Abstract

The machine, Aupackto, is designed and constructed to address the needs of a furniture manufacturer to autonomously package four types of fasteners for assembling their products. Aupackto is able to package 4 types of fasteners, bolts, nuts, spacers and washers into an eight-compartment fastener organizer box based on user instructions. The properly packaged fastener organizer box would be available to pick up by users upon completion. The total run time of the machine does not exceed 3 minutes. The budget of the final prototype is $217.33 CAD.

The design team is consisted of three members, where each member is responsible for one of the three following subsystems: electromechanical, circuit and microcontroller. The design achieves all of the design objectives and basic functionalities outlined in the client's RFP and the team's design proposal. Further improvements that can be made to increase its usability and maximize its functionality are also discussed.

Table of Contents

1. Acknowledgement

We would like to thank everyone who helped, supported, advised or encouraged our team to successfully complete this course.

In particular, we would like to pay tribute to our course instructor and also our primary client, Professor M. R. Emami, for his dedication in organizing this splendid engineering design experience that we are certainly sure to remember for the rest of our lives.

Also, we want to thank Qingrui Zhang, our teaching assistant, for all of his help and support throughout this course.

Team 34, AER201 Winter 2018

Yuxuan Chen, Yizhou Huang and Jiachen Zhou

2. Symbols and Terms

2.1 Symbols

2.1.1 Circuit Symbols

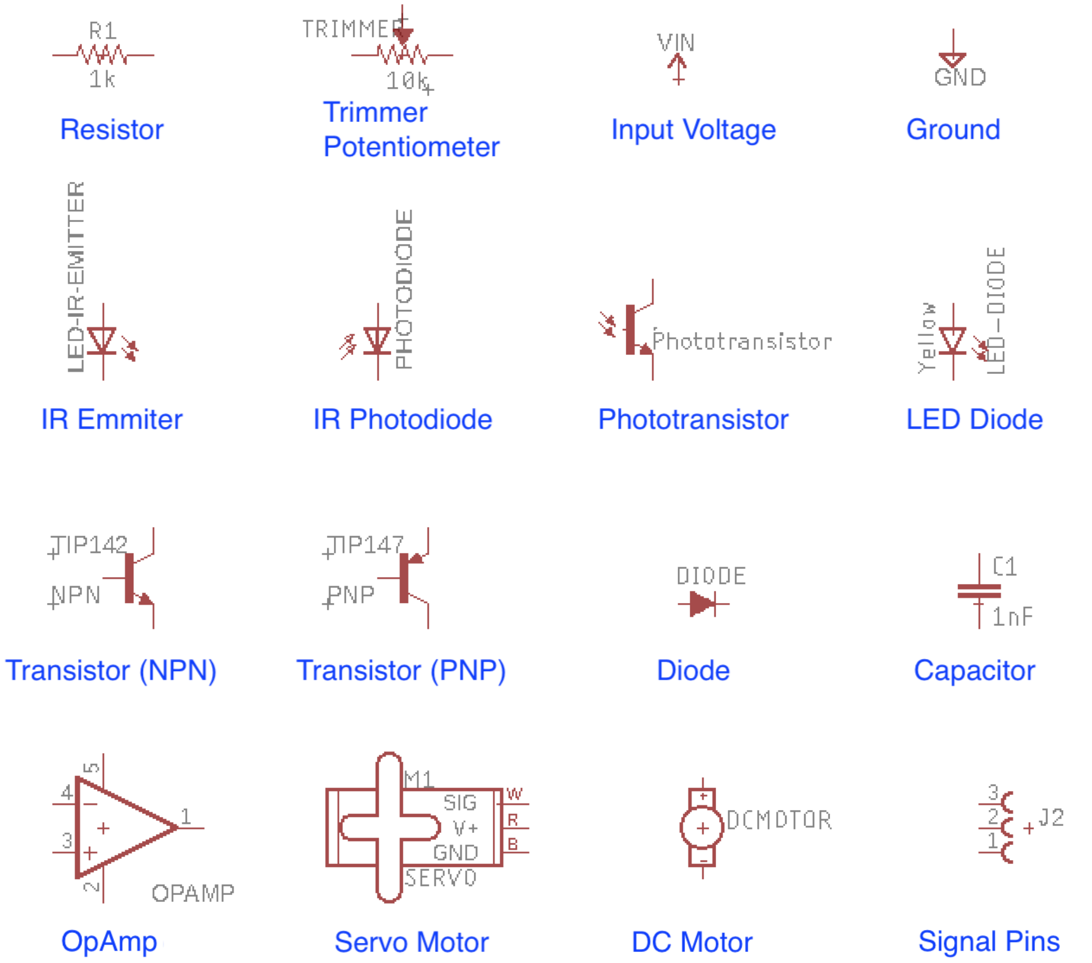


Figure 1 Circuit Symbols

2.2 Terms

- **AHP**: Analytical Hierarchy Process
- **Compartment**: Partitioned storage container inside of the fasteners box. Each compartment resembles the shape of a circular sector with 45 degrees.
- **Fasteners box**: Plastic circular box with 8 identical compartments to store different types of fasteners. It has a diameter of 190 ±5 mm, and a height of 20±1 mm.
- **Feeder**: The bottom of the ramp that directly feed the fasteners to the open compartment of the box.
- **GLCD:** Graphical Liquid Crystal Display
- **IC**: Integrated Circuit

- **LED**: Light Emitting Diode
- **I/O:** Input and Output of signals and data
- **IR**: Infrared Radiation
- **I2C**: Inter-Integrated Circuit
- **LCD:** Liquid Crystal Display
- **Machine:** The author team's design of a Hardware Packing Machine
- **Package**: Fill in a specified number of fasteners in to the corresponding compartment.
- **PIC board**: PIC DevBugger development board
- **PWM:** Pulse width module
- **Reservoir**: The rotating container of the machine to contain the pre-sorted fasteners prior to processing.
- **RFP**: Request for Proposal # 2 – The Hardware Packing Machine.
- **RTC**: Real Time Clock

3. Introduction

A furniture manufacturing company needs to autonomously pack various types of fasteners into a multi-compartment organizer box based on given instructions. Their need creates ample design space for an AER201 Engineering Design Project as illustrated in the client's RFP of a Hardware Packing Machine. This final design report details the design solution provided by the team, outlines and assesses the performance of a prototype of the machine based on the team's design proposal.

The machine, in terms of its overall functionality, accepts pre-sorted four types of fasteners–bolts (B), nuts (N), spacers (S), and washers (W), and then is required to dispense them into specified compartments of the fastener box within a 3-minute limit of operation time. The combination of fastener sets and their designated compartments are specified by the users' input instructions via keypad and LCD interface.

Overall, our design has a two-level structure; on the ground level stand a power bar, a power supply, an emergency stop button, a carousel gear set driven by a continuous servo, 4 (four) returning reservoirs, and a sensor for white tape detection; the top level supports 4 (four) reservoirs that store the fasteners, 4 (four) rotatable ramps through which the fasteners will be dispensed either to the central funnel or to the returning reservoirs, and 4 (four) IR break-beam counting sensors. The microcontroller board and user interface (keypad, LCD, GLCD) are attached vertically to the machine between the two levels.

The design operates in three different modes–Standby mode, Packaging mode, and Post-Packaging mode. During the Standby mode, pre-sorted fasteners are loaded into the corresponding reservoirs by the user. Then, the machine enters the Packaging mode, dispensing the fasteners into the box through the ramps and central funnel. Finally, during the Post-Packaging mode, the ramps will be rotated by micro servos to redirect the remaining fasteners to the bottom returning reservoirs for recollection.

In the foregoing, three main mechanisms are designed to complete the task. The dispensing mechanism is comprised of 4 (four) rotating reservoirs and ramps mounted with IR break-beam sensors to count the number of fasteners dispensed. The detecting mechanism uses an IR reflective sensor to locate the first compartment of the box marked by a white electrical tape. The rotating mechanism is responsible for opening and closing the lid, as well as rotating the box to align the correct compartment with the fasteners dispensation exit.

The prototype of the design was tested repetitively and went through multiple iterative design processes to realize its full functionality. In addition to the basic function, the design also provides extra features, such as real-time date display and a GLCD screen. The budget to build this machine is about CAD $217.33, which is within the CAD $230.00 cost constraint listed in the RFP.

Future improvements can be made in slight shape modification in the exit of each reservoir to prevent potential jamming issue. In terms of means of construction, the team suggests using more laser cutting techniques to seek further precision of each part in structure and reduce the size of the machine. Additionally, the permanent logs of operation and PC interface can be developed and incorporated in the future.

4. Problem Formulation

4.1 Motivations

The RFP from the client states the need of a furniture manufacturing company to autonomously pack 4 (four) types of fasteners–bolts (B), nuts (N), spacers (S), and washers (W) into an 8-compartment circular organizer box in their specific combinations that are instructed by the user. It is anticipated that an old-fashioned manual fastener packing process is tedious and yet both repetitive and repeated for factory workers. This manual workload can be overwhelming and is likely to result in repetitive strain injuries accumulated in the workers' muscle and limbs [2,Canadian Union of Public Employees]. The team's design is aimed to ameliorate the workers' lived and working experience and improve the furniture company's efficiency.

4.2 Problem Statement

The goal of the project is to design and construct the prototype of a machine that autonomously packs four different fasteners (i.e. bolts, nuts, washers and spacers) into a 8-compartment fastener organizer box based on given instruction.

4.3 Design Requirements

4.3.1 High-Level Objectives (HO)

HO1. The machine must include a functional and user-friendly interface.

HO2. The machine must complete the operation of packaging four types of fasteners autonomously based on given instructions.

HO3. The machine should be durably constructed and operate consistently and robustly.

4.3.2 Detailed Objectives (DO)

● The interface is self-explanatory, able to communicate with the users and display system information and operation instructions (HO1)

● All the fasteners must be accurately dispensed in their designated compartments (HO2)

● The remaining fasteners must be returned to retrievable reservoirs (HO2)

● The lid of the box must be completely closed and snapped after the operation (HO2)

● The box is available for pickup after the operation (HO2)

● The machine should be modular and easily manufactured (HO3)

● The machine should be able to operate with a low failure rate (HO3)

4.3.3 Constraints

● The machine must operate autonomously once the empty box and fasteners are loaded.

● The entire prototype must fit with 0.5m*0.5m*0.5 m

● The weight of the entire machine must not exceed 7 Kg.

● The time required to packages one fasteners box needs not to exceed 3 minutes.

● The fasteners must be discharged accurately based on given instructions from the users without contradicting with the following constraints:

○ The fastener set must be chosen from the given set: B, N, S,W, BN, BS, BW, BBN, BBS, BBW, BSW, BWW, BNWW, BSWW, BBSW, BBNW, BNNW, BNNN, BWWW.

○ The maximum number of each fastener set needs not to exceed 4.

○ The Number of assembly steps needs to be chosen from the following numbers: 4,5,6,7,8.

○ The number of each fastener to be dispensed in each compartment must not exceed their maximum number: 2 for Bolts, 3 for Nuts, 2 for Spacers, and 4 for washers.

○ The machine must not accept wrong or inconsistent input and wait for the proper input.

● The box must be placed in a designated pickup position after dispensing the fasteners in the compartments with the lid completely closed.

● The machine must return to the standby mode after each complete operation.

● The machine must display operation time, a summary of instruction parameters, number of remaining fasteners and a completion message after each operation.

● All remaining fasteners must be returned to 4 different reservoirs.

● The machine must include an easily-accessible STOP button that shut down all the mechanical moving components immediately.

● The total prototype cost must not exceed $230 CAD before shipment and taxes.

● The machine must be able to be plugged in the AC, 110V-60Hz, 3-pin outlet, with only one connection.

4.4. Function Analysis

4.4.1. Detecting Mechanism

The purpose of this mechanism is to detect the first compartment (C1) by detecting the location of the white band. As stated in the project RFP, before the operation, the box is horizontally placed with the lid completely closed and snapped. However, the orientation and the position of the first compartment (C1) as well as the opening handle is not known a priori. Since the position of C1 serves as a reference and foundation of the accuracy of future operation (rotation of the box and dispensation of the fasteners), and that the lid must be open and closed properly using the handle, detection mechanisms for these two are required and essential to the entire operation.

Metrics:

M1. Deviation between the actual and detected radial position of the white tape (C1), after the initial round of detection in degrees

M2. Deviation between the lid opener and the box's opening handle in degrees

M3. The outcome of the sensor when detecting the white tape in Voltage

M4. Time required to detect the opening handle in seconds

M5. Amount of power required to rotate to the desired position in Watts

M6. Cost of all hardware components in $CAD

Criteria:

C1. Less deviation in degree is preferred for M1 and M2

C2. More easily distinguishable and linearly classified voltage difference in M3 is preferred

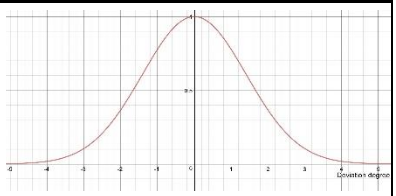
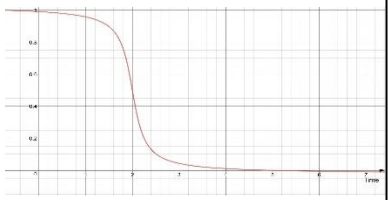
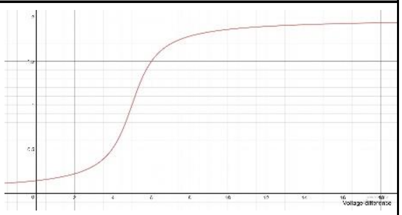
C3. Less time required as outlined in M4 is preferred

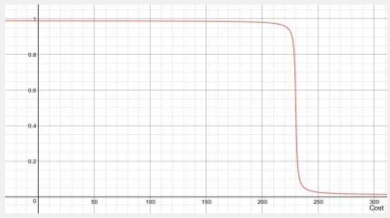
C4: Less power required in M5 is preferred

C5: Less cost as outlined in M6 is preferred Utility Function

Utility Function Table:

Table 1 Utility Function for Detecting Mechanism

Objective	Parameter	Scale	Unit	Utility
Accuracy	Deviation angle between actual and detected	Ratio	Degree	
Efficiency	Time needed for the effective detection	Ratio	Milliseconds	
Sensitivity	Output signal difference between detecting the white tape and the box	Ratio	Voltage (V)	

Cost	Unit manufacturing cost	Ratio	$ CAD	

4.4.2. Rotating Mechanism

The purpose of this mechanism is to rotate the fasteners box while keeping the lid static. Note that the feeder position is defined as a fixed position where fasteners will be dropped from the feeder to the compartment located at this position, assuming the lid of that particular compartment is open. Note that “one rotation” means to rotate any desired compartment to the feeder position.

Metrics:

M1. Deviation between the actual and desired radial position of the box when completing “one rotation” in degrees

M2. Deviation between the actual and desired radial position of the lid when opening or rotating the lid in degrees

M3. Time required to complete one rotation in seconds

M4. Time required to open the lid for the compartment at the feeder position in seconds

M5. Amount of power required to complete one rotation in Watts

M6. Power dissipation due to friction between the rotary tools and the box (potentially as a result of loose grip) in percentage. (Note that instead of directly measuring the heat generation due to friction, simply measuring the percentage differences between the input electrical power and the output power of the mechanical parts will give the power dissipation due to the first law of thermodynamics).

M7. Cost of all hardware components in $CAD

M8: Robustness and durability of all hardware components (see rubric table below)

Table 2 Rubric Table for M8

Poor	**Satisfactory**	**Good**	**Excellent**
- Poor choice of hardware materials (Ex. use of forbidden materials in the RFP - Manual assistance is sometimes required to help the machine	-Choice of materials does not violate client’s constraints in the RFP -Machine can usually autonomous complete “one rotation”. If not,	-As per “Satisfactory”, hardware parts rarely need to be replaced or rebuilt -Machine can always autonomously complete “one	-As per “Good”, minimal noise and vibration made during the rotation process

complete “one rotation”	the minor error can be fixed quickly (<20s)	rotation”. No human assistance is needed at all times	

Criteria:

C1: Less deviation outlined in M1 and M2 is preferred

C2: Less time required as outlined in M3 and M4 is preferred

C3: Less power required in M5 is preferred

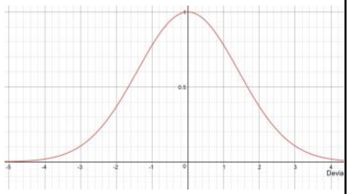
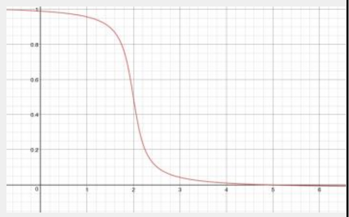
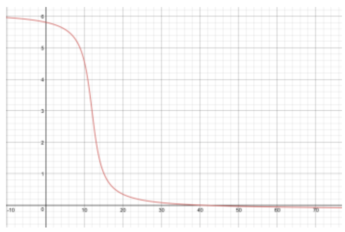
C4: Less percentage of power dissipation detailed in M6 is preferred

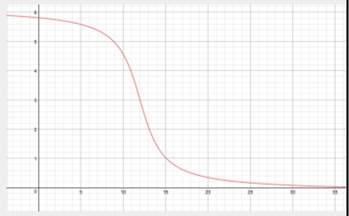
C5: Less cost outlined in M7 is preferred

C6: Higher grades of hardware components listed in M8 is preferred

Utility Function Table:

Table 3 Utility function for Rotating Mechanism

Objective	Parameter	Scale	Unit	Utility
Accuracy	The deviation angle between opening sector and the compartment	Ratio	Degree	
Opening Lid time Efficiency	Time required to open the lid	Ratio	Second	
Rotation efficiency	Time required to complete one rotation	Ratio	Second	

Power efficiency	Power required to complete one rotation	Ratio	Watts	

4.4.3. Discharging and Counting Mechanism

This mechanism enables the fasteners loaded in the reservoir to be discharged individually and keep track of the number of dispensed fasteners. Fasteners are loaded into four different reservoirs, where a discharging and counting mechanism are implemented to easily separate each type of fasteners based on their geometric shapes. The remaining fasteners after packaging the fasteners box should be return to the bottom reservoirs.

Metrics:

M1. The total run time required to discharge all of the fasteners

M2. Cost of all components to build this mechanism

M3. The smoothness of the discharging process (see Rubric below)

Table 4 Rubric Table for M3

Poor	**Satisfactory**	**Good**	**Excellent**
A large amount of fasteners get stuck during the process and affect the discharging process of remaining fasteners	Minimal fasteners get stuck during the process for a short period of time but does not affect the overall discharging process. The orientations of fasteners are not consistent	No fasteners get stuck during the process. However, the orientations of fasteners are not consistent.	No fasteners get stuck in the reservoirs or during the discharging process. All of the fasteners are in the same orientation while discharging

M4. The deviation between the counted number and the actual number of fasteners dispensed

M5. Reliability of the counting mechanism (see Rubric below)

Table 5 Rubric Table for M5

Poor	**Satisfactory**	**Good**	**Excellent**

The performance of the counting mechanism largely depends on the operation environments. The result is easily affect by factors such as temperature, lighting, vibration.	The performance can be affected by 2-3 external factors.	The performance of the counting mechanism would be affected by only one of the external factors.	The performance of the counting mechanism is completely independent from other factors.

Criteria:

C1. Less time required in M1 is preferred

C2. Less cost outlined in M3 is preferred.

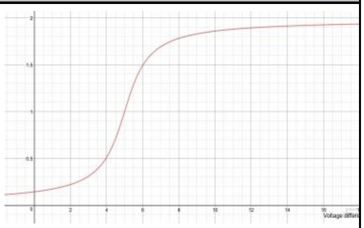
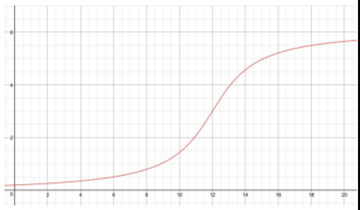
C3. Higher grade outlined in M4 is preferred.

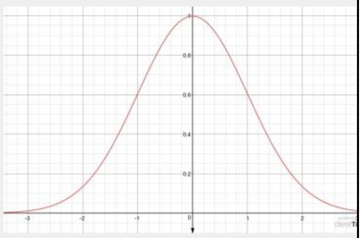
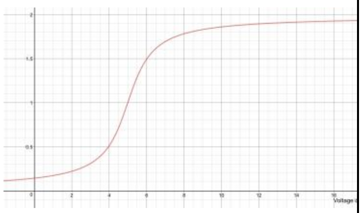
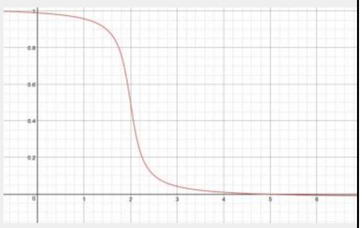
C4. Less deviation (higher accuracy) in M2 is preferred

C5. Higher grade in M4 is preferred

Utility Function Table:

Table 6 Utility function for counting and dispensing mechanism

Objective	**Parameter**	**Scale**	**Unit**	**Utility**
Efficiency	The total run time needed to discharge all the fasteners	Ratio	Second	
Manufacturability	Symmetry of the geometry shape of the parts. Level of construction, additional machine and tooling involvement, difficulty of assembly	Ordinal	NA	

Accuracy	The deviation between the counted number and the actual number of fasteners	Ratio	Number	
Smoothness of Operation	The smoothness of the discharging process	Ordinal	NA	
Cost	Unit manufacturing cost	Ratio	$CAD	

5. Design Perspectives

5.1 Background Survey

5.1.1 Literature Survey

5.1.1.1 Feeders

Vibratory bowl feeder:

It is the most common device that is utilized in industries, such as pharmaceutical, electronic, packaging and metal working industries. The device includes both electromagnetic and pneumatic drives that generates vibration to sort and orient the parts by forcing them climbing up the ramp as demonstrated in Fig. 2. The track can be customized in terms of length, width, and depth to suit the shape and size of components. The speed and amplitude of vibration can be can be adjusted [9].

Figure 2 Vibratory Bowl Feeder

Centrifugal Feeders:

This device has a smooth and gentle operation. The parts are loaded to a rotating centre disk mounted in the centre of the feeder. The centrifugal force is utilized to force the parts to the elevated edge of the feeder disc, then the force propels the parts past the mechanical and pneumatic tooling as shown in Fig. 3 [10].

Figure 3 Centrifugal Feeders

5.1.2 Idea Survey

5.1.2.1 Reflective Object Sensor

Since the white electrical tape used to indicate the first compartment is made of a reflective material, an IR sensor would the most appropriate choice.

IR sensors use a specific light sensor to detect a certain wavelength of light in the infrared (IR) spectrum [4]. They normally occur in a pair, one emitter and one receiver. When an object is approaching to the sensor, the light emitted bounces off the object surface and back into the light sensor as demonstrated in Fig 4. During this process, the intensity of light will significantly reduce, and the difference of which can be used in a threshold detection. As a result, this feature can be used to measure the "brightness" of the object, i.e. lightly colored objects reflect more IR while darker colored ones less. In addition, as specified in the datasheets of reflective sensors in the market, the typical detection distance is around 2~4 mm and preferably used in limited space [5,6].

Although IR reflective sensor requires careful calibration in order to distinguish different levels of intensity and prevent from sensing extraneous objectives when utilizing in the industry [4], the application in our project is simply distinguishing from reflective white tape and non-reflective black box surface, which will yield a significant difference in its voltage output.

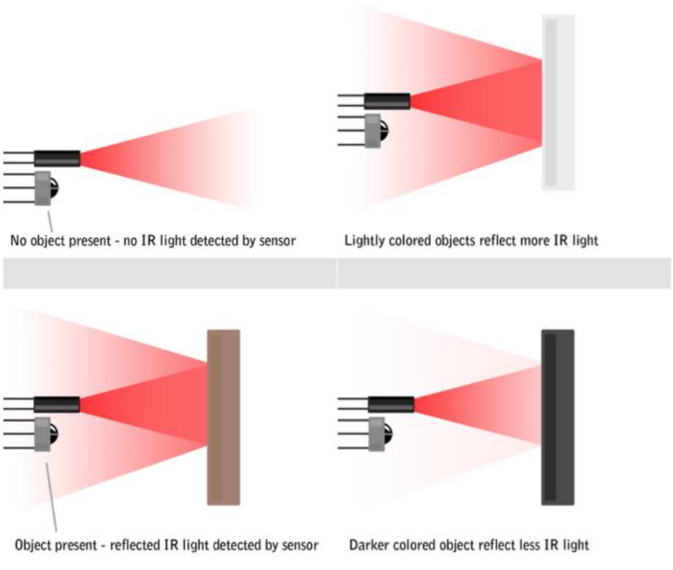


Figure 4 Demonstration of the Detection Mechanism of IR Reflective Sensor

5.1.2.2 Counting Mechanism

One ubiquitous counting mechanism is by shining IR LED directly in front of a photodiode which is called the "direct incidence". If any object passes between them, it obstructs the incident IR light beam shone onto the photodiode as demonstrated in Fig 5. A photodiode is a semiconductor device that converts light signal into an electrical resistance; when a light beam is shone on the photodiode, its resistance reduces by a large margin, resulting in the decrease of voltage drop across it and the increase of the current flowing through it. By using the "direct incidence" method, since almost the entire IR radiation falls onto the receiver, the sensitivity of detecting light beam break is boosted. Therefore, by directly counting the numbers of large voltage changes detected, the exact number of fasteners passed can be obtained immediately.

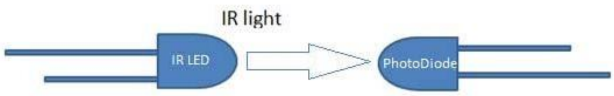


Figure 5 Mechanism of IR Beam Breaking

5.1.2.3 Automatic coin sorting machine (vibratory dispensing mechanism)

The prototype is constructed using cardboard. The coins are loaded into the trapezoidal reservoir with one slim opening at the end as displayed in Fig 6. There is a vibratory device attached to the bottom of the container such that coins are discharged from the reservoir from vibrations.

The opening of the reservoir can be modified into different shape to allow different types of fasteners to go through.

Figure 6 Vibratory Dispensing Machine [7]

5.1.2.4 Automated small parts Counting machine

The nuts are loaded into the reservoir with a rotating disc. They are stuck in the slots during rotation and are brought to the top opening such that they are discharged individually as shown in Fig. 10.

The slots in the rotating disc can be modified into different shape to fit the geometry shapes of different types of fasteners.

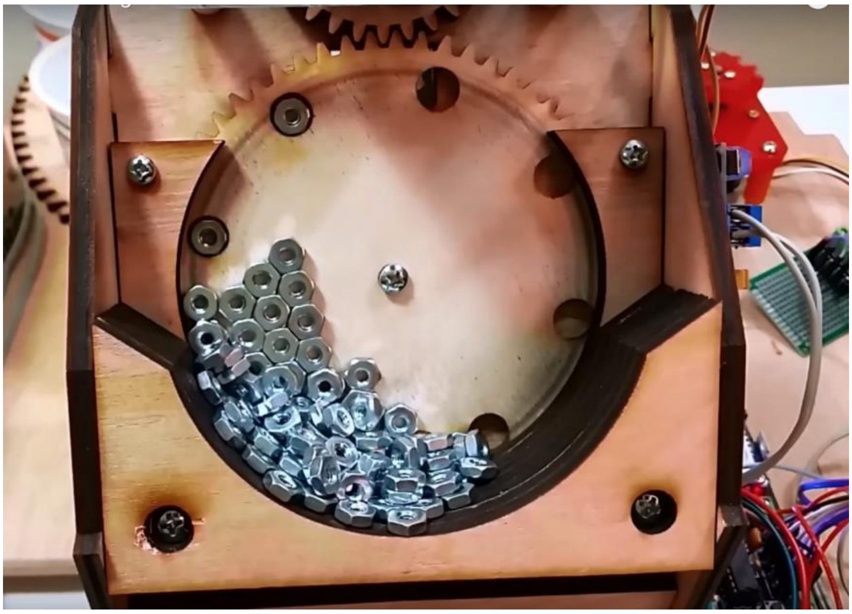


Figure 7 Automated Small Parts Counting Machine [8]

5.1.3 Market Survey

5.1.3.1 Material Selection

Material selection is a crucial part towards the robustness and the ease of manufacturing of the final prototype. It is also a huge factor that directly correlates with the budget of the project. The selection process is based on the relationships between the strength, density and cost of the material outlined in the Material and Process Selection Chart from CES 2010 Edupack [1].

Fig 3. compares the strength of the materials with respect to the relative cost per unit volume. The more upper left a material it is, the higher the ratio of strength to cost per unit volume it has. The dashed line on the bottom right corner are suggested guidelines for minimal cost designs.

