide easy navigation for users of various skill levels.

o. Each compartment is packaged "correctly" if all required pills are dispensed in correct numbers; otherwise the compartment packaging is considered as "incorrect."

p. Each compartment is closed "completely" only if its lid is completely closed and snapped.

q. Each pill (in the compartment, reservoir or machine) is considered as "damaged" if there are clear defects as a result of the operation, to the referee's discretion. The box is considered as "damaged" if there are clear defects as a result of the operation, to the referee's discretion, e.g., obvious scratches or deformations, a lid is detached or does not close/snap, etc.

r. The box is considered "unavailable" for pickup if it is not completely located in the pickup place designated in the machine, or is jammed and cannot be removed from the machine.

s. The operation time is the duration between when the <start> button on the keypad is pressed and when the machine shows the completion or termination message on its LCD. No actuation or sensing must occur in the machine prior to the start of the operation. The operation time shall not exceed 3 minutes. Further, the time required for loading the pills into the machine and entering the operator's instructions on the keypad before the operation shall not exceed 1 minute.

t. The recorded and displayed operation time is considered "correct" if it is equal to the time measured by the referee 1 second. Otherwise, it is assumed "incorrect."

u. Each operation is "qualified" for scoring if, in addition to the lack of other disqualification factors (next constraint), the machine delivers the box with a minimum of 3 compartments with pills containing correct orders and the lids of minimum 5 compartments are closed completely, returns to standby mode so that the box can be unloaded normally, displays the completion or termination message at the end of its operation, and is able to communicate the operation information.

v. An operation is "disqualified" if any of the following happens to the machine or the team declares the termination. If the first or second operation is disqualified, the team will have 2 minutes to fix the system and run for the next time, if they wish.
– structurally collapses, falls over, hangs or jams (for more than 3 minutes) with no termination display, or
– terminates the operation before delivering the box with minimum 3 compartments containing correct orders and the lid of minimum 5 compartments is closed completely, or
– does not display the termination or completion message on the LCD at the end of operation, or
– is not able to communicate with the operator after termination/completion of the operation, or
– runs longer than 3 minutes before terminating the operation, or
– takes more than 1 minute to load pills and the box in the machine and start the operation.

w. Each team will have a period of maximum 1 minute to set up the machine before it is ready to load pills and the box for each operation. (This time is extended to 2 minutes if the previous operation is disqualified.) If the preparation time exceeds 1 minute, the operation is "disqualified."

x. There will be no control over the conditions of the competition environment.

y. The machine must pose no hazard to the operator, and shall not be perceived as hazardous (e.g., excessive vibration, noise, sporadic movement, or electric sparks during the operation is perceived as dangerous.)

Appendix B: Additional Functions as per the RFP
-Robustness and Durability: Machine is durably constructed, and functions consistently in a wide range of operating environments with a low failure rate.

-Operability and Sustainability: Little time/effort is needed to set up and calibrate the machine, and the machine is modular so that parts can be replaced or repaired easily.
-Elegance and Safety: Machine looks elegant, and operates quietly and smoothly with little or no sensible noise or vibration.
-Dexterity: Machine can perform extra functions, such as packaging and delivering the remaining pills, being able to receive boxes initially with some or all compartment lids closed, utilizing a secondary GLCD (in addition to the primary LCD) for delivering some useful information during or after the operation, etc.
-Extendibility: Machine can accept and package two boxes in each operation with little or no need for modifications.
-Compactness and Portability: The entire prototype weighs no more than 3 kg (i.e., half of the maximum permitted weight,) and fits within a cubic envelope of 0.300 x 0.300 x 0.300 m3 (i.e., ~22% of the volume of maximum allowed envelope.)
-Real time Date/Time Display: Date and time of each operation are displayed on the LCD in standby mode.
-Permanent Logs: Machine stores sorting logs of at least 4 previous runs in permanent (EEPROM) memory.
-PC Interface: The operation information, including sorting logs and date/time, can be readily downloaded from the machine to a PC.