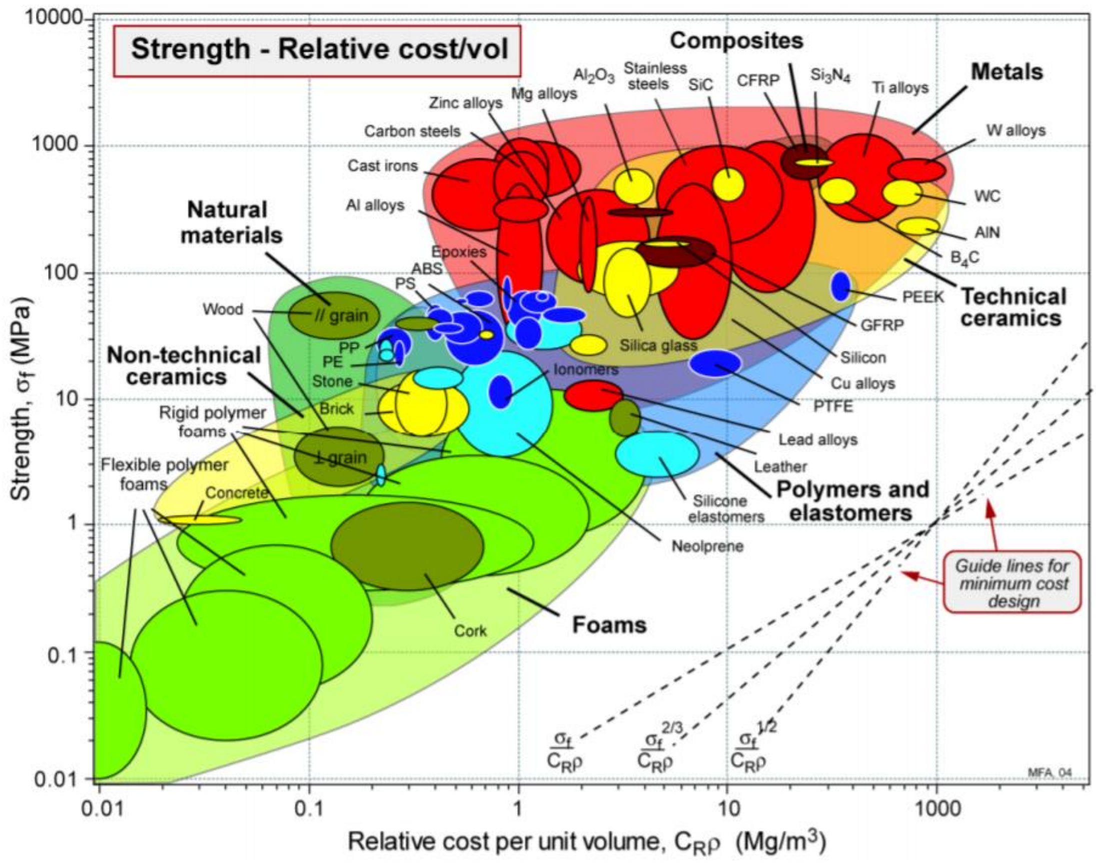


Figure 8 Strength of Various Materials versus Relative Cost (CES2010 Edupack)

The next chart (Fig. 4) compares the strength of the materials with respect to its density. Materials like foams and polymers and ceramics are excluded due to their relative low strength to density ratio. Wood is very effective when comparing against both metrics, but the direction of the grain must be allied with the direction of the applied force. Most metals are very strong, but considering the cost constraint of the machine, metals will not be the primary go-to choices of materials. Plastics, such as PVC and ABS, also provides relatively high strength at reasonable costs.

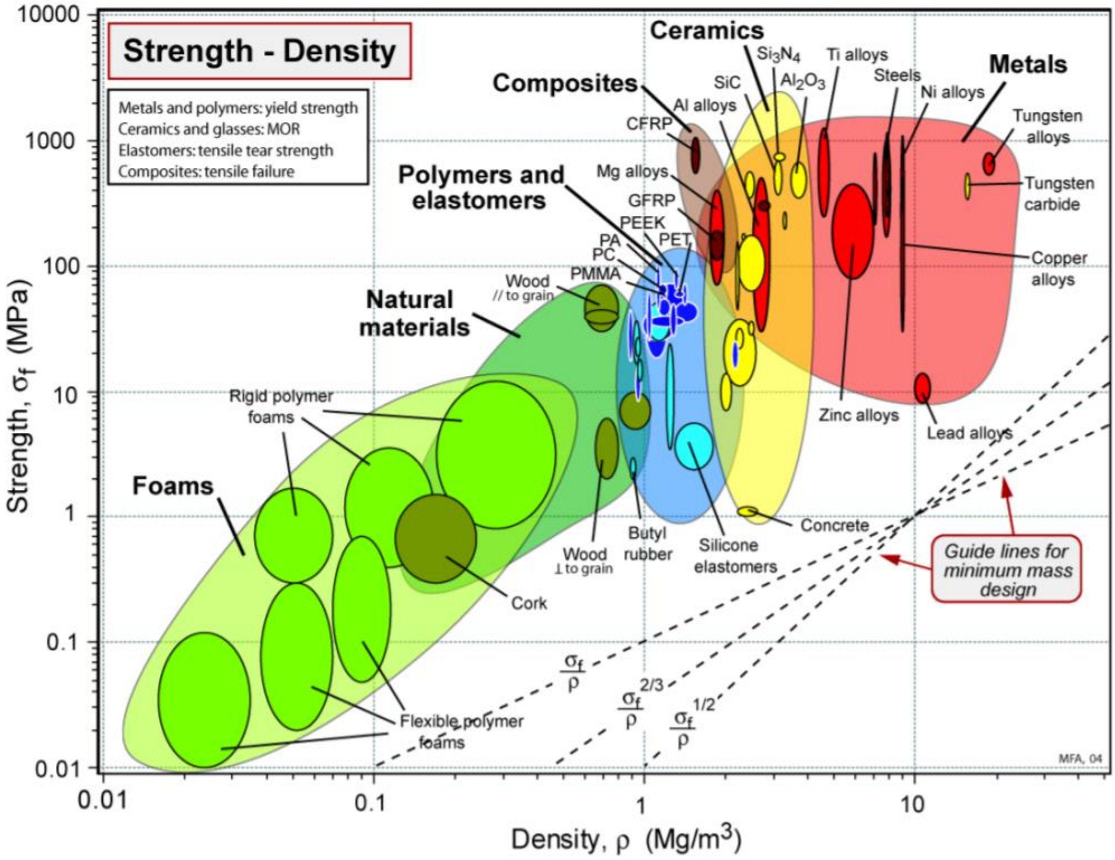


Figure 9 Strength of Various Materials versus Density (CES2010 Edupack)

5.1.3.2 Related Patents

1. **CN Patent 105984696A** demonstrates a screw feeding device, consists of a base, a bearing, a hollow wedged block and a driving device that turns the bearing parts on **an inclined surface** as shown in Fig. 5. There are three main ideas in this patent that could potentially be used for separating fasteners in the hardware packing machine. Firstly, screws are falling into predetermined locations on the bearing parts rather than random distribution. Secondly, this reduces the amount of vibrations during the screw feeding processes compared to conventional linear tracks which utilizes vibrations. Lastly, the overall structure is relatively simple, and thus easily manufacturable and maintainable [2].

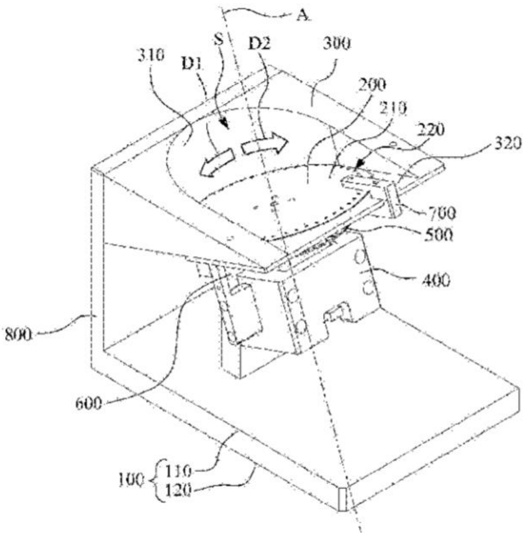


Figure 10 Patent Schematics of a Screw Feeding Device

2. Another patent (**CN 203094522 U**) provides a fastener automatic packaging device that utilizes a feeding part, a control weight sensing part, a conveying part and a packaging part. The highlight of this patent is the counting of the number of fasteners for packing, which utilizes a tray, a sensor, a counter, and digital weight requirement and weight analyzer. The conveying part utilizes a spiral, vibrational conveying part that will feed fasteners into the weighing tray (labeled No. 4 in the Fig. 6). The weighing sensors will then send the digital signal back to the computer to further coordinate with the packaging part and the rotational fastener delivering part [3].

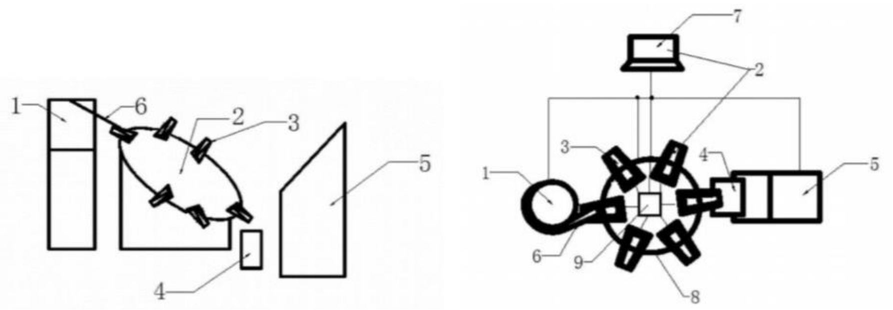


Figure 11 Patent Schematics of a Fasteners Automatic Packaging Device

5.2 Conceptualization

5.2.1 AHP-aided, Utility-based Decision-Making Process

The decision-making process will be addressed in the following fashion: For each important function outlined in the functional analysis section (i.e. Counting mechanism, Detection Mechanism, etc.), we will provide an overview of all alternative design for this feature. Then we perform utility-based and AHP-aided decision-making process to reach a final design. The selected designs for each feature will together build up the specification of the proposed design.

5.2.1.1 Dispensing and Counting system:

There are 3 potential solutions to implement the dispensing and counting system. Those three solutions are evaluated using utility-based analysis and AHP.

A. Vibratory bowl feeder

The device in Fig. 11 includes both electromagnetic and pneumatic drives that generates vibration to sort and orient the parts by forcing them climbing up the ramp. The track can be customized in terms of length, width, and depth to suit the shape and size of components. The speed and amplitude of vibration can be can be adjusted.

B. *Vibratory dispensing mechanism*

The inclined trapezoidal reservoir has a vibratory device attached underneath it, which shakes the fasteners out of the reservoir individually. The slim opening at the end of the reservoir allows only one fasteners to go through. See Fig. XX.

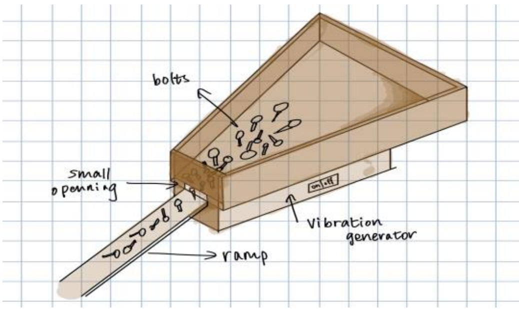


Figure 12 Vibratory Dispensing Mechanism

C. *Automated rotating reservoir*

The device includes a circular rotating disc with 6 holes corresponding to the geometric shapes of the fasteners, and a fixed base disc with only one opening. The fasteners get stuck in the hole during rotation, and get dispensed from the reservoir one the hole align with the opening in the base disc. See Fig. XX.

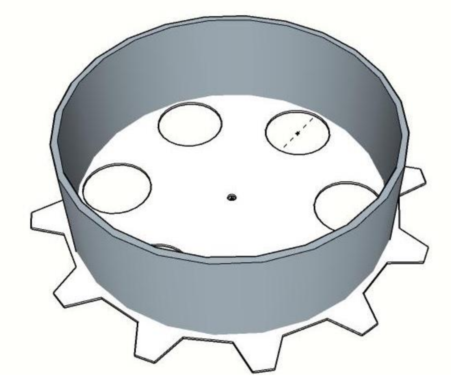


Figure 13 Automated Rotating Reservoir

Utility based evaluation:

Table 7 Utility Based Analysis for Counting and Dispensing Mechanism

		A. Vibratory bowl feeder		B. Vibratory dispensing machine		C. Automated rotating reservoir	
Objectives	Weight	Estimated value	Utility Value	Estimated Value	Utility Value	Estimated value	Utility Value
Efficiency	1	27 secs	0.86	40 secs	0.63	35 secs	0.68

Accuracy	3	0	0.78	3	0.29	1	0.76
Cost	2	40$	0.35	10$	0.71	20$	0.65
Utility Weighted Sum	6.27			4.60		6.85	
Normalized Total	0.35			0.26		0.39	

AHP based evaluation:

Table 8 Numerical scale of preference

Judgement of Preference	Numerical Scale
Extremely preferred	9 8
Very strongly preferred	7 6
Strongly preferred	5 4
Moderately preferred	3 2
Equally preferred	1

Those three potential solutions are compared using AHP again two metrics: manufacturability and smoothness of operation. A numerical value is assigned to each judgement of preference, and three potential solutions are compared with each other in the matrix. The consistency index is shown below.

1. Relative importance with respect to Manufacturability

A: Vibratory bowl feeder

B: Vibratory dispensing

C: Automated Rotating reservoir

Table 9 Relative Importance with respect to Manufacturability

	A.	B.	C
A	1	1/8	1/5
B	8	1	3
C	5	1/3	1

Table 10 Normalized Matrix of Relative Importance

	A	B	C	Overall Preference
A	0.077	0.034	0.130	0.08033
B	0.538	0.241	0.217	0.332
C	0.384	0.724	0.652	0.587

Consistency = 4.6%

2. Relative Preference with respect to Smoothness of Operation

Table 11 Relative Importance with respect to Smoothness of Operation

	A	B	C
A	1	5	3
B	1/5	1	1/2
C	1/3	2	1

Table 12 Normalized Matrix

	A	B	C	Overall Preference
	0.652	0.625	0.66	1
	0.130	0.125	0.111	0.366
	0.217	0.250	0.3	0.767

Consistency = 2.4%

It can be seen from the utility-based analysis that option 3, **automated rotating reservoir** scores the highest, and it is the second-best option in terms of manufacturability and smoothness of operation from AHP. Hence, automated rotating reservoir will be used as dispensing and counting mechanism in the proposed design.

5.2.2 Detecting Mechanism

Utility based Evaluation:

Table 13 Utility based evaluation for detecting mechanism

		A. IR Sensor		**B.** Color Sensor		**C.** Image Sensor Vision Tool	
Objectives	Weight	Estimated value	Utility Value	Estimated Value	Utility Value	Estimated value	Utility Value
Accuracy	4	1	0.78	1	0.78	0	1
Efficiency	2	1	0.88	2	0.52	2	0.52
Sensitivity	1	5	1	5	1	0	0.1
Cost	3	1.7	0.82	6.11	0.48	11	0.01

Utility Weighted Sum	8.34	6.6	5.17
Normalized Total	0.41	0.33	0.26

AHP based evaluation:

Relative Preference w.r.t **Power Consumption**

A: IR Sensor

B: Color Sensor

C: Image Sensor Vision Tool

Table 14 relative preference with respect to power consumption

	A	B	C
A	1	2	4
B	1/2	1	3
C	1/4	1/3	1

Table 15 normalized matrix

	A	B	C	Overall Performance
A	0.57	0.6	0.5	1.67
B	0.29	0.3	0.375	0.965
C	0.14	0.1	0.125	0.365

Consistency Ratio: CR = 1.9%

Suggested by utility-based analysis and AHP, **IR sensor** is the best option to detect the first compartment and the location of opening handle, since it scores the highest. It has high accuracy, high sensitivity, low cost, and low power consumption.

6. Overall Design Description

6.1 Overview

The hardware packaging machine consists of a dispensing mechanism, a rotation mechanism, and a ramp system. The dispensing mechanism includes four circular reservoirs that are mounted on the top layer of the machine, and four remaining reservoirs mounted at the bottom layer. The rotation mechanism includes a square base with a plug in the middle to lock the fastener organizer box in place. After loading the fastener box onto the rotation mechanism, and loading the fasteners into the designated reservoirs, users can enter instructions via the user interface. While packaging the box, the rotation mechanism opens the lid of the fastener box and rotate to the correct compartment, and the dispensing mechanism would dispense the correct amount and type of fasteners into the compartments. The rotation mechanism is also responsible to close the lid of the fastener box.

The ramps would rotate after packaging the box, and redirect the dispensed fasteners to the remaining reservoirs at the bottom.

After all fasteners are dispensed and lid is closed, users can easily retrieve the packaged fastener box and the operation summary such as operation time and number of remaining fasteners through user interface.

This design effectively addresses the problem stated in the proposal of packaging four types of fasteners into the circular 8-compartment fastener organizer box.

6.2. Dimension and Weight

The dimension of the machine is $49 \times 45 \times 45$cm, which is within the dimension constraints. And the machine weighs 6.48 kg in total.

6.3 Function Glass Box

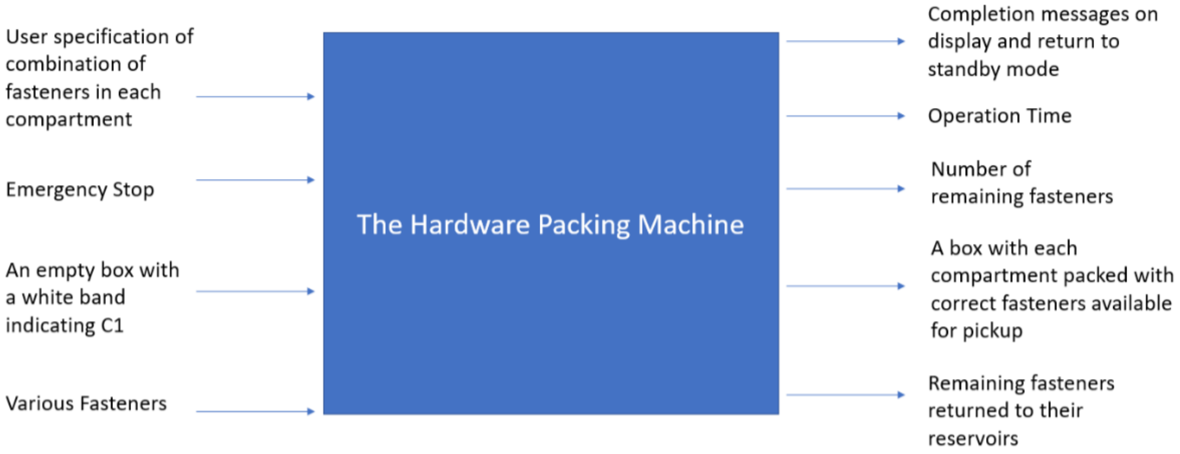


Figure 14 The function glass box of the machine

6.3 Standard Operating Procedure

1. Plug in the machine.
2. Load four types of fasteners, bolts, nuts, spacers, and washers into designated reservoirs.
3. Load an empty 8-compartment fastener organizer box onto the machine.
4. Enter instruction via the user interface.
5. Enter the assembly step
6. Repeat the previous step if the error message is displayed on the LCD screen.
7. Enter the valid fastener set to be dispensed for the current step
8. Repeat the previous step if the error message is displayed on the LCD screen.
9. Enter the number of fastener set to be dispensed for the current step
10. Repeat the previous step if the error message is shown on the LCD screen.
11. Repeat step 7 until instruction of fastener set and the number of fastener set is entered for all steps.
12. Press '#' to start operation.
13. Press the emergency stop if needed, which ends the operation immediately.
14. Wait for the termination messages to show on the LCD screen if the emergency stop is not pressed.
15. Retrieve the operation summary via the user interface
16. End of the operation.

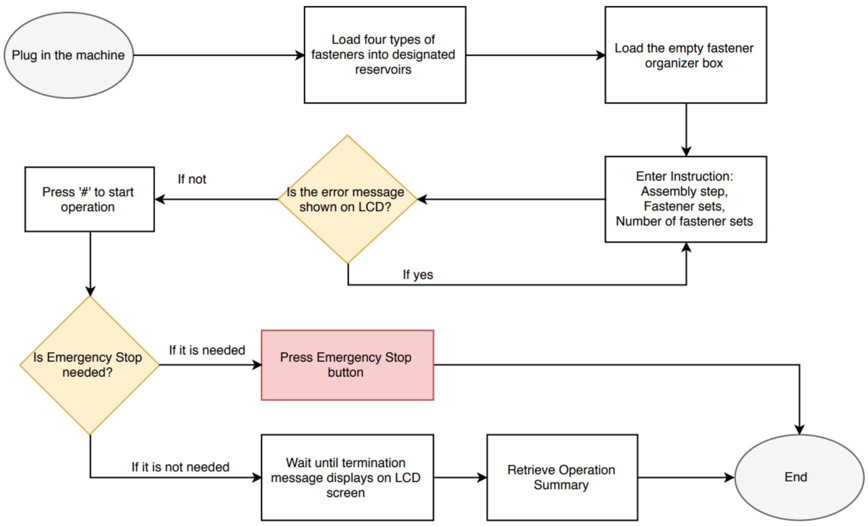


Figure 16 Flowchart of the operating procedure

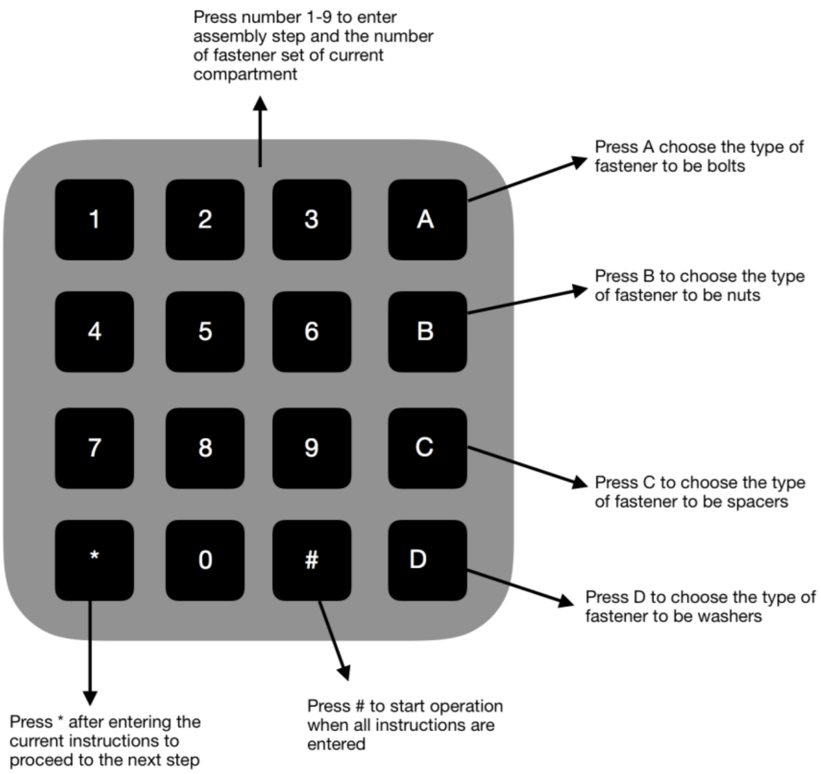


Figure 15 Keypad description

7. Budget

Table 16: the total budget of the machine

Item	Unit Price ($)	Quantity	Total Prices($)	Sources
4*2*2 Birch plywood	6.58	1	6.58	Home Depot
2*2*2 Fir plywood	9.04	1	9.04	Home Depot
1*2*3 Pine wood	2.26	1	2.26	Home Depot
9g Micro Servo Motor	2.43	4	9.72	HobbyKing
Continuous Servo	15.00	1	15.00	Prof. Emami
8’’*10’’ 2mm Acrylic Sheet	3.79	4	15.16	Lowe’s
Shenzhen DC Gearhead Motor	4.00	4	16.00	Prof. Emami
9’’* 11’’ Sandpaper	1.39	1	1.39	Home Hardware
1/16’’ Thin Wooden Plate	11.25	1/3	3.75	Home Hardware
Circular Plastic wrappers	0.06	4	0.24	Dollarama
Plastic reservoirs. (COUPLING,PVC SWR 3’’*3’’)	1.49	4	5.96	Home Hardware
Electromechanical SubTotal			$85.10	

Item	Unit Price ($)	Quantity	Total Prices($)	Sources
Power Supply	15.41 (US $11.95)	1	15.41	JAMECO Electronics
Power Bar	2.00	1	2.00	IKEA
Emergency Stop	2.85	1	2.85	DiGiKey
Transistor TIP142	1.53	4	6.12	DiGiKey
IR Emitter	0.35	4	1.40	DiGiKey
IR Phototransistor	0.33	4	1.32	DiGiKey
Wires + Solder	6.32	1	6.32	DiGiKey
Dual OpAmp LM358	0.61	2	1.22	DiGiKey
Prototyping Board (Solderable) 2 cm x 8 cm	1.25	3	3.75	Creatron
Prototyping Board with Trace 4.2 cm x 7 cm	1.95	1	1.95	Creatron
Capacitor 0.1nF	0.45	4	1.80	DiGiKey
Resistors (various)	0.058	24	1.39	DiGiKey
LED Diode	0.35	5	1.75	Creatron
IR Reflective Sensor	6.80	1	6.80	Creatron
Photo-interrupter	7.15	1	7.15	DiGiKey
Circuit and Sensor SubTotal			$61.23	

Item	Unit Price ($)	Quantity	Total Prices($)	Sources
PIC DevBugger Development Board with AC/DC Adapter and Cable Bus	50.00	1	50.00	Prof. Emami
Character LCD+Keypad	6.00	1	6.00	Prof. Emami
Real-time Clock (RTC) Chip and Coin Battery	5.00	1	5.00	Prof. Emami
GLCD	5.00	1	5.00	Prof. Emami
Arduino Nano	5.00	1	5.00	Prof. Emami
Microcontroller SubTotal			$71.00	

Total Cost of the Machine: <u>$217.33</u>

8. Statement of Work

Electromechanical

The electromechanical member of the team(Philip) will be responsible for creating the overall physical mechanism of the machine. This includes the overall frame of the robot, the vertical supports, the construction of ramps, reservoirs, carousels and the mounting of all sensors, circuits, actuators and controller board. The electromechanical member is also responsible for material and actuator selection, testing the functionalities and integrating with circuit and microcontrollers subsystems.

Circuit

The circuit member is responsible for designing and implementing the overall structure of the circuits that drives the motors, connects the sensors, the power supply and the microcontrollers. The circuit member should prototype each individual circuit and sensor components and verify their functionality, and then build the entire circuit. The circuit member is also responsible for debugging the all circuit functionality and integrating with the microcontroller and electromechanical subsystems.

Microcontroller

The microcontroller member is responsible for designing user interface and the overall microcontroller system. The user should be able to communicate its needs easily with the machine by sending commands through the keypads and retrieving feedbacks from the machine through the LCD. Another important responsibility of the microcontroller is to interface with all the hardware components, including generating control signals for actuators and collect data from sensors and make decisions to the hardware mechanism. The most important responsibility of the microcontroller member is to implement both the sequential and combinational logic in the algorithm. Lastly, the microcontroller member is also responsible for extra functionalities such as Real-time Display, Permanent Logs and PC interface.

9. Electromechanical Subsystem

This section describes the details of the electromechanical subsystem. Details, including structure of the frame, material selection, actuation mechanisms, and manufacturing process will be analyzed and presented. Calculations, engineering drawings and experimentations will be provided accordingly.

9.1 Electromechanical Subsystem Problem Assessment

As outlined in the RFP, the objective of this project is to build a hardware packing machine that can deliver different combinations of bolts, washers, spacers and nuts into designated compartment in the fastener box. The biggest challenge for the electromechanical subsystem is to build a reliable and robust fastener dispensing mechanism and the lid opening mechanism. Any miscalculation, misalignment or small construction error could lead to jamming of the fasteners or slipping of the fastener box. Taking these factors into consideration, the electromechanical design of the robot must account for the difficulties of manufacturing at every step because a design that cannot be easily built is not a feasible design.

9.1.1 Defining point of the subsystem

1. Provide a frame that can structurally support all the functional components, including actuators, circuits, PIC board, wiring, reservoirs and power supplies.
2. Provide reliable and robust actuation mechanisms to dispense the fasteners one by one, open/close the lid of the fastener box, and deliver fasteners to different compartments.
3. Comply with all the constraints, including dimensions, weight, materials selections in the project's RFP.
4. Provided space and design mechanisms to mount circuits, sensors and PIC board
5. Provide safe and easy approach to maintain, improve or upgrade all components
6. Ensure the machine is safe to use and pose no risks for the operator

9.1.2 Electromechanical Subsystem Design Philosophy

The robot is designed to be a two layer structure, with all the centrifuge feeders and ramps located at the top layers, and the Lazy Susan turntable, remaining reservoirs and power supply located at the ground layer. A two-layer design also separates manufacturing and maintenance of the top and the ground layers. For example, the dispensing mechanism (i.e. ramps, centrifuge feeder) can be tested or without completing the entire structure. This vertically oriented design maximizes the use of gravity to facilitate the delivery of the fasteners from the centrifuge feeder to the fastener box. The ground layer gives large empty areas to mount the remaining reservoirs, the PIC board, the power supply, and etc. Overall, the design is kept minimalistic, and anyone should be able to understand the workflow simply by inspection. This means the design is simple, easily manufacturable but yet effective and debuggable.

9.2 Design Solution

9.2.1 Overview of the design

The overall design of the robot can be visualized as follow:

The top layer of the robot is mainly comprised of the dispensing mechanism. Each type of fastener has a set of centrifuge Feeders, DC motors, servo motors and ramps system that are responsible for dispensing them according to the instruction from the circuit and microcontroller subsystem. The overall layout of the top layer is very symmetrical, making the design very intuitive to understand and easy to manufacture.

The bottom layer of the robot includes the fastener box rotation mechanism and some other circuits and microcontroller components. The fastener box is located at the centre of the box, so that the fasteners could directly fall from the funnel into the opened compartment of the box. The remaining reservoirs are placed symmetrically near the four corners, such that remaining fasteners could fall from the ramp into the reservoirs. The PIC board are located at the side of the machine facing the user, while the power supply is located at the opposite side of the machine.

In the following sections, each electromechanical mechanism would be broken down into details. All the functioning components and their manufacturing processes will be discussed.

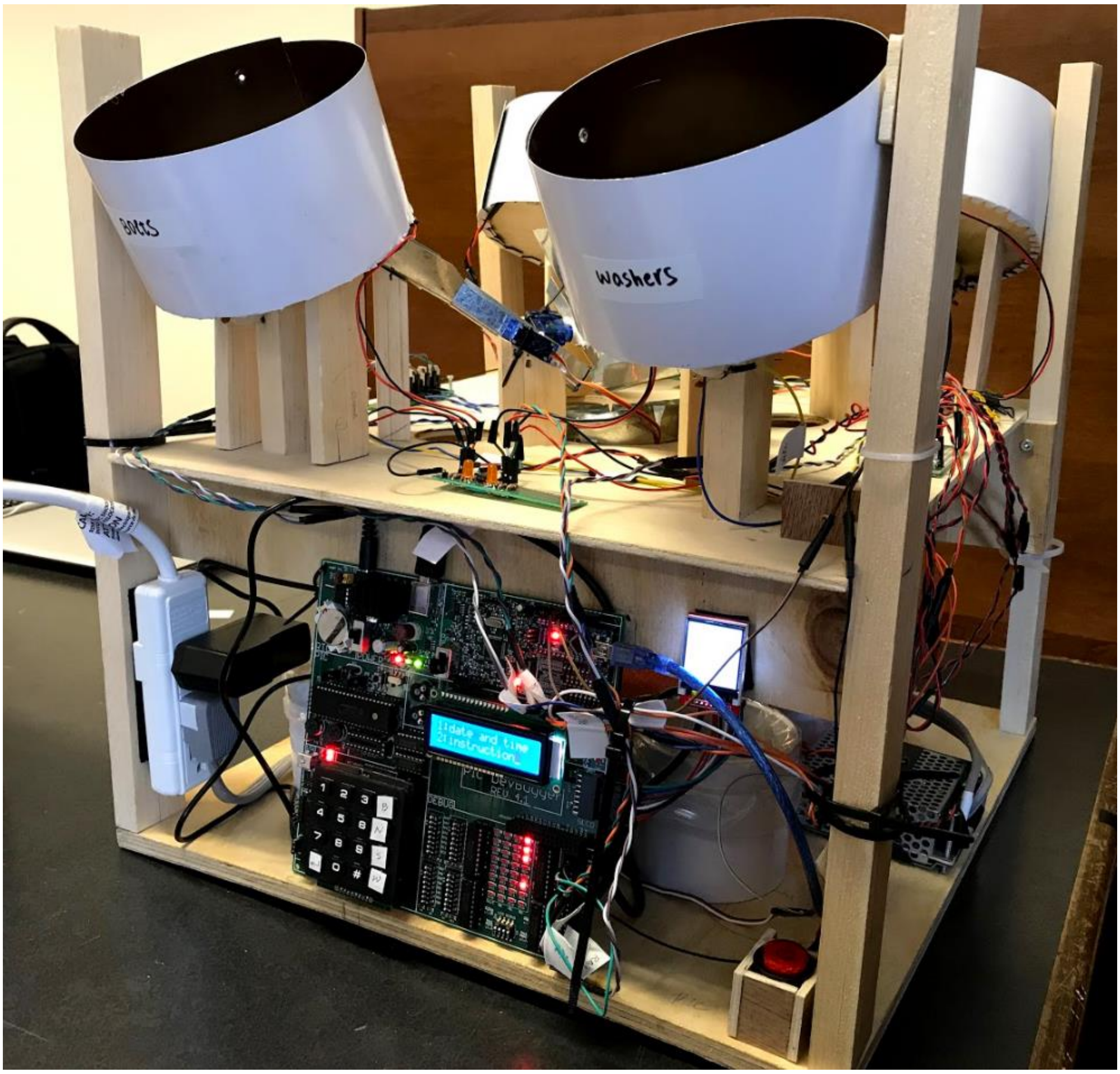


Figure 17 Overview of the machine. Photo credit to Jason Zhou. Note that the top layer is supported by the two horizontal beams connecting two vertical support.

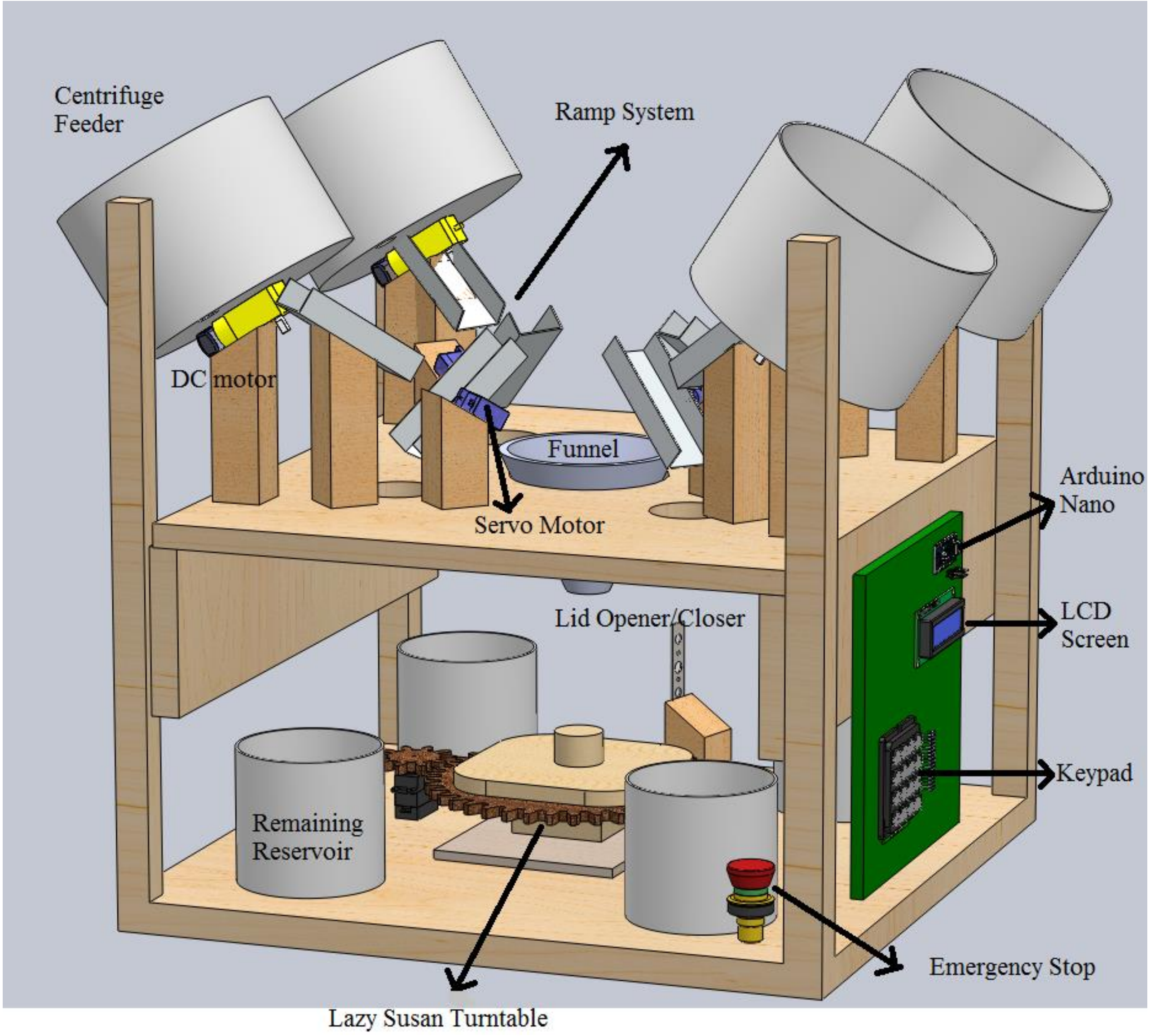


Figure 18 CAD-rendered 3D conceptual drawings of the machines with annotated parts.

9.2.2 Frame

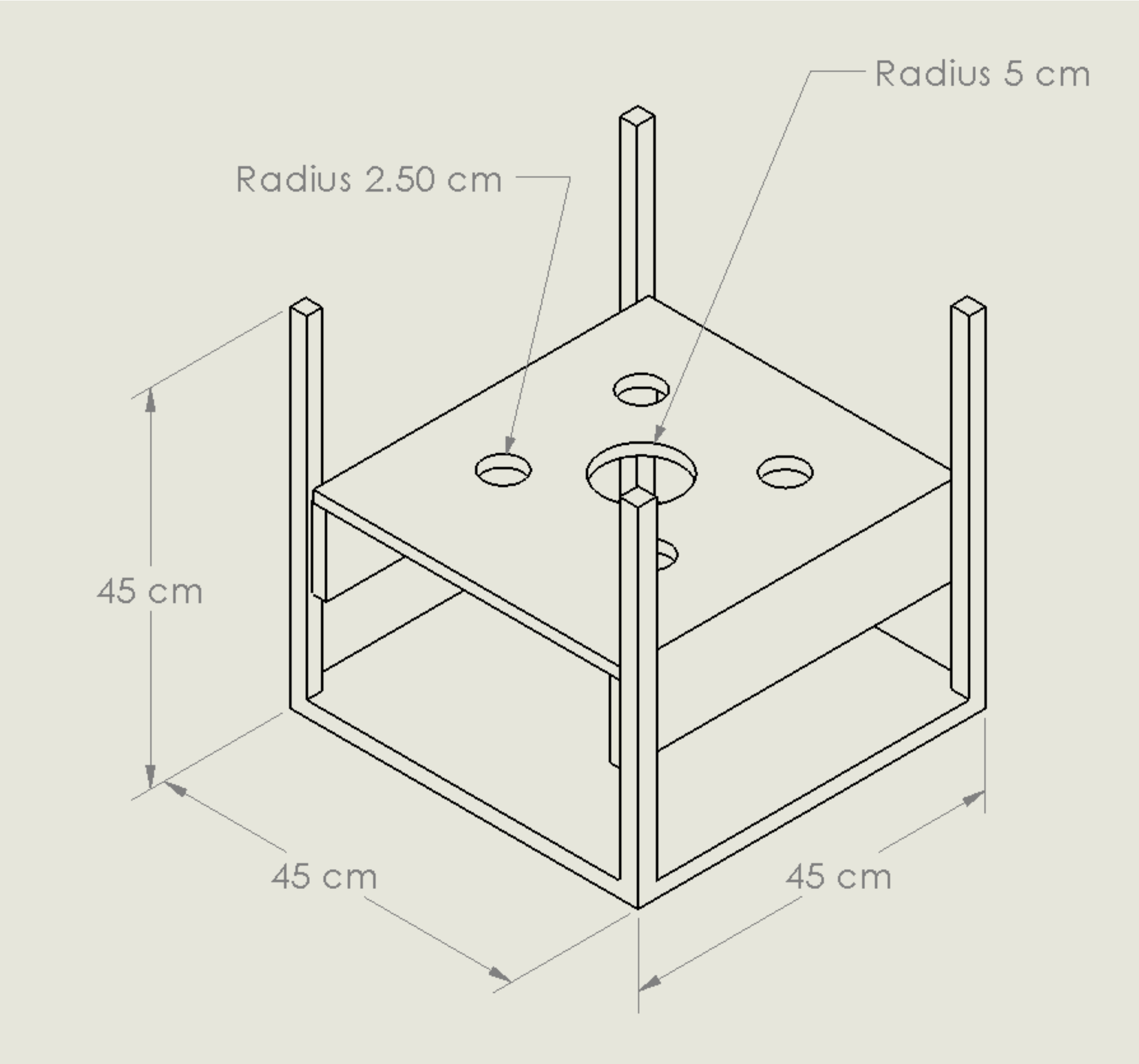


Figure 19 The overall frame of the machine drawn in SolidWorks with important dimensions labelled.

The frame of machine is designed to fit in a 45cm by 45cm by 45cm box, with 5 cm of "factor-of-safety" space to satisfy the 50cm by 50cm by 50cm size constraints. This turned out to be a crucial design decision because the centrifuge feeder located at the four corners on the top layers actually exceeds the size of the frame. Fortunately, there are "factor-of-safety" space turned out to be very useful in the end.

The manufacturing process of the frame is as follow: Four vertical support, each cut to about 43 cm long, were connected to the four corners of the bottom wooden plate with 2 inches long wood screws. Two 45cm long wooden beams, located 24 cm from the ground, are used for both stabilizing the vertical support and supporting the top layer.

The top plate of the machine is manufactured separately. A 5cm-radius hole was drilled to fit the funnel, and four 2.5cm-radius hole was drilled to allow remaining fasteners to fall to their reservoirs in their respective reservoirs.

9.2.3 Breakdown of Dispensing Mechanism

The goal of the dispensing mechanism is to reliably dispense fasteners one by one to the opened compartment or remaining reservoir without jamming.

9.2.3.1 Centrifuge Feeder

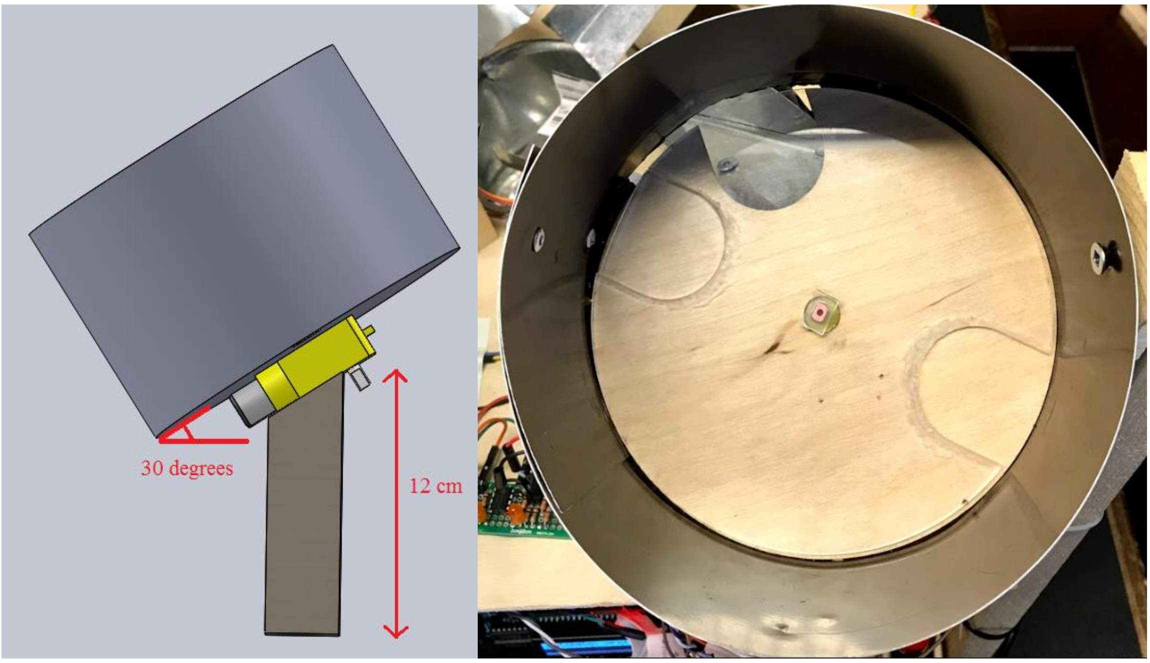


Figure 20 Example sideview rendered by the CAD drawing and the bird eye view of the washer centrifuge feeder. Note that the 30 degrees angle between the reservoir level and the ground layer are designed to make dimensions of the ramps easy to calculate and manufa

Each centrifuge feeder of the compartment box is located at the corner of the compartment box. The centrifuge feeder is supported by the a 15cm lumber wooden beam. The DC motors are connected to the beam with two zip-ties, and the bottom plate of the centrifuge feeder are epoxied to the DC motor.

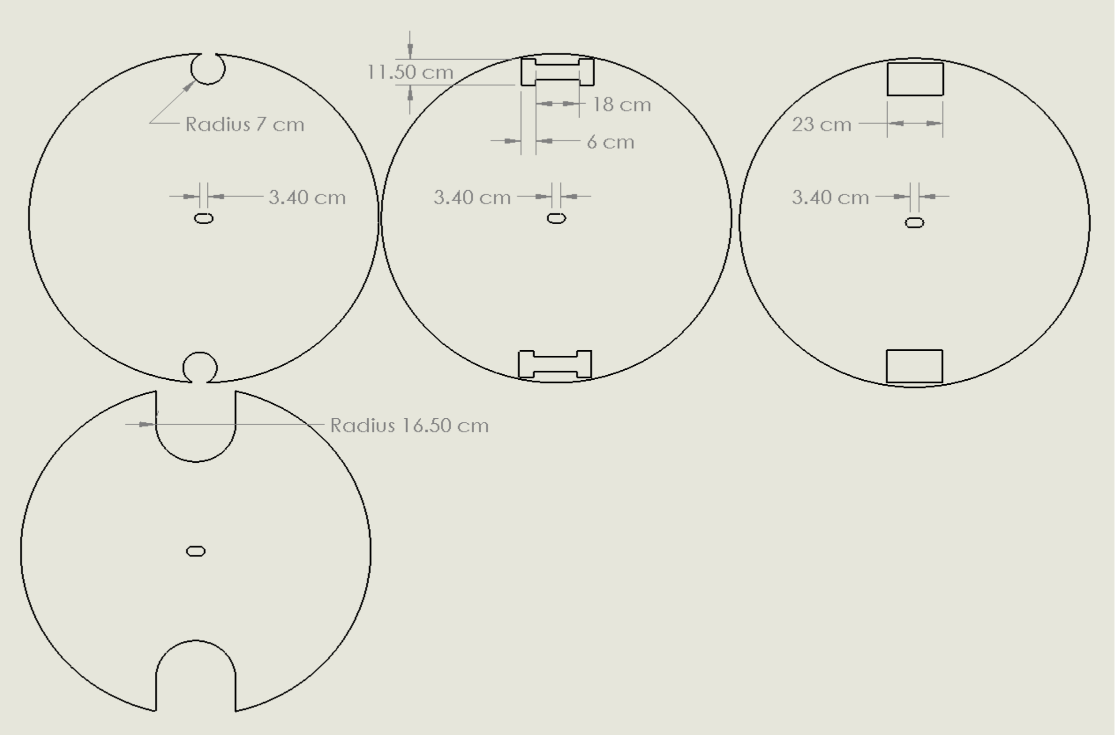


Figure 21 Example Engineering Drawing of the rotating plate. The acrylic rotating plate are manufactured using the laser cut machine in MC78 student machine shop.

There are two plates in the reservoir. The bottom plate is **fixed** with the lid facing the ramp. Aluminium sheets are wrapped around this fixed bottom plate as a boundary of the centrifuge feeder. The only rotating part is the top acrylic plate, which are manufactured with specific slots to fit specific fasteners. The DC motor and these acrylic plates are glued together with an intermediate shaft (see Fig XX). As the DC motor rotates, fasteners randomly ordered in the centrifuge feeder would fall into the specific slots. When the slot pass over the opening lid at the bottom plate, they would fall out from the feeder and into the ramps.

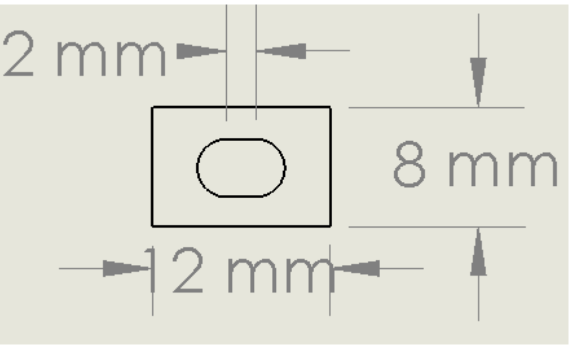


Figure 22 Engineering Drawing of the motor shaft. The thickness of the shaft is 2mm.

9.2.3.2 Ramp System and Remaining Reservoirs

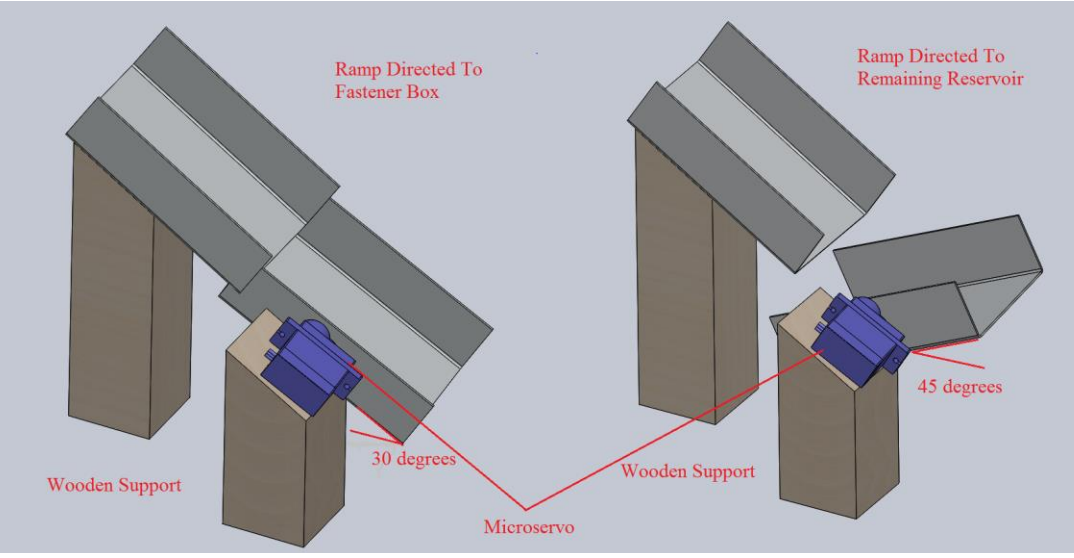


Figure 23 Side view of the ramp systems. The top ramp is stationary and sits directly below the exit of the fastener centrifuge exit. The lower ramp is controlled by a micro servo, which determines whether the fastener goes to the remaining reservoir or the funnel

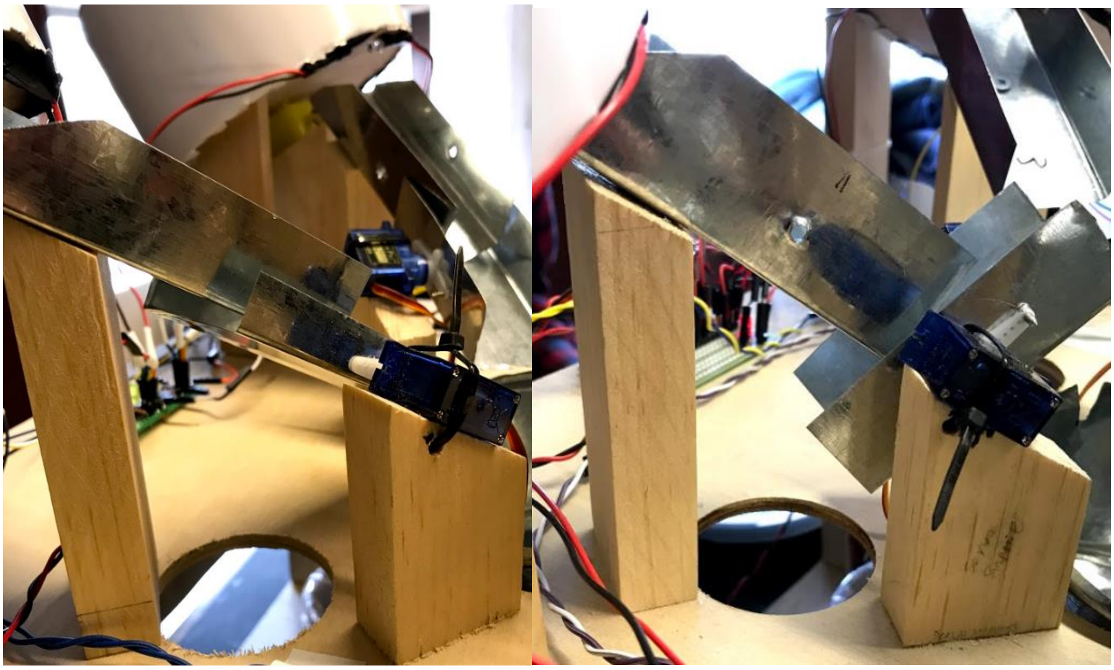


Figure 24 Ramp system on the machine, corresponding to the CAD drawing above

The goal of the ramp system is to **ensure fasteners exiting the feeder could be directed to the box or the remaining reservoir smoothly and quickly.** Each fastener has two ramp, a stationary top one and a rotational bottom one. The ramps are manufactured with thin aluminium sheets. The width of each sheet is different based on the size of the fastener. For example, the ramp for washer is designed to be wider than the ramp for nuts.

The micro servo is mounted to the wooden support using a zip tie. The rotating rap is then connected to the servo with screws.

Figure 25 Funnel (directed to the opened fastener box) and Remaining Reservoir. Note that the open compartment is located directly below the exit of the funnel. Also note that there is a rubber band which tighten the plastic wrapper

The funnel serves as a connection between all four lower ramps and the compartment box. The opening end of the funnel connects with all four lower ramps, while the exit end of the funnel are shaped to a shell with an approximately 30 degrees angle. Since each opening angle of a compartment is 45 degrees, a smaller funnel exit will ensure fasteners correctly fall in the opened compartment.

The remaining reservoirs are made of two components: The circular PVC provides a rigid frame of the reservoir, while the plastic wrapper makes fasteners easily retrievable. User could easily loosen the rubber band and pick up a bag of remaining fasteners when the operation ends.

9.2.3.3 Motor Selection and Mounting

Table 17 Comparison of the common three types of motor

DC motors	Servo Motor	Stepper Motor
➔ DC motors are good for continuous rotations for a long time ➔ Reasons: ➔ DC motors can provide both high torque and high speed ➔ DC motors can be controlled by PWM, meaning they can have a range of speed	➔ Positional servo motors are good for providing accurate angle. ➔ Continuous servo motors are good for accurate speed control. ➔ Reasons: ➔ Servo Motors has an internal feedback system to control its angular position.	➔ Stepper Motors are good for accurate small steps of rotations ➔ Reasons: ➔ Stepper Motor costs less compared to servo motor because of their open-loop control ➔ Stepper Motor needs external control systems (rotary

➔ The direction of rotation can be controlled by inverting the ground and power terminals. ➔ However, DC motors the capability of DC motor largely depends on its size. Small sized DC motor usually provides either high RPM with low torque or high torque with low RPM.	➔ For a continuous servo, the PWM determines the speed of rotations. ➔ For a positional servo, the PWM determines the angular position of the machine. ➔ However, for a positional servo, there are usually a limited range of angular position. (Typically 90-180 degrees) ➔ Servo motors that could provide high torque/RPM tend be very expensive	encoder) to achieve the required rotation. ➔ However, stepper motor requires significant amount of resources from circuits (4 + pin in total) and microcontroller. ➔ When continuously rotating, stepper motor could also generate a lot of heat because it needs to be constantly “small stepping” and would draw too much current.

DC motors(TGP01S-A130) are selected for powering the rotation of the centrifuge feeder while positional servo motors (SG90) are chosen to switch the angle of the ramp. One of the most important selection criteria here is cost, since each feeder requires two motors (so eight motors in total!) The centrifuge feeder is designed to be rotating continuously at nearly constant velocity, especially when there are large number of fasteners (high load) in the feeder. DC motor easily satisfy these constraints, and their cost are relative cheap. The ramp angle need to be precisely controlled, and only need to be rotated once (when starting to dispense remaining fasteners) during the entire operation of the machine. Therefore, micro servo is a really sensible choice due to its small size and cheap cost.