(Functions highlighted in blue are disregarded by the design team)

Appendix C: Utility Functions

Emergency Stop Button:

$$\frac{1}{1+e^{(4x-4)}}$$

Steps to Operate GUI, Load Containers

$$\left\{x < 1{:}1, x \geq 1{:} -\frac{1}{4}x + 1.25\right\}$$

Number of Components

$$\left\{x < 30{:}1, x \geq 30{:} \frac{-x}{120} + 1 \ + \ \frac{1}{4}\right\}$$

Size

$$\left\{x < \frac{3}{10}\sqrt{3} : 1,\ \frac{3}{10}\sqrt{3} \le x < \sqrt{\frac{3}{4}} : -2.5x + \frac{2.5 \cdot 3}{10}\sqrt{3} + 1, x > \sqrt{\frac{3}{4}} : 0\right\}$$

Degrees of Motion

$$e^{-\frac{x}{2}}$$

Number of Faces

$$\left\{x < 2 : 1, -\left(\frac{x}{40}\right)^2 + 1 + \frac{1}{40^2}\right\}$$

Total Time

$$\left\{x < 3 : -\left(\frac{x}{4}\right)^{\frac{5}{2}} + 1, x > 3 : 0\right\}$$

Reliability

$$e^{(40x - 40)}$$

Robustness

$$\min\left(\frac{1}{10}x, 1\right)$$

Sound

$$\left\{x < 30 : 1, -e^{\left(\frac{x}{50}\right)} + e^{\frac{3}{5}} + 1\right\}$$

Appendix D: Machine Weight Projection

Material / Part	**Quantity**	**Mass Per Unit**	**Total Mass**
PIC Microcontroller + Character LCD + Keypad	1	223 g	223 g
RTC Chip and coin battery	1	10 g	10 g

RGB colour sensor	1	4 g	4 g
Power supply	1	454 g	454 g
Wires, resistors, and electrical components	---	---	100 g
Motor driver boards	3 (1 DC (built), 2 HB (OTC))	---	40 g (est.)
Geared DC Motor	1	90 g	90 g
TGP01S-A130 DC Motor	2	10 g	20 g
ZGA25RP DC Motor	2	86 g	152 g
FEETECH FS90 Servo Motor	2	9 g	18 g
0.025” Aluminum sheet	0.19 m^2	2700 kg/m^3	326 g
V-shaped aluminum channel	0.45 m	2700 kg/m^3	60 g
¼” Plywood	0.38 m^2	500 kg/m^3	1100 g
1” x 2” Wood	1.95 m	500 kg/m^3	760 g
1” x 4” Wood	0.80 m	500 kg/m^3	700 g
2” x 4” Wood	0.38 m	500 kg/m^3	680 g
Cotton fabric (conveyor belt)	0.09 m^2	1.5 g/cm^3	30 g
1 ¼” PVC piping	0.20 m	1.3 g/cm^3	600 g
Gear shaft motor attachment	1	8 g	8 g
Bolts, nuts, screws, etc.	---	---	100 g
Other misc. materials	---	---	50 g