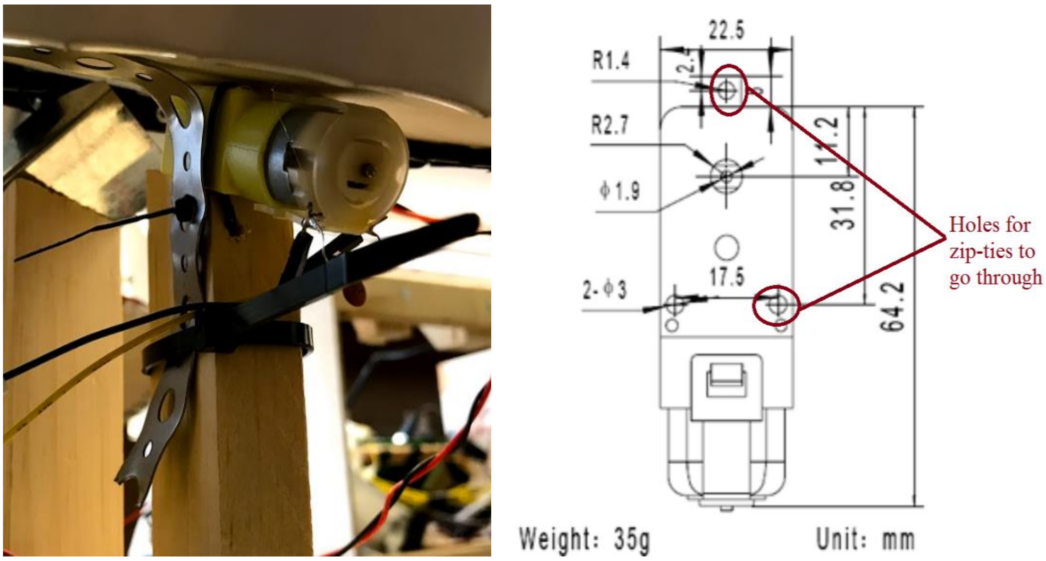


Figure 26 Motor mounting mechanism of the DC motor (left: actual picture; right: diagram).

DC motors are mounted to the vertical support plate with two zip-ties. For examples, zip ties are wrapped around the motor from the holes near the back end of the motor and the drilled hole in the vertical wooden support.

Servo motors are also mounted to its vertical support in a similar way. However, SG-78 micro servo motors do not have holes on its body for zip ties to go through. Therefore, zip-ties directly wrap around the motor and go through the holes in the vertical support to fix the servo motor in place. (see Fig. XX)

9.2.3.4 Counting Sensor Mounting

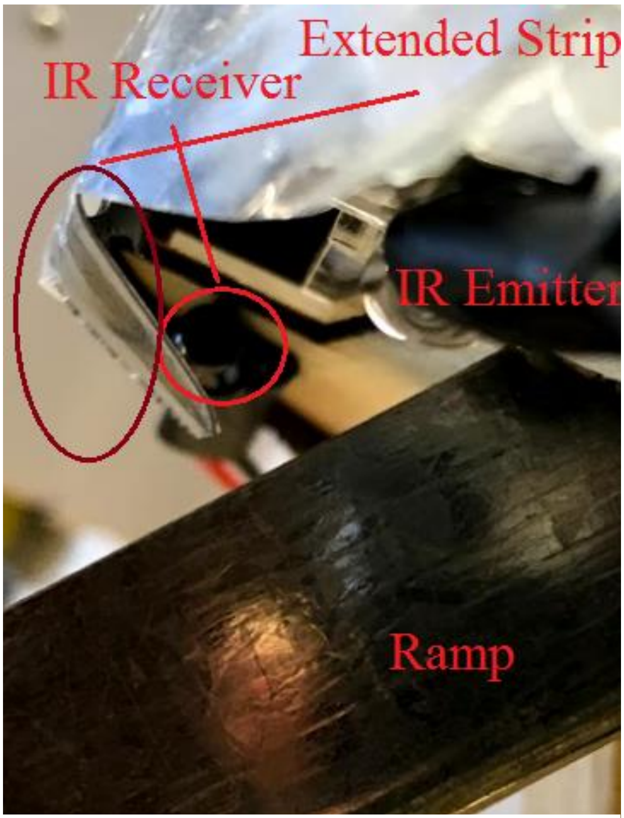


Figure 27 Photos showing the exit of the feeder and the IR sensors for counting the number of dispensed bolts. Note that the extended striped are designed to alter the trajectory of a bolt to make sure that the IR sensor can detect the dispended bolts

The IR sensor works by detecting the signal voltages of the IR receiver. If the light beam from the IR emitter is blocked by an external object, the IR receiver would not receive a signal, thereby lowering the output voltage. Therefore, the IR sensors are mounted directly below the exit of the ramp to make sure the trajectory of the fastener intercepts with the IR radiation trajectory.

9.2.4 Breakdown of Fastener Box Rotation Mechanism

The goal of this mechanism is to reliably open, close, and snap the fastener box. It should also be able to rotate any specific compartment to the designated loading spot.

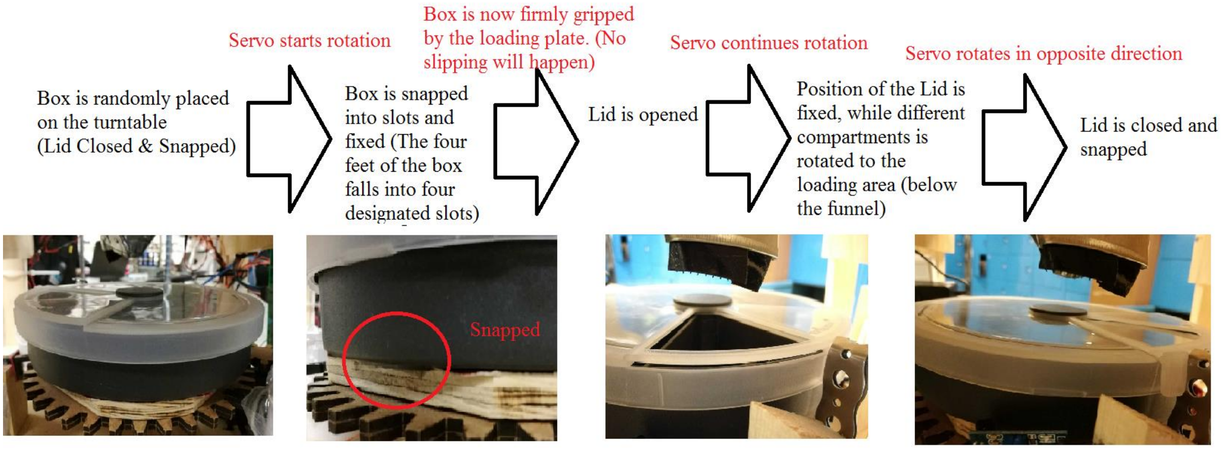


Figure 28 Procedures of the box opening mechanism with illustrations.

9.2.4.1 Lazy Susan Turntable

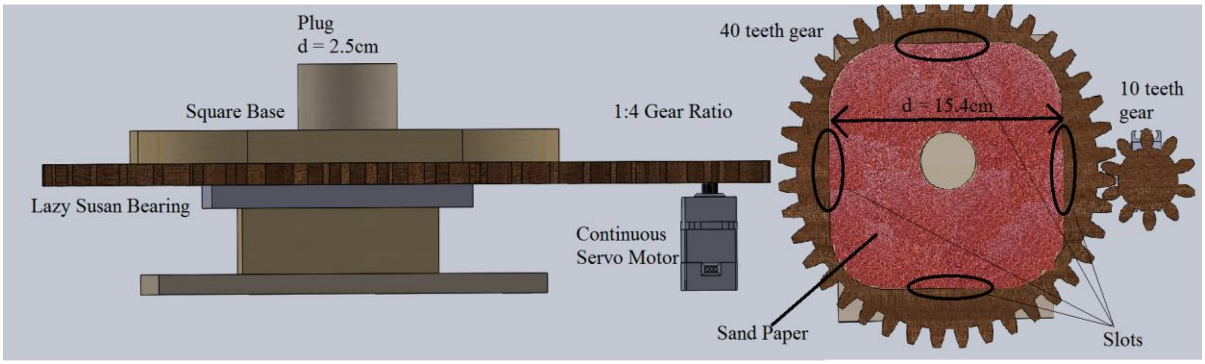


Figure 29 CAD drawing of the lazy Susan turntable with important dimension labelled. Note that the square plug is to fix the centre of the compartment box. The slots are designed to fit the feet of the box so that the box would be "locked in place". The sandpaper is used to increase the friction between the box and the square base.

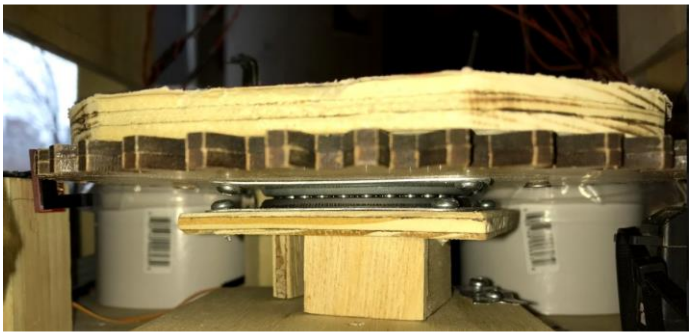


Figure 30 Photograph of the lazysusan turntable

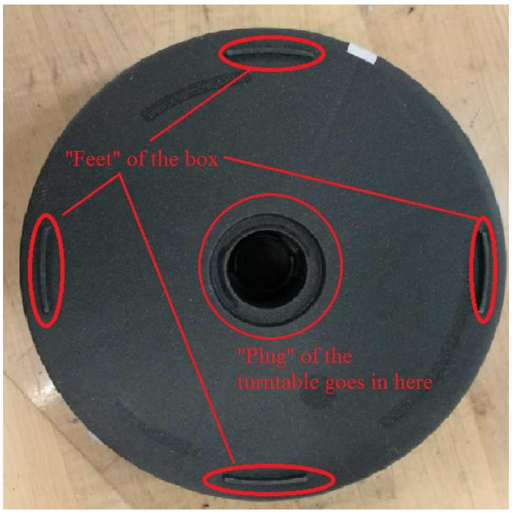


Figure 31 The bottom view of the box with illustrations. Note that the "feet" of the box is designed to fit the slots in the lazy susan turntable.

The lazy susan turntable is made of three main components. The plug marks the centre of rotation, and make sure that the box will be placed in a symmetric position. The square base of the (with four slots) are the designated loading position for the fastener box. **One of the biggest challenge for this mechanism is to ensure that the box is not "slipping" during rotation.** If the box slipped, the microcontroller program will lose track of the angular position of the box.

When a fastener box is placed on the machine, it is in arbitrary position. Then, the lazy susan turntable would rotate so that the feet of the box fall into their designated slots on the machine, "gripping" the fastener box as shown in Fig. XX. The increased friction and contact area between the box and the turntable allows more torqued to be transferred to the bottom of the box. Finally, the machine can rotate the box to any desired compartment while making sure the lid is still open.

9.2.4.2 Motor Selection and Mounting

SM-S4306R continuous servo motor is chosen for opening the fastener box because it provides sufficient torque and accurate speed control. The Table. XX in the section 9.2.3.3 still serves as a guideline here. Stepper motor is not used because it requires too much pin resources and circuit elements, which make things harder to debug. DC motors are not capable of stopping accurately, making them a poor choice in this scenario.

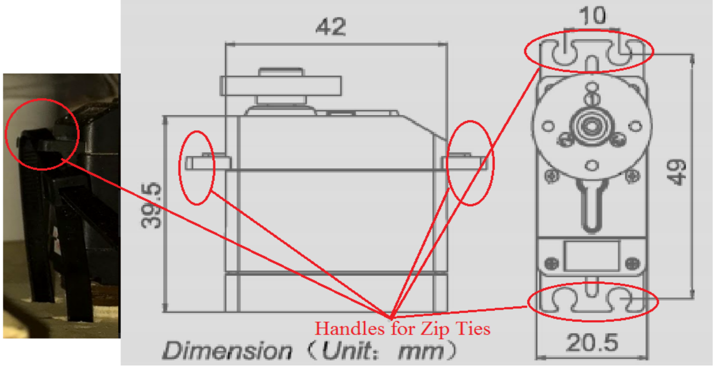


Figure 32 Motor mounting mechanisms using zip ties

Similar to the mechanisms for mounting DC motors, zip ties are used to fix the position of the motor, stopping any undesired movements during operations. One significant advantage of using **zip ties** is that they are **easily removable**, which turns out to be very advantageous during the integration phase if small modifications need to be made.

9.2.4.3 Lid Opening and Closing

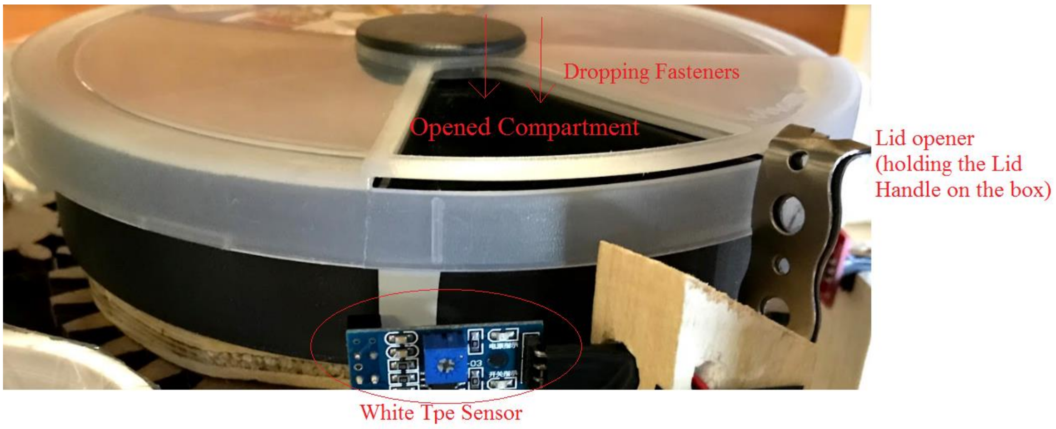


Figure 33 Illustration of the Lid opener and the white tape sensor. The bent-over part of the lid opener ensures the height of the fastener box to be kept low and reduces the chance of slipping.

The lid opener is made of a simple double layer steel strip. There are two layers of aluminium strips to increase the strength of the opener. When the box is rotated clockwise, its lid would naturally hit the lid opener. As the turntables keeps rotating, the lid will be opened gradually. Similarly, when the box (turntable) is rotated counter-clockwise, the lid will be closed gradually when it hit the lid opener.

9.2.4.4 White Tape Detection Sensor Mounting

The white tape detector is located at which the white tape (compartment 1) would be exactly opened and placed under the loading location (below the funnel). Hence, the white tape sensor shares the same vertical support with the lid opener. The white tape sensor is plugged into a hole in the vertical support, which both fix its location and allows the wires to pass through easily.

9.2.4.5 IR Interrupter Mounting

Figure 34 IR Interrupter mounting. This sensor is used for counting the angular position of the turntable. Similar to white tape sensor, the break beam sensor is inserted tightly into a slot of the vertical support.

9.2.5 Other Components Mounting

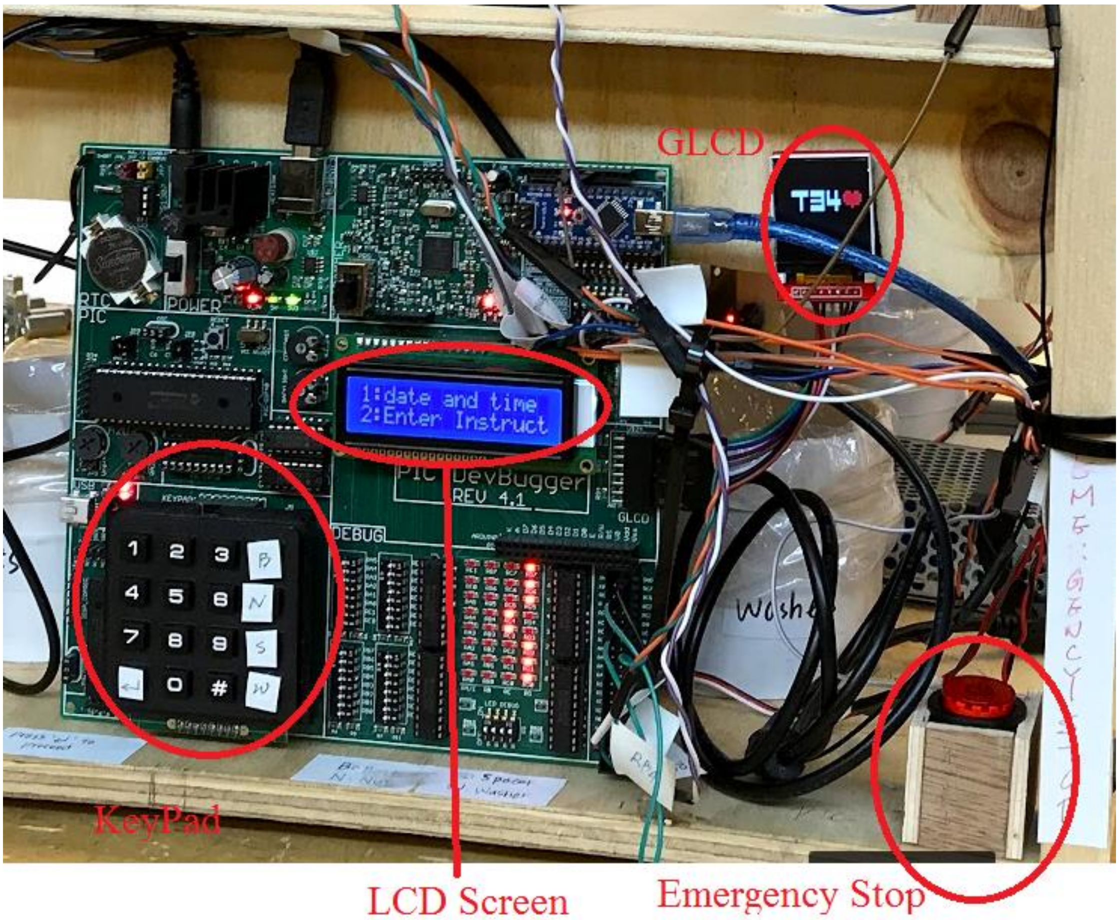


Figure 35 User operation interface. Note that all the user I/O are located on the same side of the machine, making a concise user interface

The PIC board of the machine is conveniently support by the frame of the machine directly. The emergency stop of the machine is placed into a customized 5-sided box and is glued to the main frame. The LCD screen and keypad are left on the PIC DevBugger board.

9.3 Design Rationale

9.3.1 Supporting Calculation

9.3.1.1 Torque and Gear Ratio Calculation

A. **DC motor rotating the fastener box:**

$Area\ of\ the\ rotating\ plate = \pi r^2 = 3.14 * 7.35cm * 7.35cm = 0.06596\ m^2$

$Mass\ the\ rotating\ plate = dentity * area * thickness = 1.18 \frac{g}{cm^3} * 0.06596\ m^2 * 0.002m$

$= 0.156\ kg$

$The\ moment\ of\ area\ of\ the\ rotating\ plate = \frac{1}{2} mr^2 = 0.156kg * 0.0735^2 m^2$

$= 8.43 * 10^{-4} kg * m^2$

$The\ moment\ of\ area\ of\ the\ fasteners\ in\ the\ feeder = \frac{1}{2} mr^2$

$= \frac{1}{2} * 20\ fasteers * 10g * 0.07^2 m^2 = 4.9 * 10^{-4} kg * m^2$

$The\ total\ moment\ of\ area = 13.33 * 10^{-4} kg * m^2$

$Time\ to\ accelerate = 1s$

$angular\ acceleration = \frac{40rpm}{1s} = 4.188\ rad/s^2$

$The\ total\ required\ torque\ of\ the\ DC\ motor\ is = \tau = moment\ of\ inertia * acceleration$

$= 5.58 * 10^{-3} N * m$

$Torque\ provided\ by\ the\ TGP01S - A130\ datasheet = \mathbf{0.066\ N * m > 0.0058\ N.m}$

$Selected\ DC\ motor\ should\ provide\ enough\ torque.$

B. Servo motor rotating the lower ramp

$Area\ of\ the\ flat\ ramp = 10cm * 6.5cm = 65cm^2$

$Mass\ of\ the\ flat\ ramp = area * density * thickness = 65cm * 2.7g/cm^2 * 0.1cm = 17.55g$

$Moment\ of\ Inertia\ of\ a\ lever = \frac{mL^2}{12} = 10^2 cm^2 * \frac{17.55g}{12} = 1.4625 * 10^{-5} kg * m^2$

$Time\ to\ accelerate = 0.2s$

$Acceleration = \frac{60deg}{0.5s+0.2s} = 10.5\ rad/s^2$

$Total\ Required\ Torque = Moment\ of\ Inertia * Angular\ Accelerlation = 1.54 * 10^{-4} N * m$

$Torque\ of\ a\ microservo = 1.8\ \mathrm{kg * cm} = 0.177\ \mathrm{N * m} > 1.54 * 10^{-4}\ N * m$

C. Continuous servo motor rotating the turntable

$$Required\ Torque\ for\ opening\ a\ snapped\ lid\ from\ experimentation = 0.99\ N * m$$

$$\frac{Torque}{Gear\ Teeth} = \frac{1N*m}{40\ teeth} = \frac{Required\ Torque\ Supplied\ by\ the\ servo}{10\ teeth}$$

$$Required\ Torque\ of\ the\ servo = 0.25\ N * m < 0.32361945\ N * m = 3.3\ kg * cm$$

$$= Supplied\ Torque\ of\ SMS4303R$$

9.3.2 Experiment(s)

9.3.2.1 Required Torque Determination

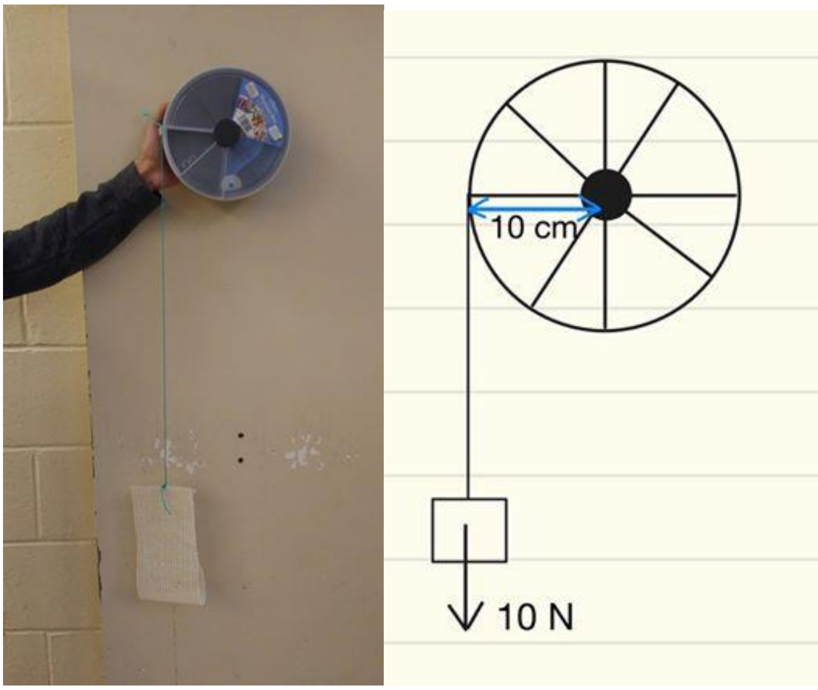


Figure 36 Experiment to determine the required torque for opening the lid

One of the convenient and accurate ways to measure the required torque is to perform an experiment. By increasingly adding more weight to hanged by the lid, we were able to determine that the minimum required torque to open the lid is:

$$Required\ Torque\ for\ opening\ a\ snapped\ lid = weight\ added * g * moment\ arm$$

$$= 1kg * 9.8 * 10.1cm = 0.99\ N * m$$

9.4 Weight Budget

Table 18 Weight budgets. Note that the weight of some components are approximated to the near ten or hundred gram

Item	Unit Weight	Quantity	Total Weight

Frame: 2kg			
Base (Birch Wood)	800g	1	0.8kg
Vertical Support	125g	4	0.5kg
Top layer (Plywood)	500g	1	0.5kg
Beam	100g	2	0.2kg
Feeding Mechanism: 1.55kg			
DC motor	50g	4	0.2kg
Servo motor	9g	4	0.036kg
Aluminum Sheet	20g	4	0.08kg
Plastic Reservoir	15g	4	0.06kg
Non-rotational plate	50g	4	0.20kg
Acrylic rotating plate	30g	4	0.12kg
Wooden motor vertical support	50g	4	0.20kg
Wooden ramp vertical support	40g	4	0.16kg
Wooden servo vertical support	30g	4	0.12kg
Ramps	15g	4	0.06kg
Funnel	38g	1	0.038kg
IR counting sensor	7g	4	0.028g
Box Rotation Mechanism: 1.50kg			

Lazy Susan Bearing	250g	1	0.25kg
40 teeth gear	200g	1	0.20kg
10 teeth gear	40g	1	0.04kg
Continuous rotation motor	44g	1	0.044kg
Wooden support of the bearing	230g	1	0.23kg
Wooden vertical support of color sensors	55g	1	0.055kg
Wooden vertical support of IR interrupter sensor	45g	1	0.045kg
IR interrupter sensor	5g	1	0.005g
Color sensor	5g	1	0.005kg
Lid Opener	10g	1	0.01kg
Sand Paper	30g	1	0.03kg
Turntable with plug	140g	1	0.14kg
Others: 1.42kg			
PIC DevBugger board	300g	1	0.3kg
Power Supply	500g	1	0.5kg
Power Cord	100g	1	0.1kg
KeyPad	20g	1	0.02kg

GLCD screen	10g	1	10g
Emergency Stop	8g	1	8g
Arduino Nano	7g	1	7g
LCD screen	12g	1	12g
Protoboard	12g	4	0.048kg
Screws	6g	52	0.312kg
Wires	0.7g/wire	150 wire	0.105kg

Total weight: 6.48kg

9.5 Suggestion for Improvements

9.5.1 More Powerful Lazy Susan Turntable

The current lazy susan turntable suffers from slipping issue significantly during our integration process. However, many accessories were used to provide temporary fix to the machine. (i.e. sandpaper, slits). The turntable should provide stronger and steadier grip to the fastener box, allowing more accurate control of the angular position and faster rotation

9.5.2 More Accurate Ramp Delivery

The ramp delivery currently relies on extensive tuning of the microcontroller subsystem due to poor construction qualities. When the fasteners were dispensed with a high momentum, it would deform the angle of the ramp. Although the servo motor is very reliable, this could potentially damage the motor because the lower ramp is only supported by the micro servo motor. It would be more ideal to have a closed tube to ensure that remaining fasteners do not fall all over the machine.

9.5.3 More Flexible and Efficient Centrifuge Feeder

Current, the speed of the centrifuge feeder of the machine needs to be tuned extensively to ensure that there is no jamming when the motor is exiting the machine. Specifically, the microcontroller has to send a step signal, a higher signal(PWM) in the beginning to generate more the initial torque in the beginning to overcome the static friction. One possible improvement on the electromechanical subsystem could be to build a smoother exit trajectory on the centrifuge feeder of the machine instead of a step function design. It would also be nice if a weight sensor could be added to the reservoir so that the motor speed could be smartly adjusted to avoid jamming.

10. Circuits and Sensors Subsystem

10.1 Circuit Subsystem Problem Assessment

The circuit subsystem is the interfacing part between the electromechanical and the microcontroller subsystems. To connect the sensors, actuators to the microcontroller board and to ensure proper power supply and distribution, the circuit design and construction is essential for all the digital and analog interfacing electrical parts of the machine. The responsibilities of the circuit member of the team is outlined as following:

1. **Provide a constant and proper power supply distributed to all the electrical components**

The circuit subsystem will handle power distribution to all the electrical components. The main power source in the machine comes from a 36W AC->DC adapter which can output both DC +5V and +12V. The actuators and sensors in the design will be using DC and only the +5V throughout the machine. The PIC microcontroller board along with the Arduino nano board mounted onto it will be plugged in the same power bar with the AC->DC adapter. The power bar will the plugged directly into a 120V 60Hz AC wall outlet as per constraint.

2. **Provide an easily-accessible emergency stop to cut the power to all mechanically moving parts and all electrical components immediately**

The machine must have an emergency stop button as per Electrical Standard for Industrial Machinery illustrated in US National Fire Protection Association NFPA 79. The team used US standard because Ontario, Canada started to adopt US NFPA regulations since 2014 [3, 4]. This mechanism ensures that a single human operator is able to cut off the all the power sent to the actuators, sensors and all mechanically moving parts in a case of emergency. This button must be made easily accessible and obviously visible to the operator such that any personnel is able to initiate it to prevent hazards.

3. **Design the Circuitry that can communicate and transfer signals between sensors, actuators and microcontrollers**

Various sensors are required in detection mechanism, counting mechanism, as well as monitoring the motion of the machine. Different types of actuators were engaged in dispensing mechanism and rotation mechanism as well. The circuitry must be able to transmit the input/output signals between various circuit modules and microcontrollers with instant response in a fashion of agility and robustness. The circuit subsystem member has the responsibility to properly select, design and build these circuits to achieve the aforementioned functionalities with an effort in meeting power requirement and eliminating signal noises.

10.2 Design Solution and Supporting Calculation

In this section, all the circuit design components will be discussed and explained, with both circuit schematics and real circuitry built on the machine prototype. The rationale behind each design as well as their supporting calculations and test results will also be shown as a proof of design attainment and design quality. Please be advised that the circuitry went through iterative design process from design proposal to this final design report, with improvements made in stability and reliability.

10.2.1 Main Connections and Power Distribution

The main connection and pin assignment are shown below in Fig. xx. The power distribution board provides +5V output from the power supply to all the sensors (IR-Breakbeam sensors, IR-Reflective sensor, IR-Interrupter Sensor), actuators (Micro-servos, Continuous Servo, DC Motors and DC Motor Driver Board); also, common ground to all parts including the microcontrollers (PIC and Arduino Nano). The power supply used in the design can provide up to 36 Walts. The detailed power requirement of each electrical components will be discussed and supported with calculations in the sections below.

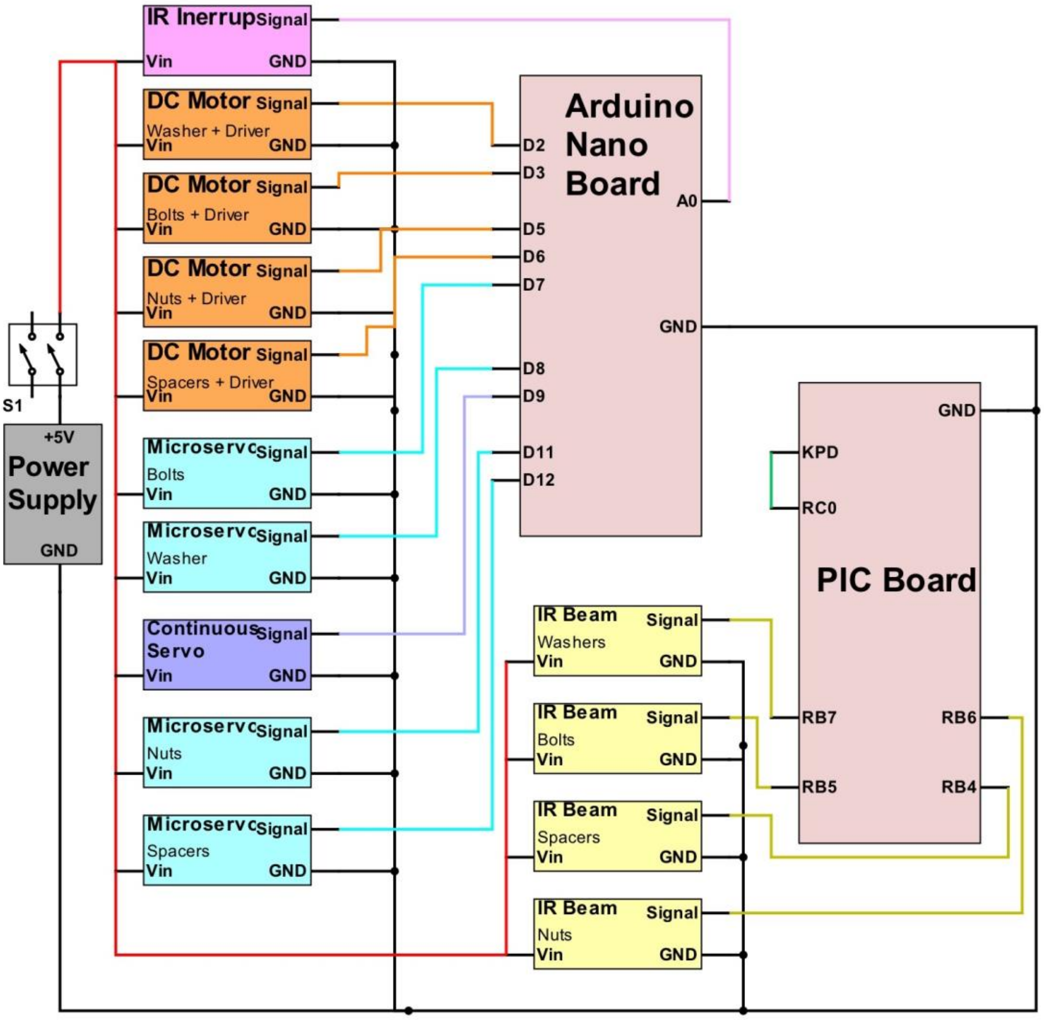


Figure 37 Main Connection Board with PIN assigned by microcontrollers

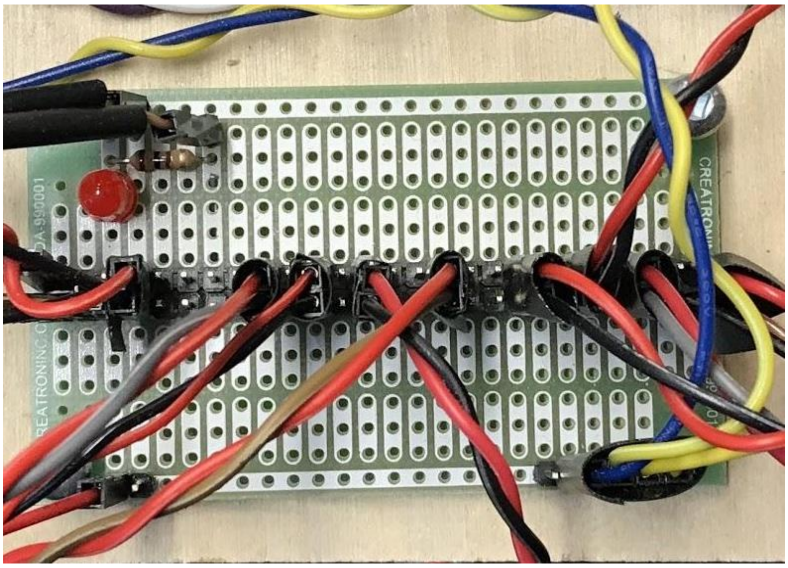


Figure 38 Main Power Distribution Board (Actual)

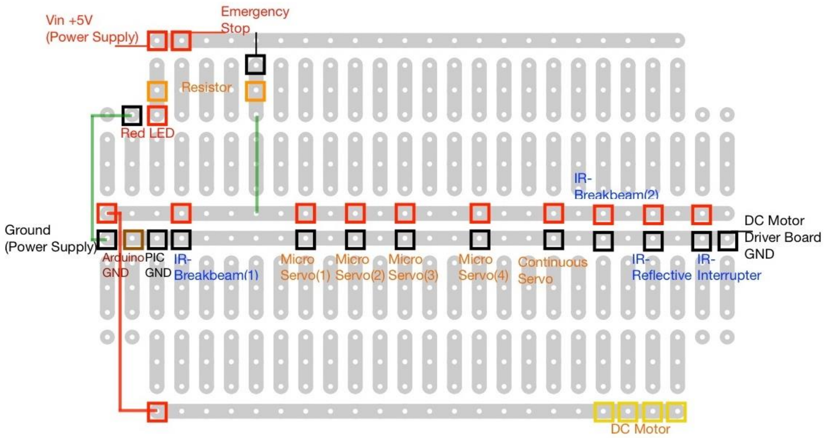


Figure 39 Main Power Distribution Board (Schematic)

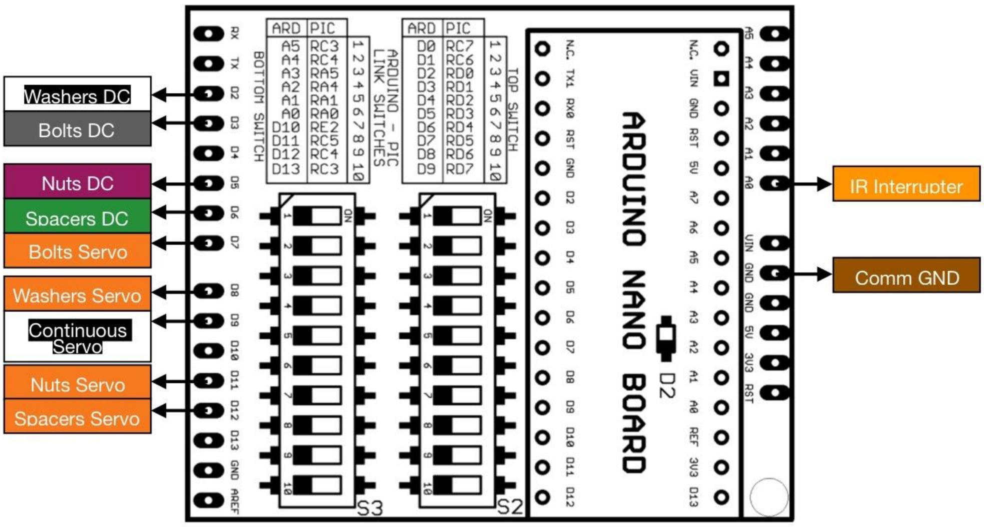


Figure 40 Arduino PIN Assignment

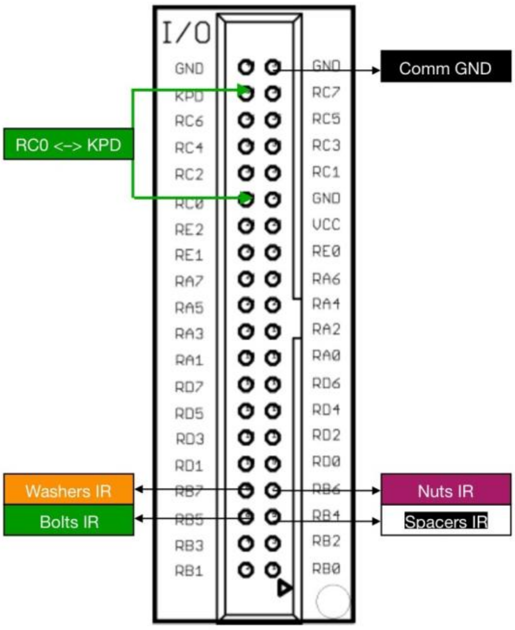


Figure 41 PIC Board PIN Assignment

10.2.2 Emergency Stop

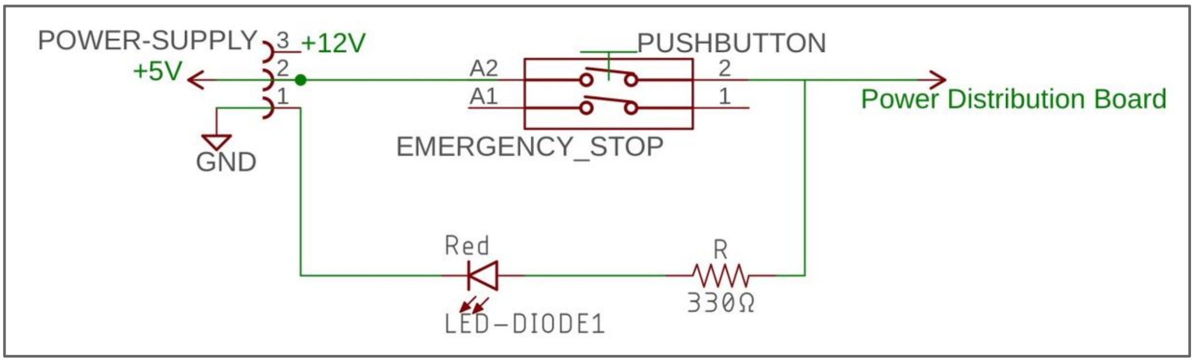


Figure 42 Emergency Stop Section Circuit Schematic

As shown in Fig. xx above, the emergency stop button is connected to the power distribution board which transmits power to all the electrical parts. Once the pushbutton is pressed down, it connects the main power distribution board to the +5V terminal of the power supply. There is also a red LED light acting as an indicator to show the user/operator that the power is ON. Vice versa, when the pushbutton is in “unpressed” mode, there is no power provided to all electrical parts and thus it deactivates all the mechanically moving components. This emergency stop button design strictly follows NFPA 79 standard; red coloured with yellow enclosure and this red/yellow colour combination is reserved exclusively for this emergency stop setup [3, NFPA].

According to the data sheet, the power calculation process is shown below

Power Calculation:
Known from Data Sheet:

1. Power Supply output voltage, $V_s = 5V$
2. 10mm Red LED has forward voltage, $V_f = 1.8V$ and current, $I = 10mA$
3. Resistor $R = 330\Omega$

Calculation:

$$\because V_f = 1.8V, V_s = 5V = V_f + V_R, \textit{where } V_R \textit{ is the voltage across the Resistor}$$

$$\therefore V_R = 5V - 1.8V = 3.2V, I_R = \frac{V_R}{R} = \frac{3.2V}{330\Omega} = 9.70mA, \textit{which is close to } 10mA \textit{ as stated}$$

$$P_R = \frac{V_R^2}{R} = \frac{(3.2V)^2}{330\Omega} = 0.031W, P_{LED} = V_f \cdot I_{LED} = V_f \cdot I_R = 1.8V \cdot 9.70mA = 0.017W$$

$$P = P_R + P_{LED} = 0.031W + 0.017W = 0.048W$$

Therefore, when the machine is powered ON, the emergency stop section needs about 0.05W of power.

10.2.3 IR-Breakbeam Sensor

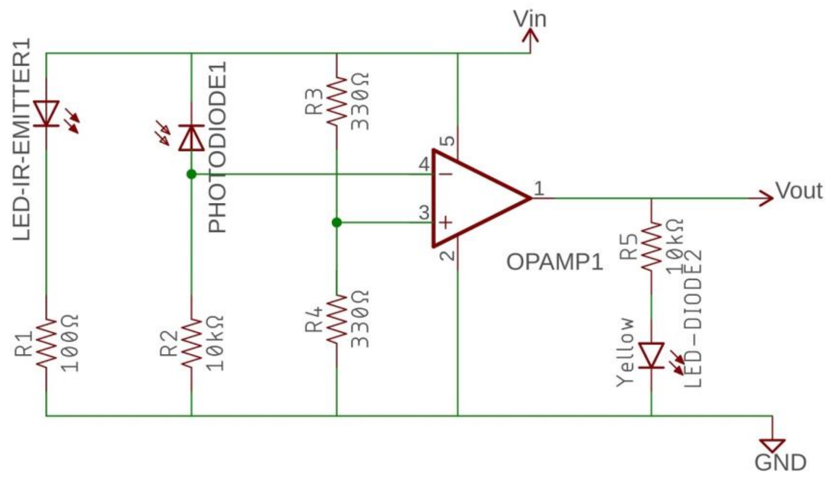


Figure 43 IR-Breakbeam Sensor Schematic

The circuit schematics of a single IR-Breakbeam sensor is shown in Fig. xx. On the left hand side of the circuit is an IR photodiode pair, consisting of one IR-emitter and one IR photodiode, forming a beam-through mechanism to detect anything passing through them. The LM-358 OpAmp used in this circuit serves as a voltage comparator; when the non-inverting (positive) input of it is less than the inverting (negative) input, $V_+ < V_-$, the output will be a digital LOW (close to 0V); when the positive input is greater, it will output a digital HIGH (close to Vin). As shown in the schematics, the Vin is +5V from the power distribution board, two same resistors act as a voltage divider such that the positive input of the OpAmp is about half of Vin, $V_+ = 2.5V$. The OpAmp will also amplify the signal output V_- of the IR photodiode such that when there is nothing being between the IR pair,$V_- > V_+$, and accordingly, the OpAmp outputs $0.01V$; however, when the IR beam gets obstructed, which in this design, by a fastener dispensed, the IR photodiode creates an open circuit, resulting in $V_- < V_+$, and thus the output of the OpAmp is about 3.86 V. With this output, the yellow LED is ON indicating one fastener dispensed and passing through while the PIC board is able to detect this HIGH signal as a peek. The circuitry is shown below as Fig. xx.

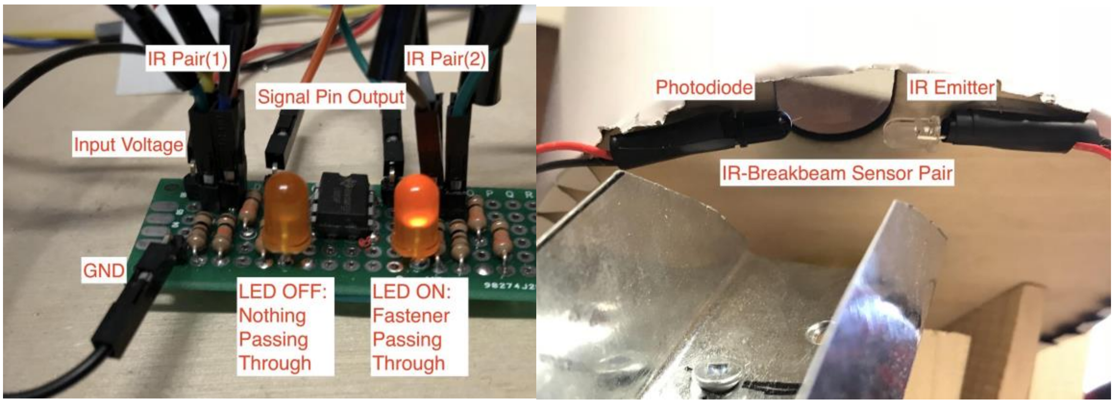


Figure 44 Actual Circuit Mounted on the Machine (left: circuit board; right: IR Sensor Pair)

The calculation below shows that the maximum power requirement for two IR-Breakbeam sensors sharing one Dual OpAmp chip is around 1.396 W. In total, two of this set are used and implemented in the machine, which corresponds to 2.792 W for all IR-Breakbeam sensor circuits.

Power Calculation:

Known:

1. The voltage input is $V_{in} = 5V$
2. The absolute maximum power dissipation of the IR Emitter (LTE-5208) is 150 mW stated in Data Sheet; of the Photodiode (LTR-3208) is 100 mW
3. The maximum power dissipation of the dual OpAmp chip is 830mW
4. 10mm Orange LED has forward voltage, $V_f = 1.8V$ and current, $I = 10mA$

Calculation:

$$V_{in} = 5V = V_f + V_{R1}, where\ V_{R1}\ is\ the\ voltage\ across\ the\ Resistor\ R1$$

$$V_{R1} = 4.8V, as\ tested$$

$$P_{R1} = \frac{V_{R1}^2}{R_1} = \frac{(4.8V)^2}{100\Omega} = 0.230W, P_{IR\ Emitter(\max)} = 0.150W, as\ stated$$

$$P_{1(upper\ bound)} = P_{R1} + P_{IR(max)} = 0.230W + 0.150W = 0.38W$$

$$V_{R2} = 3.8V, as\ tested$$

$$P_R = \frac{V_R^2}{R} = \frac{(3.8V)^2}{10k\Omega} = 0.001W, P_{Photodiode(\max)} = 0.100W, as\ stated$$

$$P_{2(upper\ bound)} = P_R + P_{photodiode(max)} = 0.001W + 0.100W \approx 0.1W$$

$$P_{OpAmp} = 830mW \times \frac{1}{2} = 0.415W, as\ stated\ (830mW\ is\ the\ total\ for\ two\ OpAmp's)$$

$$P_{R3} = P_{R4} = \frac{(2.5V)^2}{330\Omega} = 0.019W, P_{R3+R4} = 2 \times 0.019W = 0.038W$$

$$P_{R5} + P_{LED}(upper\ bound) = 0.048W, as\ calculated\ before$$

$$P_{Total} = 0.38W + 0.1W + 0.415W + 0.038W + 0.048W \approx 0.98W$$

As a result, a total of four IR-Breakbeam sensors needs $4 \times 0.98W = 3.92\ W$. Please be advised that

10.2.4 IR-Reflective Sensor

IR-reflective sensor is used to detect the white electrical tape which indicates the position of the first compartment. An IR-reflective sensor consists of an IR Emitter and a phototransistor as a receiver and can be used to detect lightly coloured object effectively. When an object is approaching to the sensor, the light emitted bounces off the object surface and back into the phototransistor. Due to the nature of reflective, lightly colored objects, such as those with white surface reflect more IR while darker colored ones reflect much less. This creates a significant intensity differences that can be used as a threshold detection.

In our design, the white tape on the box indicates the location of the first compartment of the fastener box. It is essential for the microcontroller to immediately detect and locate this position. An integrated circuit that can 1) output digital signals, 2) adjust sensitivity, and 3) is also Arduino compatible is an ideal choice. Fig. xx below shows the IR-reflective sensor (IC) that used in the design and its circuit schematic is shown in Fig. xx. Fig. xx shows the sensor in working state when the white tape on the box is detected.

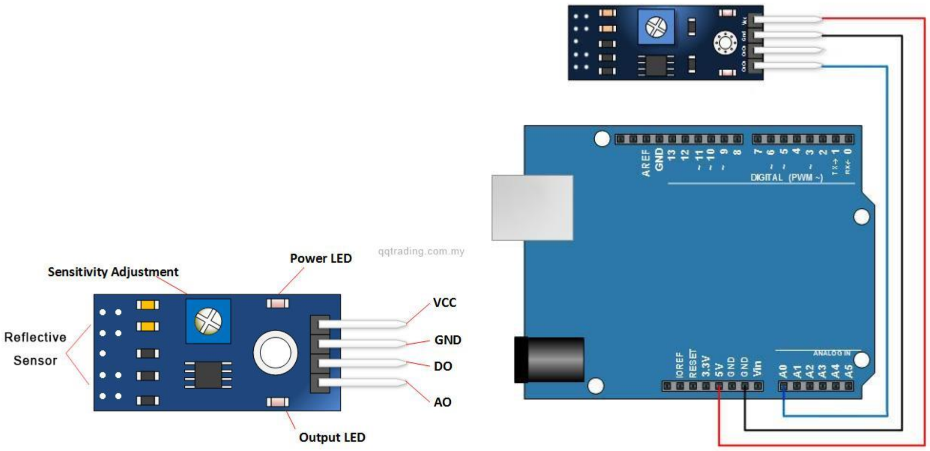
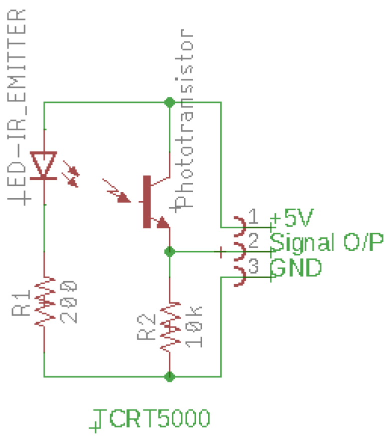


Figure 45 IR-Reflective Sensor Annotation and Arduino Connection



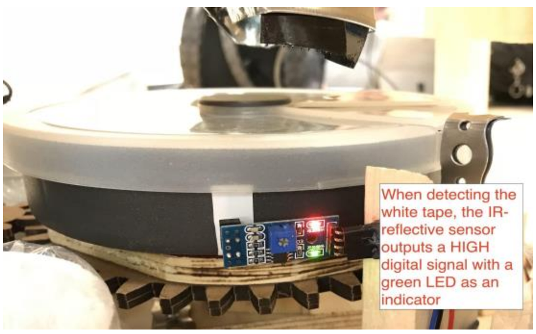


Figure 46 IR-Reflective Sensor Schematics

Figure 47 IR-Reflective Sensor Mounting

The power requirement of this IR-reflective sensor IC has an absolute maximum power dissipation of 200 mW = 0.2 W, as stated in its data sheet.

10.2.5 IR-Interrupter Sensor

The IR-Interrupter, shown in Fig. xx also known as photo-interrupter, is composed of an IR emitter on one upright and an IR detector on the other, forming a similar IR beam as the one discussed in Section x.x.x. This IR-Interrupter, different from the IR-Breakbeam sensor built, has a finite distance (slit width 1.8 mm) kept by a rigid frame. This advantage is perfectly used in counting the number of the Lazy Susan Turn Table gear keys to determine how much degree the gear plate rotates. In our design, an integrated circuit with this sensor mounted is used for its 1) reliable analog output and 2) Arduino compatibility. Whenever there is an object passing through, the sensor board outputs a lower analog value that is used for Arduino to detect this drop. The circuit schematic of this sensor is shown in Fig. xx and its power dissipation is stated below.

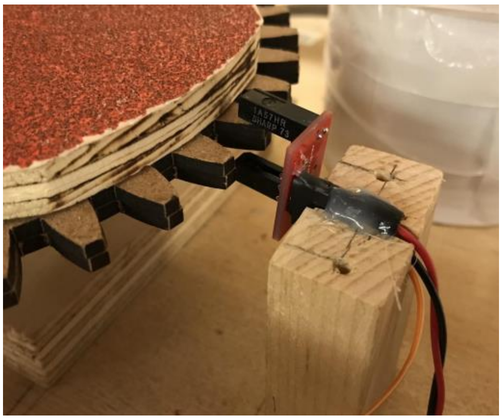


Figure 48 IR-Interrupter Sensor Mounting

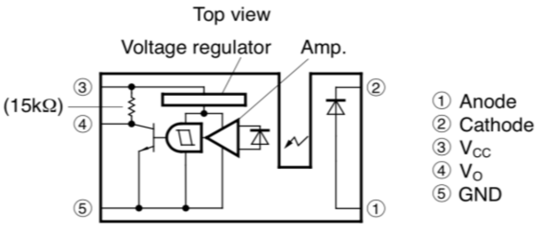


Figure 49 Schematics of the IR-Interrupter

The power requirement, stated as absolute maximum power dissipation in the data sheet, is 250 mW = 0.25 W.

10.2.6 DC Motor Circuit

The DC motors in the design are used to rotate the plate of the centrifuge feeders that contain fasteners. For each feeder, while the number of dispensed fasteners has not met the required amount, the plate keeps rotating to dispense more. In this design, the plate only needs to rotate in one direction, thus, a typical H-bridge four-transistor driver board is no longer needed. By modifying an H-bridge driver circuit, we will use one NPN transistor to take the input signal to control the start and brake of each motor. The status table of DC motor is shown in Fig. xx ("1" for logic HIGH and "0" for logic LOW, that sent by PIC).

Table 19 Motor Status Table

Input Signal	TIP142 Base	TIP142 State	Motor Status
1	1	1	Start
0	0	0	Brake

On each DC motor, a 0.1uF capacitor connected in parallel to suppress the noise generated by it. This noise, caused by the commutator brushes when the motor shaft rotates, creates fluctuation in the circuit that will result in significant signal interference with all the sensor circuits. Fig. xx shows the circuit schematics of one motor. Fig. xx shows the actual DC motor with a 0.1uF capacitor connected in parallel.

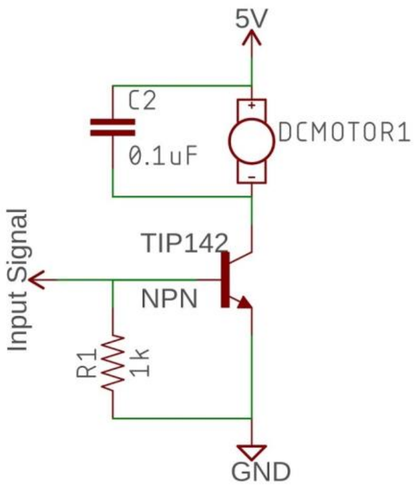


Figure XX: DC Motor Circuit

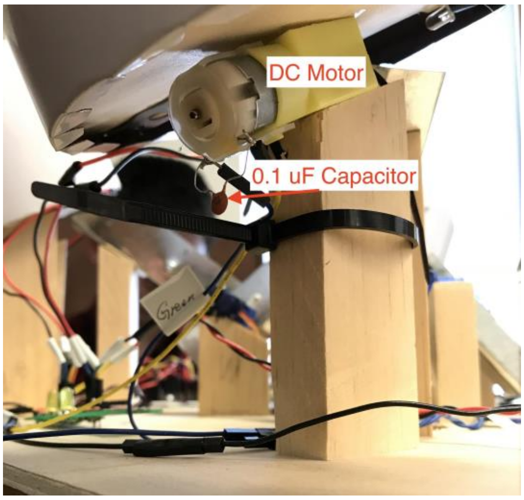


Figure XX: DC Motor on the Machine

Power Calculation:
Known:

1. DC Motor power at load is 0.6W

$$V_R = 1.2V, as\ tested$$

$$P_R = \frac{(1.2V)^2}{1k\Omega} = 0.001W$$

$$P_{Total} = P_R + P_{DC}(at\ load) \approx 0.6W$$

Since there are four centrifuge feeders are used in the design and each one is driven by a DC motor, four of the above circuits are needed. The real circuit of the DC motor driver board and its schematics are shown below in Fig. xx and Fig. xx.