Total: 5.525 kg

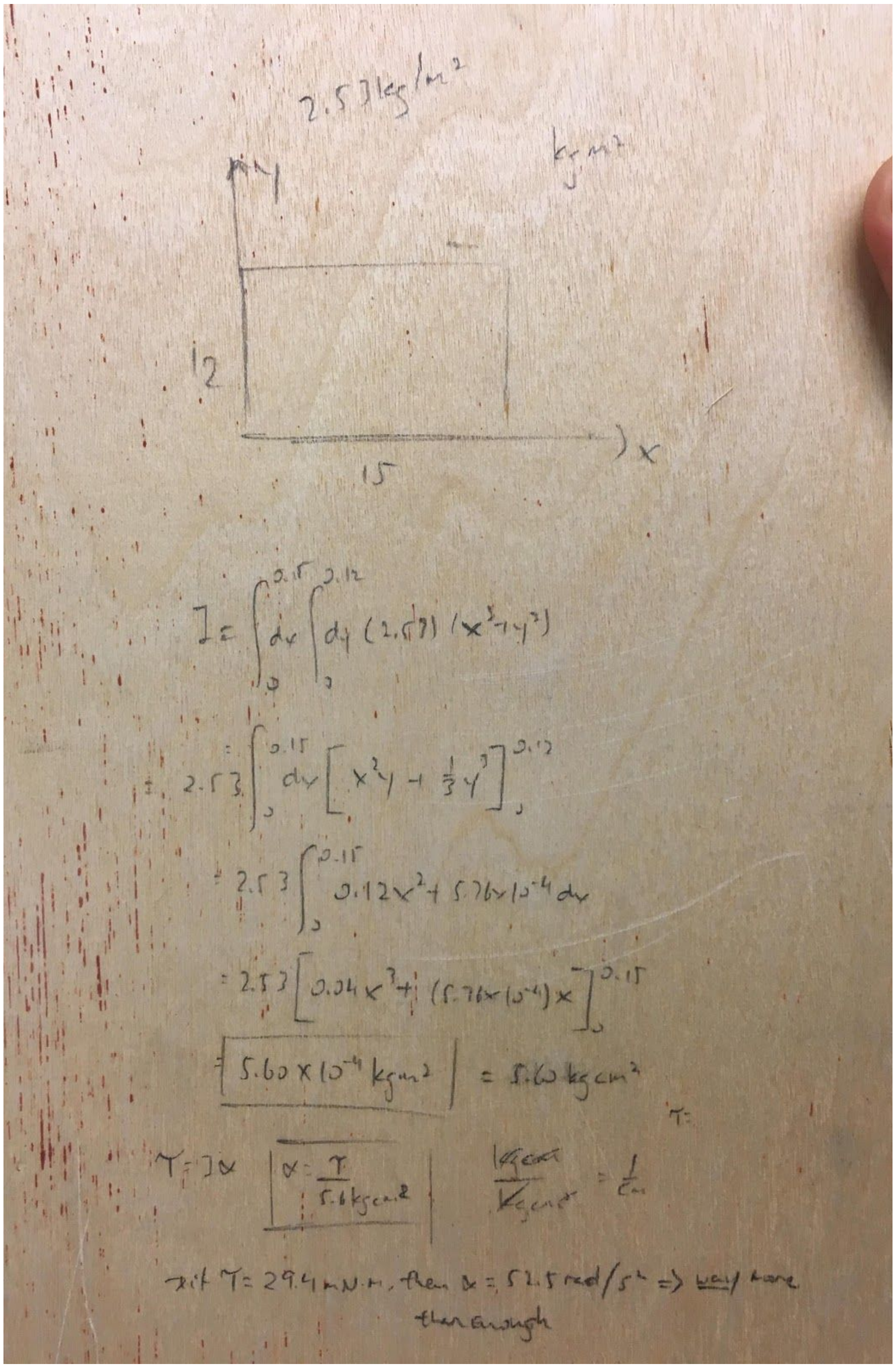
Note: Some weight values are estimated if the exact dimensions are unknown (i.e. wood is not manufactured to specified size, and thickness of most materials is unknown)

Appendix E: Machine Operation Time Projection

Task	**Efficiency**	**Projected Time**
Moving the pillbox in place	Conveyor belt runs at ~7 cm/s; box needs to travel ~20 cm	3 s
Dropping the pills	One pill per second on average; 45 pills of each type in total	Up to 60 s
Switching the “pinball mechanism”	1 s x 14 times (Motor spins 130 rpm)	14 s
Moving the pillbox forward	1 s x 7 times	7 s
Opening and closing the removable plate	2 s x 2 times (Motor spins 130 rpm)	4 s
Remaining pills drop into collection reservoir		10 s
Closing the lids	1 s x 7 times	7 s
Resetting the conveyor belt	Conveyor belt runs at ~7 cm/s; needs to travel ~40 cm	6 s
Signal delays, processing	---	5 s

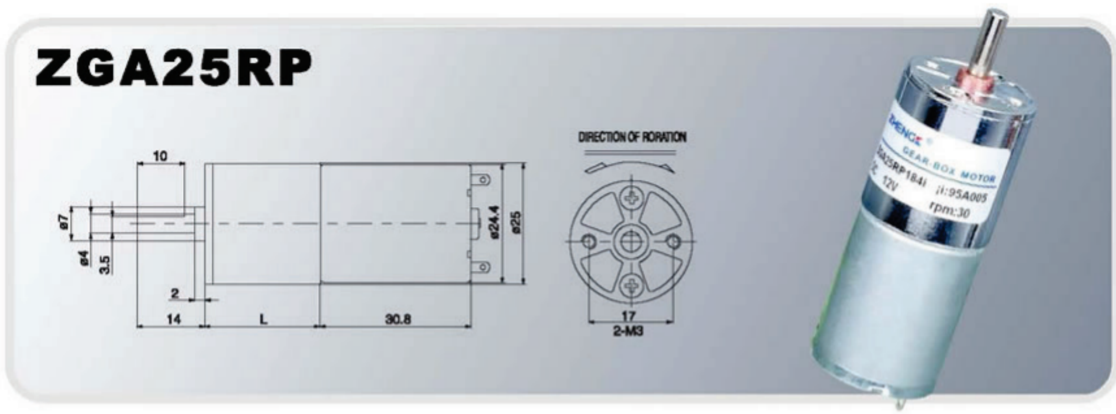
Total: Up to 116 s

Appendix F: Sample Torque Calculation of a Plate



Appendix G: Motor Data Sheets

-ZGA25RP DC Gear Motor:



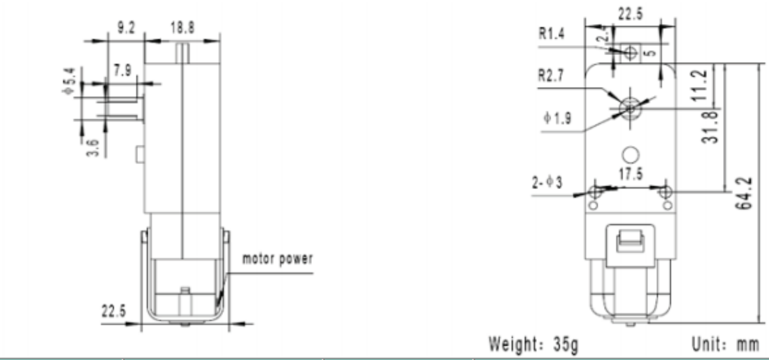
■ Technical Data

Voltage(VDC)	6V	6V	6V	12V	12V	12V	12V	24V	24V	24V
Motor Model	45P	45P	45P	23P	56P	56P	83P	47P	47P	47P
Reduction Ratio	1/292	1/156	1/71	1/474	1/184	1/113	1/83	1/216	1/71	1/37.9
Gearbox Length(mm)	27	24	22	27	24	24	22	24	22	19
No-Load Speed(Rpm)	15	30	60	5	30	50	100	20	60	120
Rated Speed(Rpm)	10.5	21	42	3.5	21	35	70	14	42	84
Rated Torque(Kg.cm)	1.4	0.75	0.35	2.9	1.45	0.87	1.4	2.9	0.95	0.46
Rated Current(Amp)	0.22	0.22	0.22	0.1	0.16	0.16	0.4	0.13	0.13	0.13

-TGP01S-A130 DC Gear Motor

Model：TGP01S-A130
Gear Motor

Applications
Description
Reduction Ratio:
1/48,、1/120、1/180、1/220、1/256、1/288



MODEL		VOLTAGE		NO LOAD		AT LOAD					STALL		
		OPERATING RANGE	NOMINAL	SPEED	CURRENT	SPEED	CURRENT	TORQUE		OUTPUT	TORQUE		CURRENT
			V	rpm	A	rpm	A	N.m	Kg.cm	w	N.m	Kg.cm	A
TGP01S-A130	14150-120	3.0-12.0	4.5	100	0.20	87	0.50	0.066	0.675	0.40	0.265	2.700	1.25
	18100-220	3.0-12.0	3.0	50	0.20	40	0.60	0.120	1.233	0.6	0.393	4.003	2.15

-FS-90 Servo Motor

FS90--Micro 9g servo for Air plane

Model No.: FS90

Product Description
Features
-Micro analog plastic gears servo
-Operating Voltage:4.8-6Volts
-Interface: (like JR)
-Wire length: 20cm

Power	4.8V	6V
Speed	0.12sec/60degree	0.07sec/60degree
Torque	1.3kg.cm/18.9oz.in	
Weight	9g(0.32oz)	
Size	23.2*12.5*22.0mm	
Application	for Air plane	

Connection description
Orange = Signal input
Red = +5V
Brown = 0V

Typical Signals
MIN_WIDTH 544 // shortest pulse sent to a servo 0°
MAX_WIDTH 2400 // longest pulse sent to a servo 180°
NEUTRAL_PULSE_WIDTH 1500 // MID pulse width when servo is at 90°
REFRESH_INTERVAL 20000 // min time to refresh in microseconds

-Creatron 120:1 25D Metal Gear Motor

120:1 25D METAL GEAR MOTOR (6V 50RPM)

MOTOR-100650

This 1.46" x 0.79" x 0.79" gearmotor is a brushed DC motor with 120:1 metal gearbox that has the power to deliver both speed and torque. These units have a 0.276"-long, 4 mm-diameter D-shaped output shaft.

CAD$15.99

1 + - ADD TO CART

Add to Wishlist

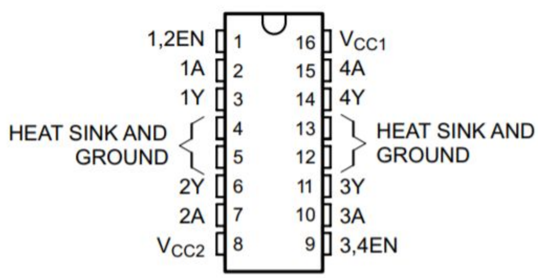
MORE INFO | PRODUCT REVIEWS(0)

Motor Rating @ 6V:

- 120:1 gear ratio
- 50RPM
- 100mA free run current
- 3A stall current
- 7.9kg*cm torque
- 4mm shaft diameter

Appendix H: Select ICs and Circuit Components

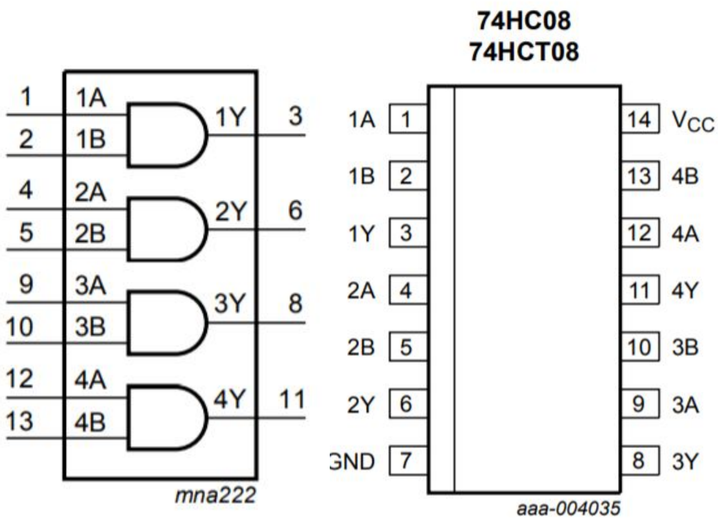
-L293 Dual H-Bridge



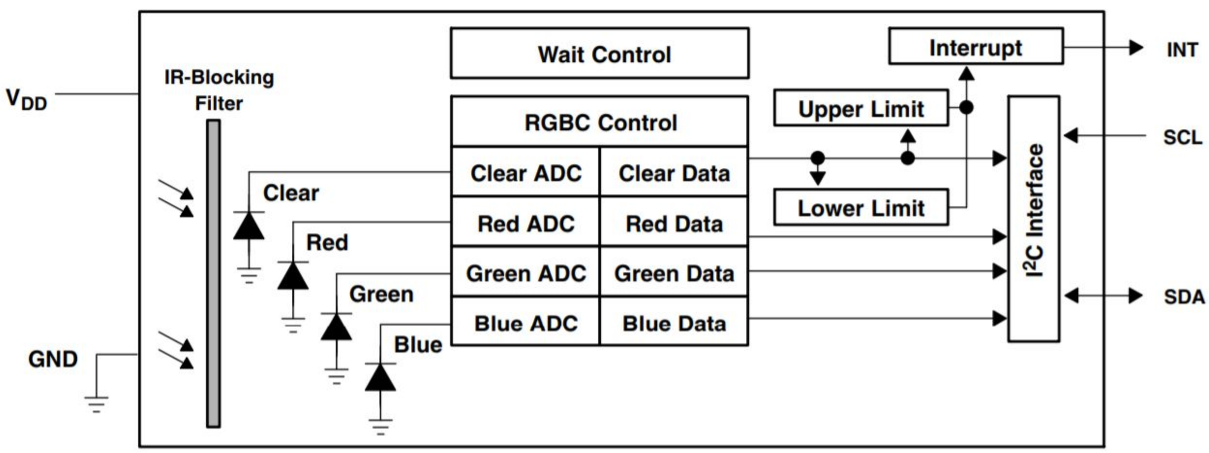
Pin Functions

PIN		TYPE	DESCRIPTION
NAME	NO.		
1,2EN	1	I	Enable driver channels 1 and 2 (active high input)
<1:4>A	2, 7, 10, 15	I	Driver inputs, noninverting
<1:4>Y	3, 6, 11, 14	O	Driver outputs
3,4EN	9	I	Enable driver channels 3 and 4 (active high input)
GROUND	4, 5, 12, 13	—	Device ground and heat sink pin. Connect to printed-circuit-board ground plane with multiple solid vias
V_{CC1}	16	—	5-V supply for internal logic translation
V_{CC2}	8	—	Power VCC for drivers 4.5 V to 36 V

-74HC08 AND Gate Chip:



-TCS34725 Color detection chip



Sodial 10A 12V Power Supply