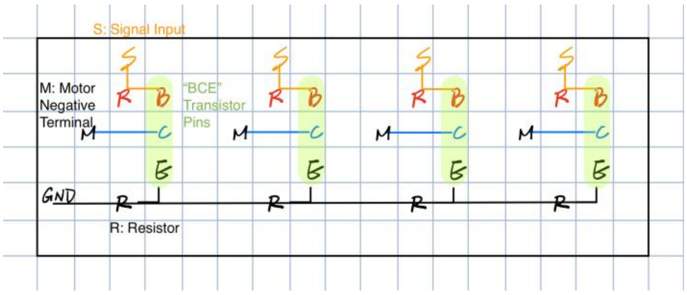


Figure 50 Motor Driver Board (Circuit)

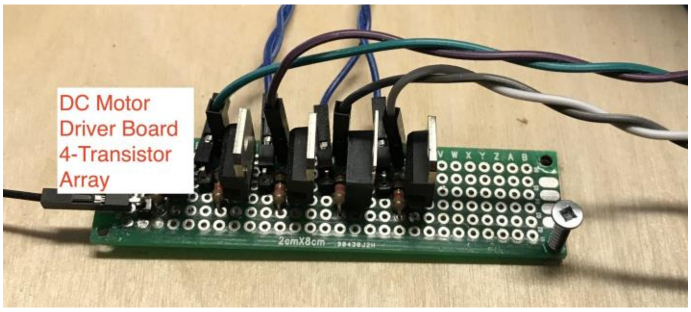
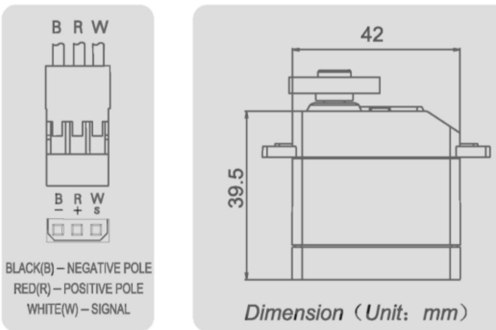


Figure 51 Motor Driver Board (Actual)

Therefore, the total power requirement of all four DC circuits is $4 \times 0.6W = 2.4W$.

10.2.6 Continuous Servo

A 360° continuous servo is used in the design to rotate a smaller gear that is complementary to a large gear (with 4:1 gear ratio) of the Lazy Susan Turn Table which supports and locks the fastener box. This continuous servo is also Arduino compatible and has one voltage input, GND, and one analog signal input to control its speed. Its drawing and circuit diagram is shown in Fig. xx and xx.



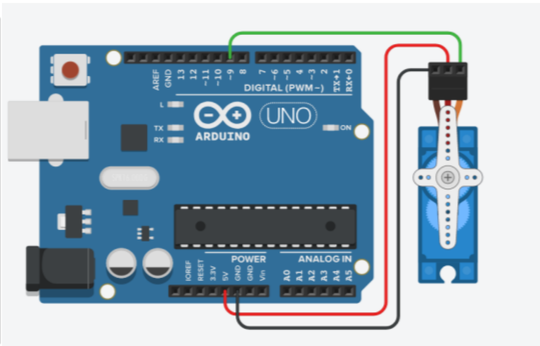


Figure 52 Continuous Servo

Figure 53 Continuous Servo with Arduino

As stated in the data sheet, the working voltage and its corresponding working current is 5V and 100 mA, making its power requirement be about 0.5 W.

10.2.7 Micro-Servo

The ramps on the top-layer of the machine, composed of 2 sections, are designed to be rotatable. The second section of the ramp decides whether the fasteners are to be dispensed into the central funnel (ultimately to the fastener box) or into the returning reservoir for recollection. A micro-servo is used to rotate the second section of the ramp to realize this function. A single micro-servo circuit is shown in Fig. xx, in which the micro-servo is connected to an Arduino board with its signal input to a PWM pin. In the Arduino PIN assignment Fig. xx. shown previously in Section x.x.x, the four micro-servos are all connected to the PWM pins such that the microcontroller member can program the Arduino board to control each one's rotational angle.
http://farhek.com/jd/p0l1860/schematic-component/p9n068/

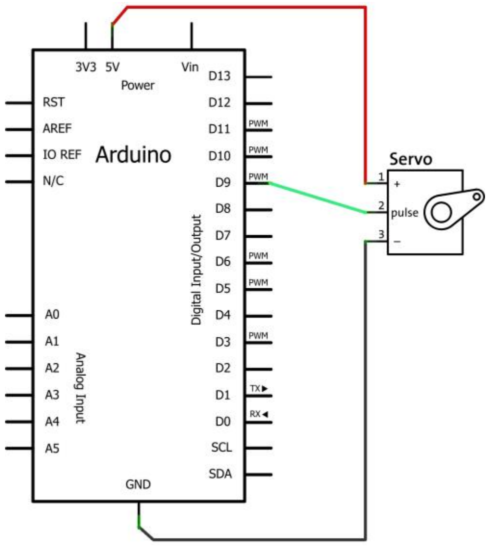


Figure 54 Micro-servo with Arduino

Power Calculation:

Known:

1. Micro-servo: Voltage 5V, Running Current 100 mA

Calculation:

$P_{m-servo} = 5V \times 0.100A = 0.50W$

In total, the power required by all the four micro-servos is around $4 \times 0.5\ W = 2\ W$.

10.3 Power Budget

In our design, the microcontrollers (PIC and Arduino) and the AC->DC power supply are connected separately to a power bar that connects to the wall outlet directly. Therefore, the microcontrollers power are not provided by the power supply on the machine. The power budget below summarizes the total power consumption of all the electrical components that powered by the Ac->DC power supply.

Table 20 Total Power Budget

Circuit Component	Power Consumption
Emergency Stop Section	0.05 W
IR-Breakbeam Sensors	3.92 W
IR-Reflective Sensor	0.20 W
IR-Interrupter Sensor	0.25 W
DC Motors	2.40 W

Continuous Servo	0.50 W
Micro-servos	2.00 W
Total Power Supply Requirement	**9.32 W**

From the above calculations, the power supply in the design has specifications of “5V 4A, 12V 1A, 32W” AC->DC. Please be advised that the current design only uses its primary output “5V 4A, 20W” since all the electrical components have 5V voltage input. This design provides sufficient power for the current design and leaves extra “12V 1A 12W” for potential future and further modifications or improvements.

10.4 Suggestion for Improvements

10.4.1 Connect All the Power to One Plug

The current design includes a power bar, to which the PIC microcontrollers board’s power cord and a 32 W AC->DC power supply both connect to. This would result in the increase in weight of one power bar and one PIC board power cord, increase in the cost of machine, as well as extra space being taken. Although the effect of the these drawbacks of separating power supply is insignificant to the current design, yet in terms of improvements, it is suggested that the PIC board can be powered by the aforementioned extra “12V 1A 12W” of the current power supply that has not been used.

10.4.1 Fit All the Individual Circuit Board into One Main Board

The current circle design is composed of multiple modular circuit units, which has significant advantages in this prototyping phase. This design decision enables the designer to easily modify and/or replace one unit without interfering the other parts. Despite the benefits it brings to the debugging and integrating process, it makes the whole circuitry less organized, and takes more space in the machine. Now that the circuitry has been proven to meet the requirements, it is suggested that the circuit subsystem designer can design and plan a new large circuit board that fits all of the circuit components, which can save space and make the machine look neat.

11. Microcontroller Subsystem

PIC18F4620 and Arduino nano are chosen as the microcontrollers to interface with various peripheral devices. The functionality of the microcontroller subsystem is elaborated in this section. The purpose of the microcontroller subsystem is to control DC motors, servo motors and various sensors to dispense fasteners into the correct compartments of the fastener box.

11.1 Microcontroller Subsystem Problem Assessment

11.1.1 Interfacing assessment

The microcontroller subsystem is responsible for hardware interfacing and user interfacing.

The user interface includes retrieving user instructions through keypad and display relevant information on the LCD screen. In addition, the current date and time and operation time can be retrieved and computed from RTC module and displayed on the LCD screen.

The hardware interface includes sending PWM signals to control 4 DC motors, 4 micro servos, and 1 continuous servo, and retrieving readings from 4 IR break-beam sensors, 1 IR interrupter sensor, and 1 IR reflective sensor.

Table 21 the user interface and hardware interface

User Interfacing	Hardware Interfacing	
	Output Devices	Input Devices
Keypad Interfacing	4 DC Motors Interfacing	4 IR break-beam Sensors Interfacing
LCD Screen Interfacing	4 Micro-servos Interfacing	1 IR interrupter Sensor Interfacing
RTC module Interfacing	1 Continuous Rotation Servo Interfacing	1 IR reflective Sensor Interfacing

11.1.2 Functionality Assessment:

The main functionality of the microcontroller subsystem include the communication between PIC 18F4620 and Arduino Nano via I2C communication protocol, and sending signals to control the I/O devices. In addition, the timer module is implemented to time the operation duration, and to terminate the operation at 3 minutes. The detailed functionality breakdown in all three modes of operation is listed in the table below.

Table 22 functionality assessment of Arduino Nano and PIC18F4620

Microcontroller Type	Standby Mode Functionalities	Packaging Mode Functionalities	Post-packaging Mode Functionalities
PIC18F 4620	1. Allow users to retrieve the current date and time via keypad and LCD screen from RTC module. 2. Allow users to enter operation instruction via keypad and display a summary of instruction on the LCD screen. 3. Allow users to press '#' to enter the Packaging Mode.	1. Send signals to Arduino via I2C to control the rotation mechanism to open the lid of the fastener box. 2. Wait for the signals from the Arduino after the lid is opened. Start rotating the reservoirs and dispense the proper amount and types of fasteners into the correct compartment. 3. Send signals to Arduino to rotate to the correct compartment. 4. Wait for the signals from Arduino after the correct compartment is in place. 5. Enter the Post-packaging Mode when all compartments are properly packaged. 6. Time the operation using the timer module, and terminates the current operation to enter the Post-packaging mode early after 2 mins 35 secs has passed.	1. Send data to Arduino to close the lid of the fastener box and rotate the ramps. 2. Activate the dispensing mechanism by rotating the reservoirs and counting the remaining fasteners. 3. Receive data from Arduino after the lid is closed and snapped. 4. If the lid is closed and all remaining fasteners are dispense, terminate the operation, and compute the operation time 5. Re-enable the keypad to enable the user interface. 6. Allow users to retrieve information of operation time, and number of remaining fasteners. 7. Allow users to reset the machine and return to the Standby Mode to wait for the next operation.

Arduino Nano	1. Wait for instruction from PIC via the I2C.	1. Receive data from PIC and open the lid of the fastener box. 2. Locate the first compartment C1, and send data to PIC. 3. Receive data from PIC and rotate to the correct compartment. Send data back to PIC when the correct compartment is in place.	1. Receive data from PIC to rotate the ramps, and close the lid of the fastener box. 2. Send data back to PIC after the lid is closed and ramps are rotated.

11.1.3 Calibration Assessment

Several parameters need to be calibrated in order to achieve more reliable and consistent operation of the machine.

- Calibrate the speed of 4 DC motors individually to optimize the dispensing mechanism.
- Calibrate the speed of the Continuous Rotation Servo in different modes of operation to ensure the fastener organizer box is rotated in a reliable manner.
- Calibrate Calibrate the rotation angles of 4 Micro Servos to ensure the consistency of dispensing fasteners.

11.2 Pin assignment

The PIC18F4620 microcontroller is used to interface LCD, keypad, sensors, RTC module, continuous servo and IR break-beam sensors, while Arduino Nano is responsible for interfacing DC motors, micro servos, IR interrupter sensor and IR reflective sensor. The PIC18F4620 sends commands to Arduino Nano via I2C protocol to initiate specific tasks. The detailed pin assignments for both PIC and Arduino Nano is listed below.

11.2.1 PIC18F4620 Pin Assignment

1. Pins Used by Onboard Module

Table 23 Pin assignment of onboard module of PIC 18F4620

Pin	I/O	A/D	Function
RD2:7	/	/	Connected to RTC module
RB1, RB4:7	/	/	Interface Keypad

RC3:4	/	/	Connected to Arduino for I2C module
RD0,RD1,RC3, RC5	/	/	Interface GLCD

2. Pins Used for Interfacing External Devices

Table 24 Pin assignment for external devices of PIC 18F4620

Pin	I/O	A/D	Function
RC0	Output	Digital	Connected to **KPD** pin, Output 1 to short **KPD** pin and disable Keypad during runtime
RB4	Input	Digital	Receive reading from Break Beam sensor for **spacers**
RB5	Input	Digital	Receive reading from Break Beam sensor for **bolts**
RB6	Input	Digital	Receive reading from Break Beam sensor for **nuts**
RB7	Input	Digital	Receive reading from Break Beam sensor for **Washers**
GND	/	/	Connected to the common ground of the Power Distribution Board.

Notes: The **KPD** pin on PIC18F4620 is wired with RC0 manually. A HIGH signal is send to RC0 to disable Keypad during runtime to allow RB4:7 pins to receive inputs from 4 break beam sensors.

11.2.2 Arduino Nano Pin Assignment

Table 25 Pin assignment of Arduino Nano

Pin	I/O	A/D	Function
D3	Output	Analog	Interface DC motor 0 to rotate **bolts** reservoirs

D5	Output	Analog	Interface DC motor 1 to rotate **nuts** reservoirs
D6	Output	Analog	Interface DC motor 2 to rotate **spacers** reservoirs
D2	Output	Analog	Interface DC motor 3 to rotate **washers** reservoirs
D7	Output	Analog	Interface micro servo 0 to rotate ramp at certain angle **(bolt)**
D11	Output	Analog	Interface micro servo 1 to rotate ramp at certain angle **(nuts)**
D12	Output	Analog	Interface micro servo 2 to rotate ramp at certain angle **(spacers)**
D8	Output	Analog	Interface micro servo 3 to rotate ramp at certain angle **(washers)**
D9	Output	Analog	Interface continuous Servo to rotate the gear
A0	Input	Analog	Receive analog inputs from IR interrupter sensor

11.3 PIC18F4620 and Arduino Nano Communication

The I2C communication protocol allows the transmission of data between the master device, PIC18F4620 and the slave device, Arduino Nano. The communication can be run in parallel with PIC's main code,

The master device selects the receiver by specifying the slave device address and initiating the read or write transactions between the master and the slave. Afterwards, the master PIC sends a specific byte of data to slave Arduino to initiate specific tasks. Arduino would send a byte of data back to PIC to signal that the task has been completed. A detailed table of the communication between PIC and Arduino is shown below.

Table 26 I2C communication between PIC and Arduino

Data sent from PIC to Arduino	Description	Data received by PIC from Arduino	Description

‘0’	Open the lid and locate C1	‘0’	Lid is open and C1 is located
‘1’	Rotate 1 compartment	‘1’	One compartment is rotated
‘5’	Start DC motor 0 (Bolt)	/	/
‘6’	Stop DC motor 0 (Bolt)	/	/
‘7’	Start DC motor 1 (Nut)	/	/
‘8’	Stop DC motor 1 (Nut)	/	/
‘9'	Start DC motor 2 (Spacer)	/	/
’10’	Stop DC motor 2 (Spacer)	/	/
’11'	Start DC motor 3 (Washer)	/	/
’12'	Start DC motor 3 (Washer)	/	/
’13'	Rotate all four servos	/	/
’14'	Close the lid	14'	lid is closed

11.4 Design Solution

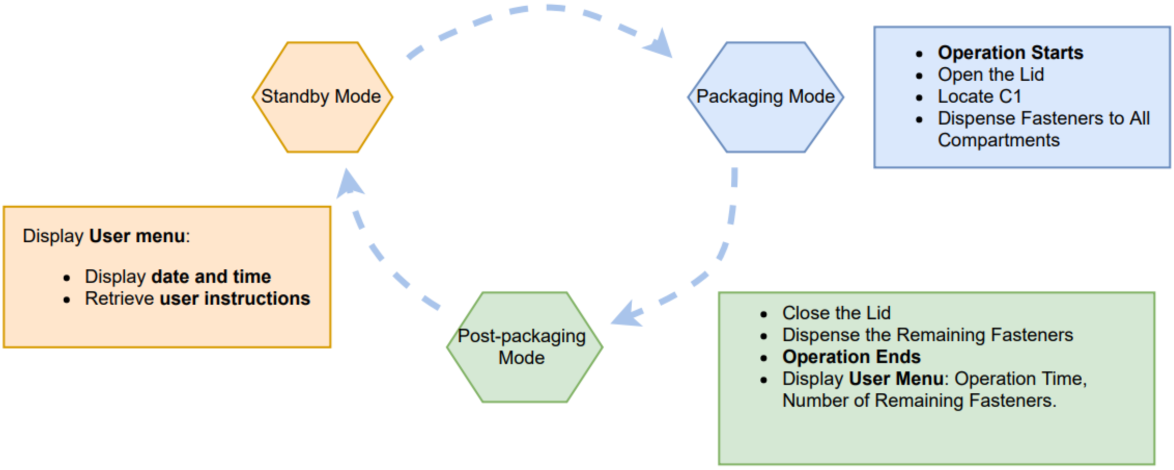


Figure 55 Three modes of operation

The overall microcontroller logic of the machine can be specified into three modes. In **Standby Mode**, the machine is idle and waiting for the instruction. The user menu is displayed on the LCD screen, where user can check the current date and time and enter user instructions. A detailed summary of user instruction is displayed after entering instructions. In the **Packaging Mode**, the fastener box would be rotated by gears to open the lid, and the first compartment C1 is located by detecting the location of white tape. After C1 is found, the four fastener reservoirs would start dispensing specific number and type of fasteners into designated compartments. After the box is properly packaged, the machine will enter the Post-packaging Mode, where the fastener box's lid is closed, and the remaining fasteners are dispensed from the top reservoirs into the returning reservoirs.

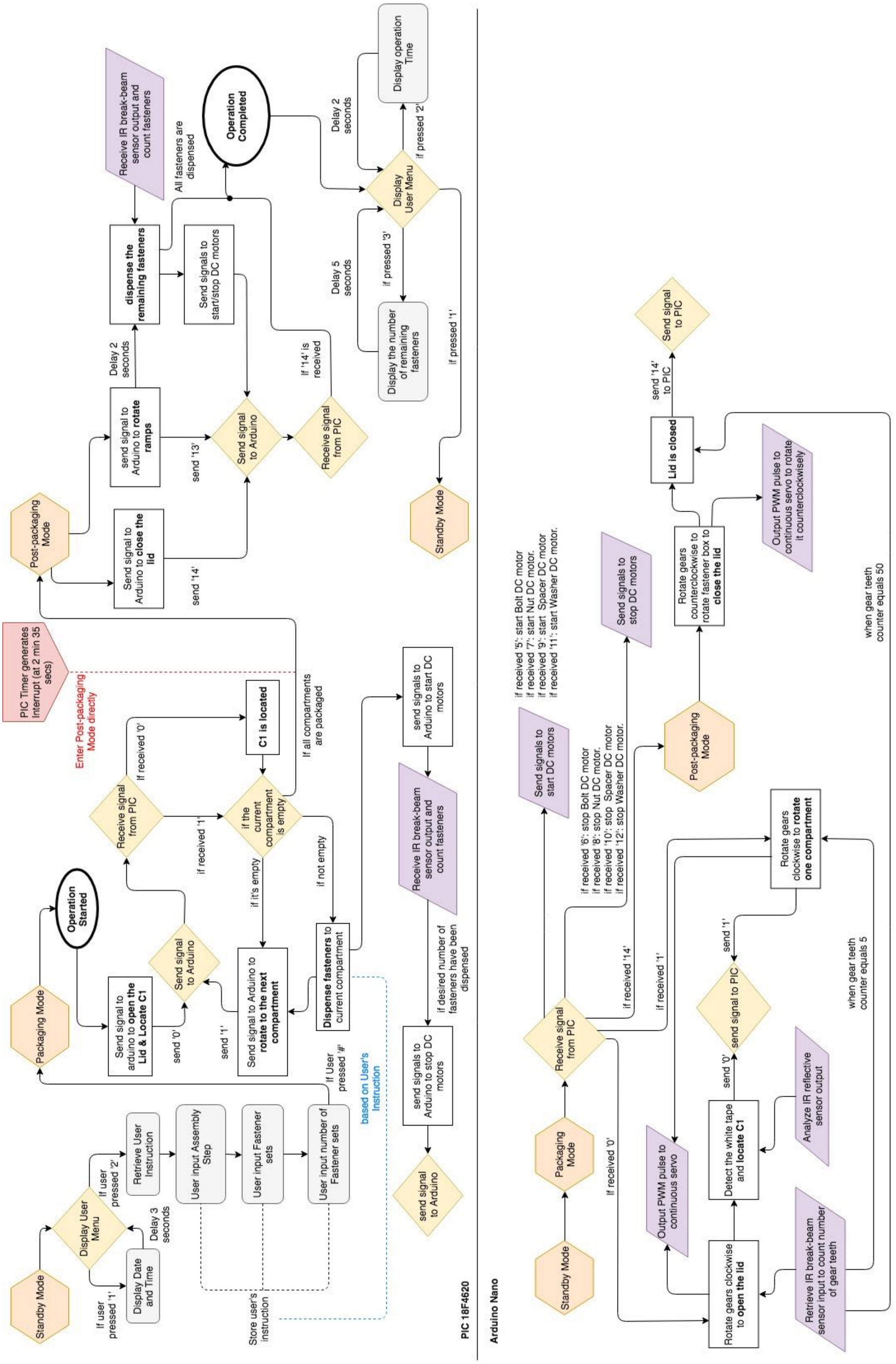


Figure 56 Flowchart for overall operation

11.4.1 User Interface

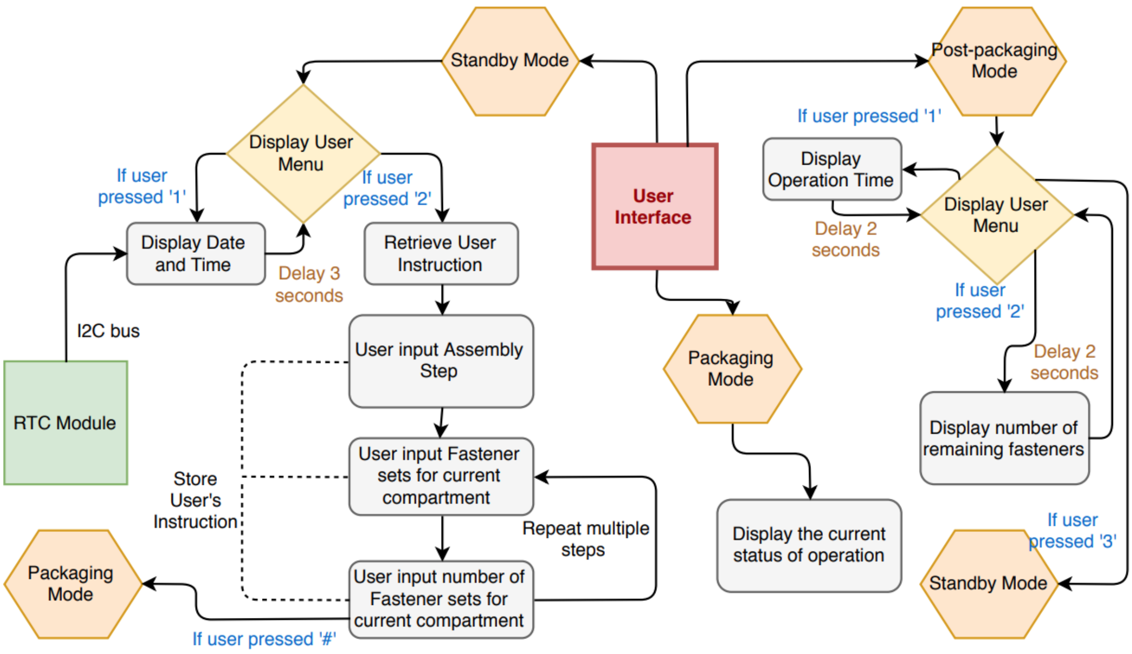


Figure 57 flowchart of the user interface

The user interface of the machine includes a LCD screen, a GLCD screen, and a 4 x 4 matrix keypad.

In **Standby Mode**, the GLCD screen would display the team name, and the LCD screen would display the user menu, where user can enter specific keys on the keypad. In the user menu, users can retrieve the current date and time from RTC module by pressing '1', and enter instructions by pressing '2'. Users can enter the number of assembly step, fastener sets and number of fastener sets for each compartment. Error messages would be displayed on the LCD screen if the input is not valid, and the invalid inputs won't be accepted.

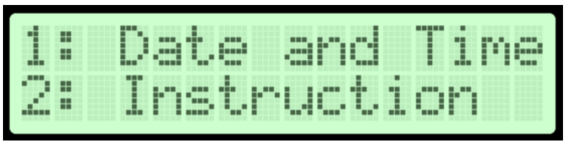


Figure 63 User Menu

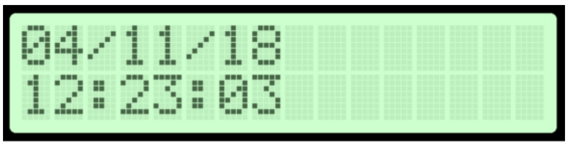


Figure 62 Real Date and Time

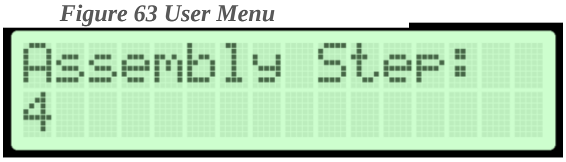


Figure 61 Enter Assembly Step

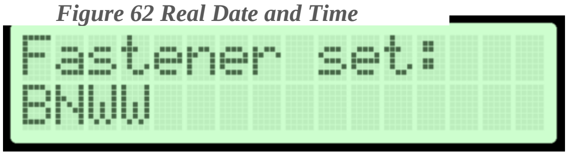


Figure 60 Enter Fastener Set

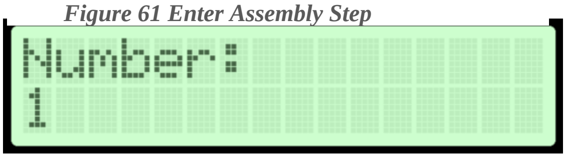


Figure 59 Number of fastener set

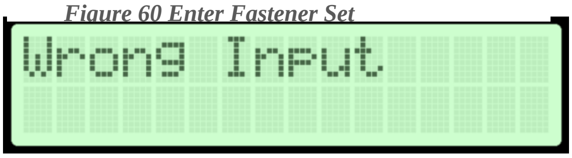


Figure 58 Error Message

The user input is stored in the microcontroller, and the machine would operate based on the user instruction in **Packaging Mode**. After users have entered all relevant instructions, the **packaging operation** would start with the ‘#’ key.

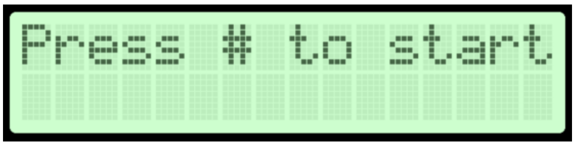


Figure 68 Wating for the user to press start

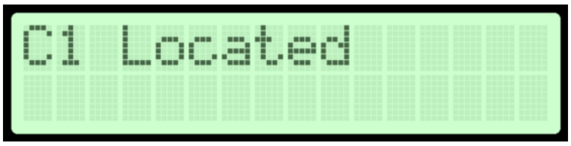


Figure 65 Located C1

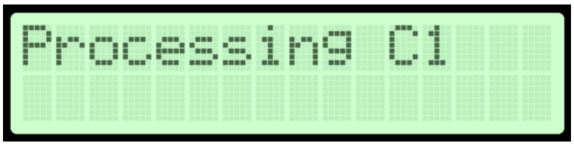


Figure 67 Processing C1

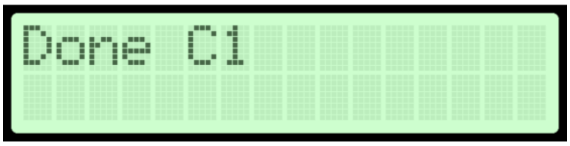
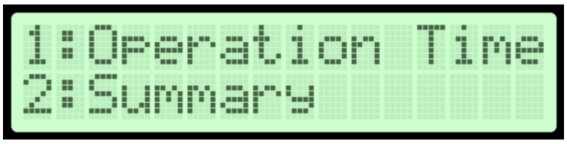


Figure 66 Done C1

Figure 64 GLCD display: team name, bolt, washer, nut, pacer

During the **Packaging Mode**, the LCD screen would display the current status of the operation. The GLCD screen would display the image of the type of fasteners that’s currently been dispensed.

At the end of **Post-Packaging Mode**, the user menu allows users to retrieve the operation time computed from the RTC module by pressing ‘1’ and the summary of operation by pressing ‘2’ and. In addition, users can press ‘3’ to return to **Standby Mode**.



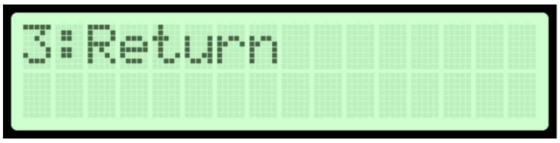


Figure 69 User Menu

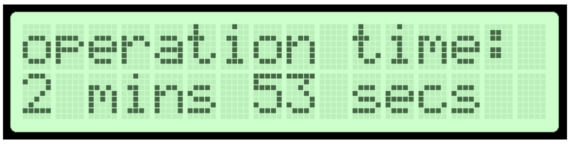


Figure 70 Operation Time

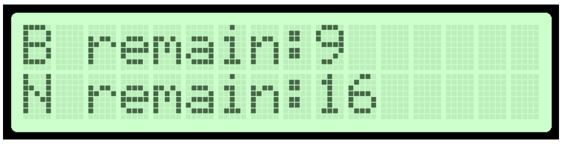


Figure 71 Number of remaining fasteners

11.4.2 Rotation Mechanism

The Rotation Mechanism of the machine incorporates 1 Continuous Rotation Servo, 1 IR reflective sensor, and 1 IR Interrupter sensor, which are interfaced by Arduino Nano. The Continuous Rotation Servo is responsible for rotating the gears and rotate the fastener organizer box, the IR reflective sensor detects the white tape and determine the location of the first compartment, and the IR Interrupter sensor counts the number of gear teeth that pass through.

The three main tasks performed by Rotation Mechanism are:

- Open the lid and locate C1

- Close the lid
- Rotate one compartment

Open the Lid and Locate C1 Task

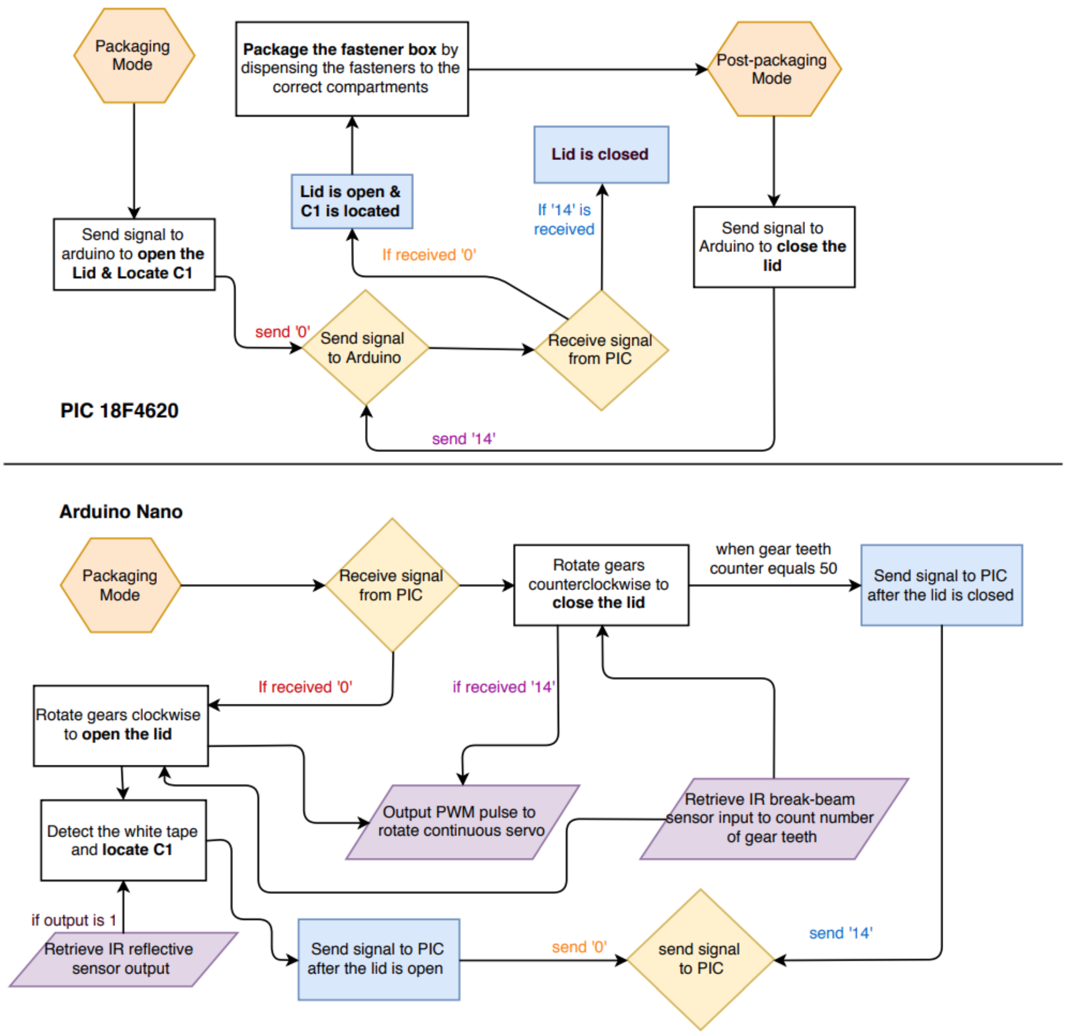


Figure 72 flow chart for open the lid and locate C1 task

In Packaging Mode, PIC18F4620 sends a signal to Arduino Nano via I2C bus to open the lid and locate C1. After receiving the signal, Arduino Nano would initiate the task by sending PWM pulse to rotate the Continuous Rotation Servo in clockwise direction. The reading retrieved from IR Interrupter sensor would be analyzed by Arduino Nano using **analogRead()** function. When nothing is detected, the analog voltage reading ranges from 411 to 423, and the reading drops to around 40 when obstacles are detected. When the reading is below the preset threshold, the gear teeth counter would increment. The fastener box would be locked in place on the square base and the lid would be fully open when the gear has been rotated for one and a fourth round, in which case, the gear teeth counter would equal to 50. The following function perform the task of opening the lid.

```
int Analog_val;      //store the analog reading of the sensor
int gear_counter;
int gear_prev = 0;

con_servo.attach(9);       //attach the continuous servo to pin 9
con_servo.write(83);        //rotate the servo clockwise
```

```
while(1){
   Analog_val = analogRead(A0);
   if (gear_counter >= 50){   // the lid is open
          break;
    }
   if (gar_analog<=260)   //threshold
   {
          if (gear_prev == 0){
                 gear_counter++;
                 Serial.println(gear_counter);
          }
          gear_prev = 1;
          continue;
  }
  else if (gear_analog> 260){
    gear_prev = 0;
}
}
con_servo.writeMicroseconds(1500);  //stop the servo
```

Open the Lid Function (Arduino Nano)

After the lid is open, the gear would continue to rotate by the servo to locate the C1. Since the first compartment C1 is marked by a white tape, and the output from IR reflective sensor would be LOW when the white tape is detected. The reading retrieved from the sensor is analyzed, and Arduino Nano would send a signal to Continuous Servo to stop the rotation once the output from the sensor changes to LOW. The function below demonstrates the detection of white tape to locate C1.

Arduino Nano would then send a signal back to PIC18F4620 to report back that the task is finished, the lid is open and the C1 is located.

```
int white_tape_val = 1;
con_servo.write(83);  //rotate the servo
while(1){
      white_tape_val = digitalRead(IR_sensor);
      if (white_tape_val == 0){    //0: detected       1:not detected
        con_servo.writeMicroseconds(1500);    //stop the servo
        delay(800);
        break;
      }
}
```

L (Arduino Nano)

Close the Lid Task

In **Post-packaging Mod**e, the PIC18F4620 sends signal to Arduino Nano to close the lid of the fastener organizer. The main logic is similar to the Open the Lid Task, where the continuous servo rotates the fasteners box and the IR interrupter sensor counts the number of gear teeth that pass through. However, in this task, servo is instructed to rotate in counterclockwise direction, and the lid would be closed after rotating one and a fourth round.

Upon the completion of the task, the Arduino Nano would report back to PIC18F4620, signalling that the task has completed.

Rotate one Compartment Task

This task is called upon whenever the current compartment has properly packaged with fasteners, or doesn't need to be packaged. To initiate the task, PIC would send a signal to Arduino Nano via I2C bus.

Arduino would then send PWM pulse to the continuous servo to rotate the fastener box in clockwise direction. The reading from the IR interrupter sensor would be retrieved and analysed by Arduino Nano, and the gear teeth counter would increment when the reading drops below the pre-set threshold. The function for this task is similar to function XX, however, the gear counter is compared with 5 instead of 50, since around 5 gear teeth need to pass through the sensor in order to rotate one compartment.

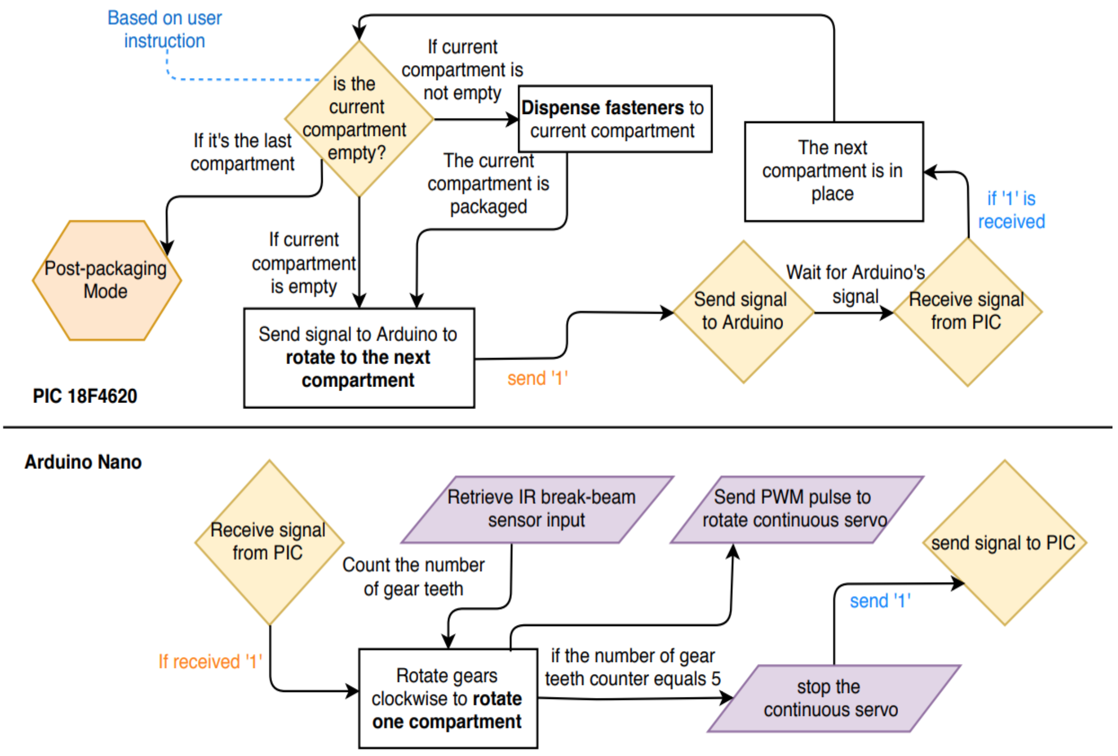


Figure 73 Flowchart for Rotate One Compartment Task

11.4.3 Dispensing and Counting Mechanism

This mechanism includes four DC motors to rotate the reservoirs for four types of fasteners, four IR break-beam sensors to count the dispensed fasteners, and four micro servos to rotate the ramps to direct the fasteners to either the central funnel or the corresponding remaining reservoirs.

The mechanism has two main tasks to perform.

- Packaging the Compartment
- Rotate the Ramp

- Dispense the remaining fasteners

Packaging the Compartment Task

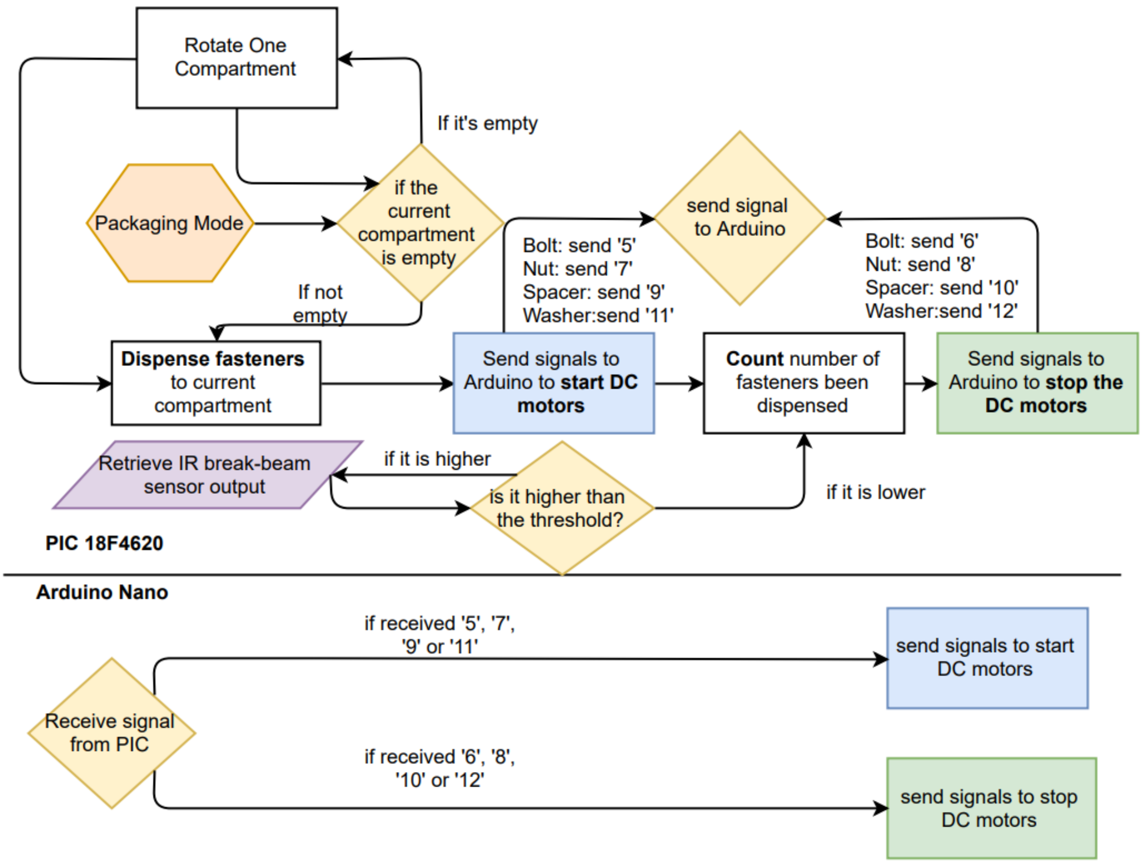


Figure 74 flowchart for packaging the compartment task

If fasteners are needed to be dispensed to the current compartment, the DC motor of the corresponding reservoir would start to rotate. When a fastener is dispensed from the reservoir, it would pass between the IR break-beam sensor mounted at the exit, and the output voltage would be high as it passes through.

The four IR break-beam sensors are connected to the RB4:7 pins on PIC board, which are interrupt on change pins [insert data sheet]. Since those pins are occupied by the keypad, the keypad is disabled during the Packaging Mode by shorting the KPD pin. [insert data sheet]. In order to do that, the KPD pin is wired with RC0, which outputs HIGH when entering the Packaging Mode to disable the keypad, such that RB4:7 would be available to receive inputs from the IR break-beam sensors.

Whenever a break beam sensor changes it's digital output, it would generates interrupt, and the interrupt handler function would determine which sensor interrupted and retrieve the output value to update the corresponding fastener counter. Once the fastener counter reaches its desired value, it indicates that a desired amount of fasteners has been dispensed into the current compartment. PIC would then send a signal to Arduino Nano to stop the DC motor.

```
int B_counter = 0;
```

```
int B_input;        //store sensor reading

void Bolt_dispense(int B_max){    //B_max is the number of bolts to be
dispensed
    if (B_max == 0){
        return;
     }
    __delay_ms(100);
    I2C_sendData('5'); // send signal to Arduino to rotate DC motor
    while(B_counter < B_max){
        __lcd_clear();
        __lcd_home();
        printf("B:%d",B_counter);
    }
    I2C_sendData('6');    //send signal to Arduino to stop DC motor
        return;
}
void interrupt interruptHandler(void){
    if (RBIF){
        TRISBbits.RB5 = 1;        // sets data direction to input
        B_input = PORTBbits.RB5;    //read input from RB5
        if (B_input == 1){       //if the sensor reading is HIGH
            B_counter++;    //increments B_counter
        }
        RBIF = 0;        //reset the flag
        return;
    }
}
```

Function XX: count number of dispensed bolts (PIC184620)

```
int x;
int motor_speed = 130;

void receiveEvent(void){
if (x == '5'){
        analogWrite(DC_motor0,motor_speed);     // rotate bolts motor
        Serial.println("'5' received: bolts motor rotate");
    }
if (x == '6'){
        analogWrite(DC_motor0,0);     //stop bolts motor
        Serial.println("'6' received: bolts motor stop");
    }
return;
}
```

Function XX: rotate/stop DC motor for bolts (Arduino Nano)

Rotating the Ramps Task

This task includes controlling the four micro servos that are attached to the lower ramps, such that the lower ramps would rotate to a specific angle by the micro servos. In **packaging Mode**, the angle of the ramps is initialized to 30 degrees, which direct the fasteners to the central funnel.

The machine enters the **Post-packaging Mode** when all compartments of the fastener organizer box are properly packaged. PIC would then send a signal to Arduino Nano to rotate the micro servos. The lower ramp would rotate by 60 degrees and redirect the dispensed fasteners to the remaining reservoirs at the bottom.

```
Void Ramp_Rotate(){
    …     //initialize I2C
```

```
    I2C_Master_Start();
    I2C_Master_Write(13);
    I2C_Master_Stop();
    return;
}
Function XX: send signals to Arduino to rotate ramp (PIC)

Servo myservo_B;
Void setup(){
    myservo_B.attach(7);
    myservo_B.write(30);  //initialize ramp angle to 30 degrees.
    ...
}
Void receiveEvent(void){
    If (x == 13){
            myservo_B.write(60); //rotate ramp to 60 degrees
            ...
}
}
```

Function XX: rotate ramps by rotating servos (Arduino Nano)

Dispensing Remaining Fasteners Task

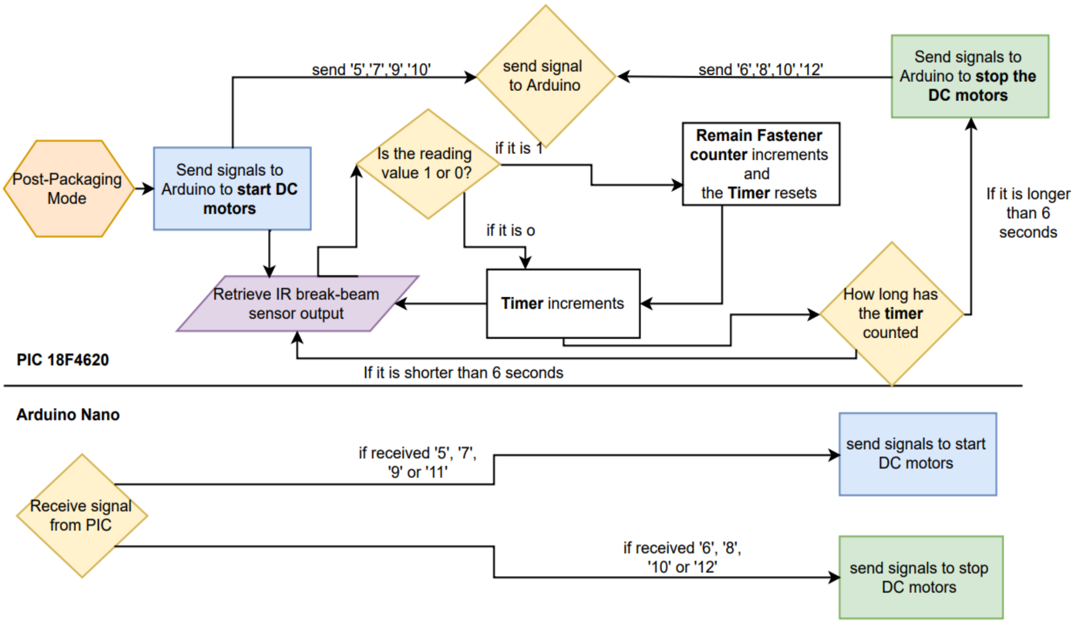


Figure 75 : flowchart for dispensing remaining fastener task

This task is initiated when entering the **Post-Packaging Mode**, after the ramps are rotated**.** The PIC sends signal to Arduino to dispense the remaining fasteners in the top reservoirs into the remaining reservoirs.

The logic is similar to the task of packaging the compartments, except that timer is implemented in this task keep track of the time elapsed since the previous dispensation.

The timer starts as the DC motor starts to rotate, and it would be reset every time when a fastener has been dispensed from the reservoir.

The timer value is compared with a preset value, which is 6 seconds in every iteration. If the timer exceeds 6 seconds, which means that no fasteners have been dispensed or detected in the last 6 seconds. Hence, it would be safe to assume that all of the remaining fasteners have been dispensed and the reservoir is empty. The PIC would send a signal to Arduino Nano to stop the DC motor, signalling that this task has been completed.

```
int time = 6000;      //6000 ms
int B_spacingTime = 0;       //timer
void Bolt_remain(int time){
    __delay_ms(100);
    I2C_sendData('5');                // rotate bolt motor
    while(B_spacingTime < time){
         B_spacingTime +=100;
    }
    I2C_sendData('6');    //stop the DC motor
}
```

Function XX: Dispense the remaining fasteners(PIC)

11.4.4 Timing Mechanism

The timing mechanism of the machine incorporates the RTC module and the Timer0 Module. This mechanism performs two main tasks:

- RTC and Operation Time Task
- Timer Interrupt Task

RTC and Operation Task

The current date and time is retrieved from the RTC module via I2C bus,

The operation time is computed from RTC module, it counts the time duration of the operation, which starts from the beginning of Packaging Mode and ends when the operation terminates. When the user presses # to start the operation, the value of RTC is stored in the initial time variables. The RTC value is retrieved again when the machine terminates, and the value is stored in the final time variables.

The operation time can be obtained by subtracting the initial time from the final time.

```
int i,hr_initial,min_initial,sec_initial;
int hr_final,min_final,sec_final;
int initial_time,final_time;
int operation_time;

void get_RTC_initial(){
    /* Read current time. */
    I2C_Master_Start(); // Start condition
    I2C_Master_Write(0b11010001); // 7 bit RTC address + Read
    for(i = 0; i < 6; i++){
        time[i] = I2C_Master_Read(ACK);
    }
    time[6] = I2C_Master_Read(NACK); // Final Read with NACK
    I2C_Master_Stop(); // Stop condition

    hr_initial = time[2]/16*10+time[2]%16;   //convert hex to decimal,
```

```
            min_initial = time[1]/16*10 + time[1]%16;
            sec_initial = time[0]/16*10 +time[0]%16;
            return;
    }
```

Function XX: get initial time from RTC module (PIC18F4620)

```
    void get_RTC_final(){
            /* Read current time. */
            I2C_Master_Start(); // Start condition
            I2C_Master_Write(0b11010001); // 7 bit RTC address + Read
            for(i = 0; i < 6; i++){
                time[i] = I2C_Master_Read(ACK);
            }
            time[6] = I2C_Master_Read(NACK); // Final Read with NACK
            I2C_Master_Stop(); // Stop condition

            hr_final = time[2]/16*10+time[2]%16;     //convert hex to decimal
            min_final = time[1]/16*10 + time[1]%16;
            sec_final = time[0]/16*10 + time[0]%16;
            return;
    }

Function XX: get final time from RTC module (PIC18F4620)

        void get_operation_time(){
           initial_time = hr_initial*3600 + min_initial*60 + sec_initial;
           final_time = hr_final*3600 + min_final*60 + sec_final;
           operation_time = final_time - initial_time;
           return;
        }
```

Function XX: compute the operation time(PIC18F4620)

Timer Interrupt Task

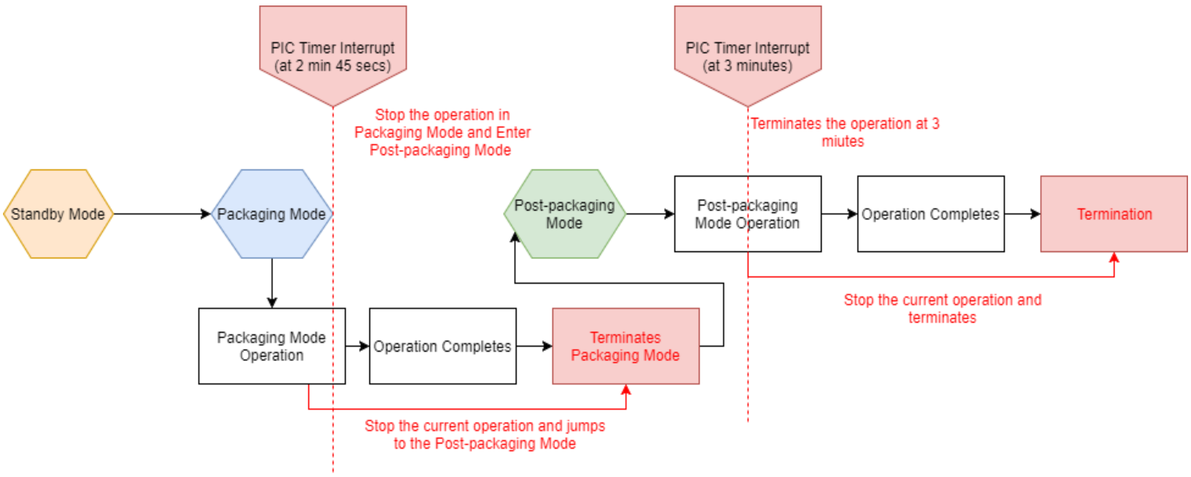


Figure 76 flowchart for timer interrupt task

To ensure the qualification of the machine operation, timer interrupt is implemented to ensure the lid is closed and snapped at the end of each operation and the total run time does not exceed three minutes. The Timer0 module is configured to be a 16-bit timer, and the output clock frequency can be computed using the following formula:

$$f_{out} = f_{clk} / (4 \times prescaler \times (Max\ Count - TMR0\ Load\ Value))$$

$$f_{clk} = FOSC1 = 32\ MHz\ (internal\ oscillator\ with\ PLL)$$

$Max\ Count\ =\ 2^{16}\ (16\ bit\ Mode\ is\ chosen)$

$TMR0\ Load\ Value\ =\ 0$

$Prescaler\ =\ 2^{8}\ =\ 256$

$f_{out}\ =\ 0.477\ Hz$

$T_{out}\ =\ 2.097\ secs$

If the previous operation lasts for too long, the timer interrupt would kick in at 2 minutes 45 seconds to stop the Packaging Mode and initiates Post-packaging Mode to close the lid and dispense the remaining fasteners. The timer would interrupt again at 3 minutes to terminates the operation to ensure that the operation time does not exceed the 3 minutes limit.

The counter value for 2 minutes 45 seconds and 3 minutes can be computed from the clock period:

$EndProgramTimerCount$ =(3×60 $secs$)/2.097 $secs$ = 86 $\mathrm{EndProgramTimerCount} = (3 \times 60\mathrm{secs})/2.097\mathrm{secs}\ = 86$

$CloseLidTimerCount\ =\ (2 \times 60\ secs\ +\ 45\ secs)/2.097\ secs\ = 79$

The counter increments every time when the timer overflows, which is 2.097 seconds. The value of the counter is compared with the variable *CloseLidTimerCount* and *EndProgramTimerCount.* The machine would jump to Post-Packaging Mode when the counter equals to *CloseLidTimerCount*, and the operation would terminates when the counter reaches the *EndProgramTimerCount.*

```
#define EndProgramTimerCount 86;  //3 mins
#define CloseLidTimerCount 79;    //2 mins 45 secs
int timerCounter;

void initTimerInterrupt(){
    /* Enable Timer Interrupt */
    INTCONbits.TMR0IE = 1;
    ei();

    T0CONbits.T08BIT = 0;   // 16-bit mode selected
    T0CONbits.T0CS = 0;     // Internal clock selected (timer mode ON)
    T0CONbits.PSA = 0;      // Prescaler assigned
    T0CONbits.T0PS0 = 1;    // Prescaler values
    T0CONbits.T0PS1 = 1 ;    // Prescaler values
    T0CONbits.T0PS2 = 1;    // Prescaler values
    T0CONbits.TMR0ON = 1;   // Turn ON the timer
}

void interrupt interruptHandler(void){
if(TMR0IE && TMR0IF){
          timerCounter ++;
          if (timerCounter >= CloseLidTimerCount){
                NeedToCloseLid = 1;  //start closing the lid
          }
          if(timerCounter >= EndProgramTimerCount){
                timerCounter = 0;
                EndOfProgram = 1;       //terminate the operation
          }
```

```
            TMR0IF = 0; //clear flag
        }
    }
```

Function XX: Timer Interrupt Function(PIC18F4620)

11.5 Calibration Process

As outlined in the calibration assessments in section 11.1.3, there are various parameters that need to be calibrated in order to balance the performance and efficiency of the machine operation. Some of the essential calibration process are elaborated in this section.

DC Motor Speed Calibration

One of the major issues experienced during testing is the jamming of fasteners in the top reservoirs, specifically bolts, nuts and spacers. The fasteners usually get stuck at the exit of the reservoir between the edge of the openings of the rotating disc and the bottom disc. This is due to the fact that the motor speed is too fast, such that there is insufficient amount of time to allow the fasteners to fall through the openings of the reservoirs. As a result, the top rotating disc would push the fastener to the other edge of the opening before it has a chance to fall through, and continue to exert force on it such that the fastener gets completely stuck, and the reservoir is jammed.

On the other hand, when the speed of the DC motor is too low, it doesn't generate enough torque to rotate the top disc, and it is unable to pick up any fastener during rotation.

The issue associated with the counting mechanism also concerns with the DC motor speed. The issue is that the fasteners dispensed from the reservoirs fall too fast to be detected by the IR break-beam sensors.

To resolve those issue, the speed of each DC motor is adjusted and calibrated through multiple iterations of testings and experiments. Based on those testings and experiments, the performance is maximized when rotating the DC motor at a speed of 40 rpm, such that it has sufficient torque to rotate the top disc of the reservoir to pick up and dispense fasteners, and the speed is slow enough to minimize the risk of getting jammed and allow the fasteners to be detected by the sensors.

Continuous Servo Speed Calibration

The problem that emerges while integrating with the rotation mechanism is that the continuous servo speed is too fast for the fastener organizer box to be properly locked in place by the square base. The fastener organizer box slips from the base during the Packaging Mode, which causes inconsistency during packaging.

To resolve the issue, two servo speeds are implemented during the operation. When opening the lid, the servo rotates at 60 rpm, and the servo speed decreases to 10 rpm when rotating to the next compartment during packaging the fastener organizer box, such that the servo speed is slow enough to prevent the fastener box from slipping from the square base.

Ramp Servo Angle Calibration

When dispensing the fasteners into the remaining reservoirs, the angle needs to be calibrated such that the fasteners can be dispensed accurately into the corresponding reservoirs. The angles are calculated based on the trajectory of the fasteners, but since there might be some inconsistency between the output servo angle and the input angle, the angle is calibrated through testings and experiments to determine the optimal ramp servo angle that allow majority of the fasteners to be dispensed into the remaining reservoirs.

11.6 Suggestions for Improvements of Microcontroller Subsystem

More Intuitive User Interface

The current user interface is functional, but not very user-friendly due to lack of guidance and insufficient information provided. This is due to the fact that the size of the current LCD screen used is only 2*16, hence, very limited information can be displayed on the screen. For further improvements, a larger LCD screen or GLCD can be incorporated to display relevant information to guide user to go through the entire process. Additionally, the GLCD screen can be used to display the full view of the package box to visually inform users the current compartment that is been packaged and the type of fasteners that is currently been dispensed.

Improve Runtime Efficiency

The current machine operation is not very efficient, since the operation runs overtime sometimes. To improve the runtime efficiency, some of the tasks can run in parallel to minimize the operation time.

Currently, the four reservoirs dispense fasteners sequentially, which means that only one reservoir is dispensing fasteners at one time. The dispensing process can be much more efficient if all four of the reservoirs rotate at the same time. This would require the microcontroller to select a faster oscillator to obtain a higher clock speed, such that it can detect and count the dispensed fasteners in a reliable manner and does not miscount any dispensed fasteners.

12. Integration Process

12.1 Stages of Integration

12.2.1 Rotation of Centrifuge Feeder

Functionality to be accomplished:

- Centrifuge feeder able to successfully rotate the rotating plate
- Fastener could be dispensed one by one
- Centrifuge feeder could be stopped

Major Steps:

Mount the circuit board, power supply on the machine and solder the ground and power terminal of the DC motor to the machine. Connect the control pin of all four DC motors to the microcontroller. Test if a start signal using the program could start and end the rotation of the motor.

12.2.2 Counting of fasteners

Functionality to be accomplished:

- Able to dispense the number of fasteners according to user specification
- Centrifuge must not jam

Major Steps:

Mount the IR sensor near the exit of the feeder. Connect the output on of the IR sensor to the microcontroller. Test if the microcontroller could correctly increment fastener as they are being dispensed. Test if the stop signal from the microcontroller could stop the fasteners from being dispensed in time. Finally, test if the feeder could handle large number of the fasteners (+20)

12.2.3 Ramp Angles

Functionality to be accomplished:

- Able to deliver the required number of fasteners to either the remaining reservoirs or the compartment box.
- Remaining fasteners should not be left to on the machine.

Major Steps:

Connect the power supply and PWM pin to the circuit board. Connect the PWM input pin to the designated pin from the microcontroller. Test if the microcontroller could control the motion of the ramp angle. Tune the ramp angle to make sure if the remaining fasteners will be directed to the remaining fastener.

12.2.4 Lid Opening and Detection of Compartment 1

Functionality to be accomplished:

- Able to open the lid of the fastener box when the box is placed into the machine in arbitrary position
- Able to detect the location of compartment 1 when the box has been opened already
- Able to close the lid of the fastener box

Major Steps:

Connect the power supply and PWM pin to the circuit board. Connect the PWM input pin to the designated pin from the microcontroller. Test if the microcontroller could control the speed and direction of the lazy susan turntable. Test if the lid could be opened properly. Connect the output of the white band sensor output to the microcontroller. Test if the sensor could detect the white band when the box is in motion. Adjust the speed of the turntable.

12.2.5 Rotation of Fastener Box

Functionality to be accomplished:

- Able to rotate the desired compartment of the fastener box to the loading area (directly below the funnel) while the lid remains open

Major Steps:

Connect the output of the IR interrupter to the motor. Test if the microcontroller could count the gear properly. Test if the microcontroller could control the angular position of the turntable without load. Test if the compartment of the fastener box could be rotated to accurate angular position. Test if the fastener box would slip.

12.2.6 Full functionality

Functionality to be accomplished:

- The user should be able to load the box, input the requirements and the machine can autonomously pack the fasteners to the box.

Major Steps:

- Test the logic of the integrated ode that includes all the partial functionalities. Test if fasteners could be dispensed into the correct opened compartment. Test the full run of the machine according to in a continuous way. Test if the overall run of the machine would satisfy the time constraints. Verify that all constraints would be satisfied. (Weight, Size, no jamming).

12.2 Problems encountered during integration

12.2.1 DC Motor Speed Optimization to Avoid Jamming

DC motor is connected to PWM pins in Arduino, and can be controlled by writing analog value to the corresponding pins. When the reservoirs are loaded with fasteners, the DC motors don't have enough torque to rotate the top disc in the reservoirs. However, as the majority of the fasteners get dispensed, the speed of DC motor increases to around 76 rpm, causing fasteners to jam at the exit of the reservoirs.

Solution:

To solve the problem, gradually decrease the DC motor speed during the operation to ensure a relatively constant DC motor speed.

12.2.3 Signal Interference between DC motors and IR break-beam sensors

When integrating with DC motor, the reading retrieved from IR break-beam sensors are inconsistent with fluctuations. The solution includes adding capacitors across each DC motors to filter out the noise.

Solution:

To suppress and diminish the noises generated by the DC motor's commutator, a 0.1uF capacitor is added and connected to each DC motor in parallel to act as an passive filter. Without this filter, the signal interference will cause unpredicted behaviour in sensor circuits' output. The 0.1uF capacitor typically is able to absorb high-frequency noises by absorbing the transient voltage spike and thus smooth out the voltage.

12.2.4 Reading Voltage Output of IR break-beam sensors

When reading the voltage output of the IR break-beam sensors, there are generally two options available: 1) treat it as an analog signal and continuously pool the reading of the sensor using A2D. 2) treat it as digital signal and uses the interrupt on change feature of the PIC board to count the fasteners. However, both has its fallbacks and suffers from its own issues. 1) Pooling is not desirable if we need to pool four inputs from the four IR break-beam sensor at the same time. Also, it suffers to fluctuations and noises in the oscillator of the PIC. 2) If we want to treat the signal as a digital one, the value of it must be high enough to ensure that it is recognized as a digital signal (5V). A voltage that is too low (<2V) would simply be recognized as a digital low and a intermediate voltage(2-3V) could flip randomly between digital high and low.

Solution:

The second option is chosen because of its ability to interface with different sensors at the same time and increased reliability due to its less dependencies to the clock frequencies. The interrupt change function works very well when there are only one connected sensor(one pin), but not as good as expected when all four sensors are connected simultaneously. Therefore, the op-amp circuit was rebuilt to amplify the voltage output to 3.6-3.8V, which could be safely recognized as a digital high. Also, the IR break beam sensor was reconfigured to have a active high instead of active low when it detects a fastener. This further reduced noise in the signal since the ground voltage is much more stable for the large empty window than the 5V voltage supply.

12.2.5 Runtime Efficiency

The three minute runtime limit is a hard constraint for the robot. However, according to the extensive amount of testing, the robot could not dispense all the remaining fasteners within the given amount of time. One simple idea is to make sure that all four remaining fasteners are rotating at the same time. However, the control of DC motors would become very unreliable during this process.

Solution:

The principle of solving this issue could be summarized in one simple sentence. **To make sure the machine has a qualified operation according to the RFP**.

First of all, a timer interrupted is added to the main program and tested extensively to make sure that the operation would **always** end before three minutes (i.e. all motor stops, print termination message). Next, we would try to minimize as much time as possible within the “qualified” limit.

For example, one potential solutions tried was to rotate all four feeder at the same time to deliver the fasteners at a faster rate. However, this turned out to significantly hinder the ability of the robot to properly count the number of fasteners dispensed due to unexpected signal interference between all the sensors. Also, another issue discovered is that the four motors fail to rotate at the same time when there are a large number of fasteners in the feeder (20+). After debugging the microcontroller program thoroughly and trying many different implementations, this is suspected to be a power issue because too much current needs to drawn initially at the same time to overcome the huge static friction. Therefore, we decided to always dispense the fasteners one by one to make sure that the counting and dispensing works reliably.

Another attempt to solve the issue is to increase the servo motor speed for the turntable. However, the downside is that the slipping issue would occur much more frequently because there is less time for the slot on the loading disc to grip the “foot” of the fastener box. If the compartment box slip, none of the remaining compartment would be dispensed correctly because the sensor could only determine the location of compartment one, and the angular position of all other compartments are calculated as offsets. Therefore, the speed of rotation has to be set to be low enough to ensure that no slipping will happen.

12.2.6 Interference between GLCD and I2C

During our final push for the full functionality, we integrated the extra functionalities of the GLCD drawings with the I2C. However, the GLCD also uses the master slave communication protocol, which is also shared by the I2C protocol. Thus, the interface between Arduino Nano and PIC was not functioning.

Solution:

Since the I2C comprises of the more important basic functionalities and would determine the success of the machine, our first approach to solve the problem is simply to make a backup code containing the exact same and functioning program except the GLCD part. This way, GLCD debugging could be proceeded without worrying about disqualification. The GLCD bug shares the same bus with the I2C. Therefore, GLCD should not be receiving signals of new information whenever the PIC board is communicating with the Arduino to ensure the stable functionalities of the motors and sensors. Moreover, a 100ms delay time is added every time we switch the master slave bus from interfacing with GLCD to Arduino or vice versa, which serves as a factor of safety to ensure the signal is stabilized before any information is being sent.

12.3 Overall System Improvement Suggestion

Some of the subsystem improvement suggestion have been discussed in the subsystem specification sections. In addition to the subsystem improvements, some of the improvement suggestion for the overall system is outlined below:

12.3.1 Increase portability

The size of the machine is 49 cm*45 cm*45 cm, and weighs around 6.48 kg. The size and the weight of the machine limit the portability of the design. To improve on that, the size of the machine can be further reduced by mounting the mechanisms in a more compact way, and reducing the size of the circular reservoirs as well as the returning reservoirs. Heavier materials such as aluminum and wood can be replaced with lighter yet more durable materials to reduce the weight.

12.3.2 Increase Robustness or the machine and the program

To increase the robustness of the program, code should be written in a more organize and clean way, with proper comments to increase readability and can be easily debugged. The program should be tested thoroughly to ensure the reliability. In addition, the program should be written in a way that can be easily modified whenever a new change of the design has been proposed.

The structural robustness of the machine can be achieved by selecting stronger and more durable materials to increase the life span of the machine.

12.3.3 More user-friendly UI

To improve on the user interface, permanent logs can be implemented in the design, such that the previous runs can be stored in permanent memory. PC interface can also be implemented to allow users to download the logs of previous runs from the machine to a PC.

13. Experiments

Team 34 Full-Run Experiment

Maximum Load:	Bolts (B)	20
	Nuts (N)	25
	Spacers (S)	20
	Washers (W)	35

Notations:		
Status:	▲	Issue/ Alert
	✓	Correct
	✗	Wrong # dispensed

2018-04-08			# less than Max. Load
1st Run:	B	20	
	N	25	
	S	17	-3
	W	15	-20

Assembly Steps: 8

Sets:	BWWW	BBSW	SS	NN	BBW	BS x 2	S	BNNN
Status:	▲							

Problem: *W not appropriate counting
*Abort!

2018-04-08			# less than Max. Load
2nd Run:	B	20	
	N	25	
	S	18	-2
	W	29	-6

Assembly Steps: 8

Sets:	BS x 2	BNNN	BNS	BW x 2	BWWW	S x 2	N x 2	BNNW
Status:	▲	✓	✓	✓	✓	✓	✗	✓
Problem	*B stuck (manual intervene)						extra 1 N	

2018-04-08			# less than Max. Load
3rd Run:	B	18	-2
	N	25	
	S	20	0
	W	20	-15

Assembly Steps: 5

Sets:	W x 2	S x 2	N x 2	B x 2	BS			
Status:	✓	✗	✗					
Result		2S, 2N, 2B	1S					

Problem: *Abort!
*Box not locked properly, slipped at the second compartment

2018-04-09			# less than Max. Load
4th Run:	B	18	-2
	N	25	
	S	20	0
	W	20	-15

Assembly Steps: 5

Sets:	W x 2	S x 2	N x 2	B x 2	BS			
Status:	✓	✗	✗	✗				
Result		1S	3N + 2B	1S				

Problem: *Abort!
*Box not locked properly, slipped at the third compartment
*S dispensed less than required
*N dispensed more than required

Problem Found: There is one small piece of metal sheet on the plate, underneath the fastener box such that the box is lift up-> cannot be properly locked firmly.

2018-04-09			# less than Max. Load
5th Run:	B	18	-2
	N	25	
	S	20	0
	W	20	-15

Assembly Steps: 5

Sets:	W x 2	S x 2	N x 2	B x 2	BS			
Status:	✓	✓	✓	✓	✓			

Result: Successful Full Run!

Modification: Extra featured "GLCD" added

2018-04-09			# less than Max. Load
6th Run:	B	20	0
	N	25	
	S	20	0
	W	34	-1

Assembly Steps: 7

Sets:	BNWW	BBS	BBN	N x 2	BBNW	S x 2	W x 2	
Status:	✗	✓	✗	✗	▲			
Result	2B + 1N + 2W		2B + 1N + S	2N + W	*B did not stop dispensing			
	one extra B		one extra S	one extra W				

Problem: *Abort!
*Bolts kept dispensing and did not stop
*Unexpected fasteners appeared in other compartments

Interpretation: *May cause by the GLCD which interferes with the PIC's interrupt

Problem Found: Confirmed the interpreation that it is the GLCD causing problem. Solved by adding more delay time and debugging the code.

2018-04-09			# less than Max. Load
7th Run:	B	20	0
	N	25	
	S	20	0
	W	34	-1

Assembly Steps: 4

Sets:	B x 2	N x 2	S x 2	W x2				
Status:	✓	✓	✓	✓				
Result	Successful Full Run!							

Mock Trial (Fully mimicing actual demo, ask another team to conduct)

2018-04-09			# less than Max. Load
8th Run:	B	16	-4
	N	20	-5
	S	17	-3
	W	18	-17

Assembly Steps: 7

Sets:	BNWW	BBS	BBN	N x 2	BBNW	S x 2	W x 2	
Status:	✗	✓	✓	✗	✗	✓	✓	
Result	one extra B			one extra W	one less W			
	Qualified Full Run!							
					One washer droped in the previous compartment			

Attempt: *Modify DC motor speed of the Bolts reservoir

2018-04-09			# less than Max. Load
9th Run:	B	16	-4
	N	20	-5
	S	17	-3
	W	18	-17

Assembly Steps: 7

Sets:	BNWW	BBS	BBN	N x 2	BBNW	S x 2	W x 2	
Status:	✓	✓	✓	✓	✓	✓	✓	
Result	Successful Full Run!							

2018-04-10			# less than Max. Load
10th Run:	B	20	0
	N	25	0
	S	20	0
	W	30	-5

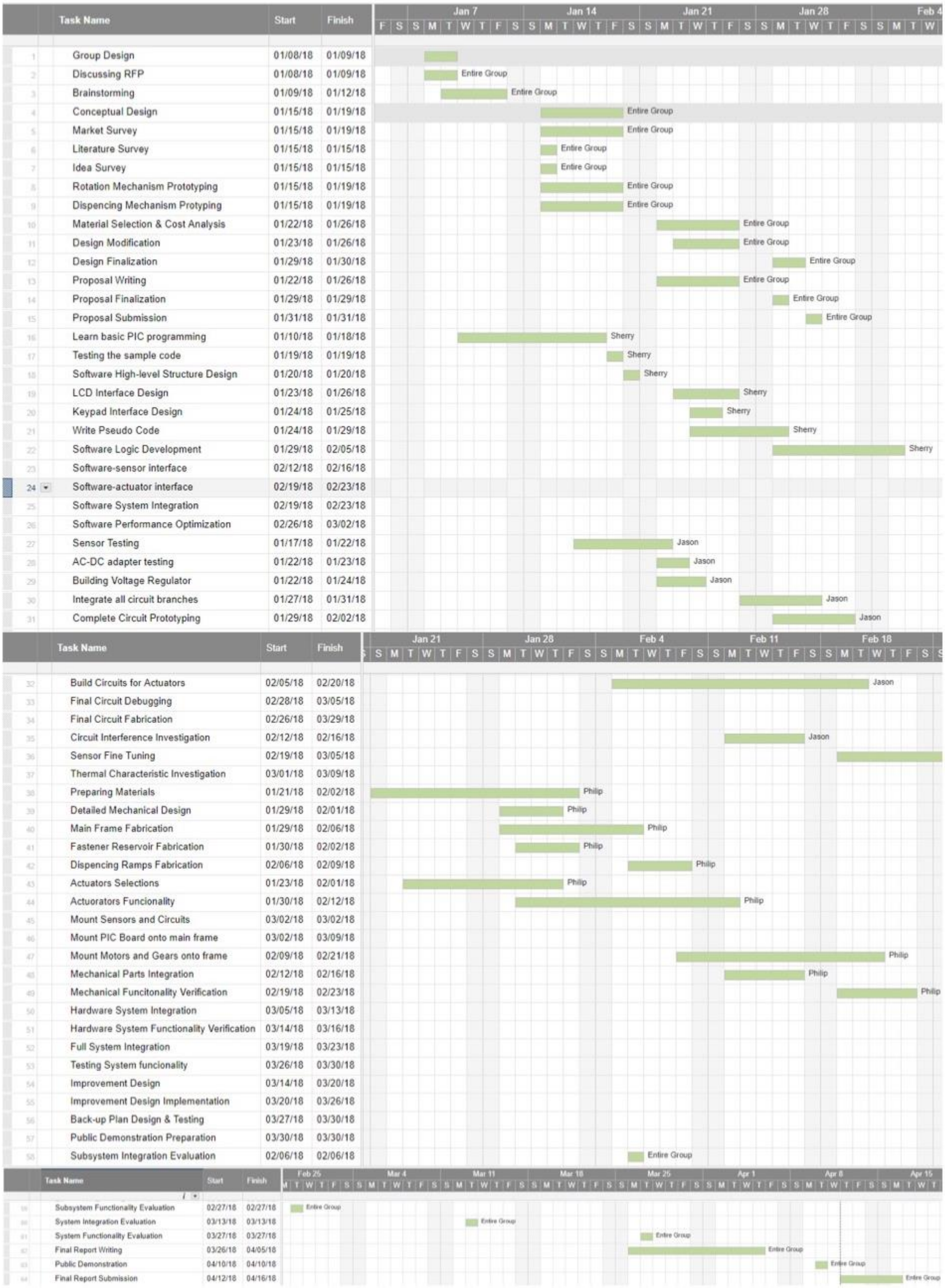
Assembly Steps: 5

Sets:	BS x 2	BBN	BWWW	S x 2	BNNN			
Status:	✓	✓	✓	✓	✓			
Result	Successful Full Run!							

Figure 77 Experiments and testing logs

14. Schedule of Work

14.1 Original and Revised Gantt Chart

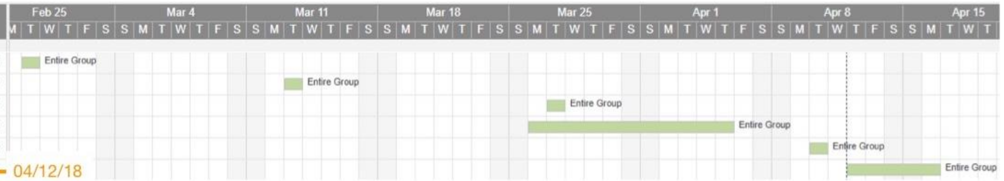


#	Task Name	Start	Finish
1	Group Design	01/08/18	01/09/18
2	Discussing RFP	01/08/18	01/09/18
3	Brainstorming	01/09/18	01/12/18
4	Conceptual Design	01/15/18	01/19/18
5	Market Survey	01/15/18	01/19/18
6	Literature Survey	01/15/18	01/15/18
7	Idea Survey	01/15/18	01/15/18
8	Rotation Mechanism Prototyping	01/15/18	01/19/18
9	Dispencing Mechanism Protyping	01/15/18	01/19/18
10	Material Selection & Cost Analysis	01/22/18	01/26/18
11	Design Modification	01/23/18	01/26/18
12	Design Finalization	01/29/18	01/30/18
13	Proposal Writing	01/22/18	01/26/18
14	Proposal Finalization	01/29/18	01/29/18
15	Proposal Submission	01/31/18	01/31/18
16	Learn basic PIC programming	01/10/18	01/18/18
17	Testing the sample code	01/19/18	01/19/18
18	Software High-level Structure Design	01/20/18	01/20/18
19	LCD Interface Design	01/23/18	01/26/18
20	Keypad Interface Design	01/24/18	01/25/18
21	Write Pseudo Code	01/24/18	01/29/18
22	Software Logic Development	01/29/18	02/05/18
23	Software-sensor interface	02/12/18	02/16/18
24	Software-actuator interface	02/19/18	02/23/18
25	Software System Integration	02/19/18	02/23/18
26	Software Performance Optimization	02/26/18	03/02/18
27	Sensor Testing	01/17/18	01/22/18
28	AC-DC adapter testing	01/22/18	01/23/18
29	Building Voltage Regulator	01/22/18	01/24/18
30	Integrate all circuit branches	01/27/18	01/31/18
31	Complete Circuit Prototyping	01/29/18	02/02/18
32	Build Circuits for Actuators	02/05/18	02/20/18
33	Final Circuit Debugging	02/28/18	03/05/18
34	Final Circuit Fabrication	02/26/18	03/29/18
35	Circuit Interference Investigation	02/12/18	02/16/18
36	Sensor Fine Tuning	02/19/18	03/05/18
37	Thermal Characteristic Investigation	03/01/18	03/09/18
38	Preparing Materials	01/21/18	02/02/18
39	Detailed Mechanical Design	01/29/18	02/01/18
40	Main Frame Fabrication	01/29/18	02/06/18
41	Fastener Reservoir Fabrication	01/30/18	02/02/18
42	Dispencing Ramps Fabrication	02/06/18	02/09/18
43	Actuators Selections	01/23/18	02/01/18
44	Actuorators Funcionality	01/30/18	02/12/18
45	Mount Sensors and Circuits	03/02/18	03/02/18
46	Mount PIC Board onto main frame	03/02/18	03/09/18
47	Mount Motors and Gears onto frame	02/09/18	02/21/18
48	Mechanical Parts Integration	02/12/18	02/16/18
49	Mechanical Funcitonality Verification	02/19/18	02/23/18
50	Hardware System Integration	03/05/18	03/13/18
51	Hardware System Functionality Verification	03/14/18	03/16/18
52	Full System Integration	03/19/18	03/23/18
53	Testing System funcionality	03/26/18	03/30/18
54	Improvement Design	03/14/18	03/20/18
55	Improvement Design Implementation	03/20/18	03/26/18
56	Back-up Plan Design & Testing	03/27/18	03/30/18
57	Public Demonstration Preparation	03/30/18	03/30/18
58	Subsystem Integration Evaluation	02/06/18	02/06/18
59	Subsystem Functionality Evaluation	02/27/18	02/27/18
60	System Integration Evaluation	03/13/18	03/13/18
61	System Functionality Evaluation	03/27/18	03/27/18
62	Final Report Writing	03/26/18	04/05/18
63	Public Demonstration	04/10/18	04/10/18
64	Final Report Submission	04/12/18	04/16/18

#	Task Name	Start	Finish	Revision	Assigned
1	Group Design	01/08/18	01/09/18		
2	Discussing RFP	01/08/18	01/09/18		Entire Group
3	Brainstorming	01/09/18	01/12/18		Entire Group
4	Conceptual Design	01/15/18	01/19/18		Entire Group
5	Market Survey	01/15/18	01/19/18		Entire Group
6	Literature Survey	01/15/18	01/15/18		Entire Group
7	Idea Survey	01/15/18	01/15/18		Entire Group
8	Rotation Mechanism Prototyping	01/15/18	01/19/18		Entire Group
9	Dispencing Mechanism Protyping	01/15/18	01/19/18		Entire Group
10	Material Selection & Cost Analysis	01/22/18	01/26/18		Entire Group
11	Design Modification	01/23/18	01/26/18		Entire Group
12	Design Finalization	01/29/18	01/30/18		Entire Group
13	Proposal Writing	01/22/18	01/26/18		Entire Group
14	Proposal Finalization	01/29/18	~~01/29/18~~	01/30/18	Entire Group
15	Proposal Submission	01/31/18	01/31/18		Entire Group
16	Learn basic PIC programming	01/10/18	~~01/18/18~~	01/17/18	Sherry
17	Testing the sample code	~~01/19/18~~	~~01/19/18~~	01/18/18	Sherry
18	Software High-level Structure Design	01/20/18	01/20/18		Sherry
19	LCD Interface Design	01/23/18	01/26/18		Sherry
20	Keypad Interface Design	01/24/18	01/25/18		Sherry
21	Write Pseudo Code	01/24/18	~~01/29/18~~	01/31/18	Sherry
22	Software Logic Development	01/29/18	02/05/18		Sherry
23	Software-sensor interface	02/12/18	02/16/18		
24	Software-actuator interface	02/19/18	02/23/18		
25	Software System Integration	02/19/18	02/23/18		
26	Software Performance Optimization	02/26/18	03/02/18		
27	Sensor Testing	01/17/18	01/22/18		Jason
28	AC-DC adapter testing	01/22/18	01/23/18		Jason
29	~~Building Voltage Regulator~~	~~01/22/18~~	~~01/24/18~~	Task Removed	Jason
30	Integrate all circuit branches	01/27/18	01/31/18		Jason
31	Complete Circuit Prototyping	01/29/18	02/02/18		Jason

Figure 78 Gantt Chart

	Task Name	Start	Finish
59	Subsystem Functionality Evaluation	02/27/18	02/27/18
60	System Integration Evaluation	03/13/18	03/13/18
61	System Functionality Evaluation	03/27/18	03/27/18
62	Final Report Writing	03/26/18	04/05/18
63	Public Demonstration	04/10/18	04/10/18
64	Final Report Submission	04/12/18	~~04/16/18~~ 04/12/18



15. Conclusions

Aupackto, a Hardware Packaging Machine, is designed and constructed to address the needs of furniture manufacturers to autonomously package fasteners to assemble their products. This machine packs four types of fasteners, bolts, nuts, spacers, and washers into an eight-compartment fastener organizer box based on user instructions within 3 minutes. The packaged fastener box is available to pick up by users after the operation completes.

Aupackto has successfully achieved all of the functionality and design objectives stated in the client's RFP and the team's proposal. The dispensing mechanism and the rotating mechanism both work reliably, which ensures a high packaging accuracy. The machine is easy to set up and intuitive to use due to the simplicity of the design and user-friendly interface..

The 2-layer design creates spaciousness in structure and leaves room for further improvements and modifications. The circuitry design follows symmetry and modular-unit design, making it easy for future maintenance and examination. In terms of microcontrollers, a GLCD display along with a real-time-display LCD screen provides the users with the display of current type of fastener being dispensed and the machine's operation time.

The budget for this machine is $ 217.33 CAD, which is within the budget limit of $ 230 CAD.

It is acknowledged that some minor issues still exist in the design, which need to be fixed or improved upon.

Some of the further improvements of the machine include reducing the size and weight of the machine to maximize its portability. The machine can also be made more robust in terms of the mechanical structure and the program, such that it can reach its maximum performance in the long term. Additionally, the user interface can be further improved by incorporating the permanent logs and PC interface.

16. Reference

[1] RFP

[2] Canadian Union of Public Employees https://cupe.ca/repetitive-strain-injuries

[3] NFPA 79 https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=79

[4] Ontario NFPA https://www.nfpa.org/News-and-Research/News-and-media/Press-Room/News-releases/2013/Ontario-Canada-to-adopt-NFPA-Professional-Qualification-Standards-in-2014

[5] Moment of Inertia formula http://www.livephysics.com/physical-constants/mechanics-pc/moment-inertia-uniform-objects/

[6] Density of Acrylic

https://www.engineeringtoolbox.com/density-solids-d_1265.html

[7] Density of Wood

https://cedarstripkayak.wordpress.com/lumber-selection/162-2/

[8] Lazy Susan bearing

http://www.leevalley.com/en/wood/page.aspx?p=44042

17. Appendices

Appendix B Code: