Division of Engineering Science
UNIVERSITY OF TORONTO

Hardware Packing Machine

DESIGN PROPOSAL

Prepared by

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1. Terms and Definitions

RFP

Request for Proposal # 2 – The Hardware Packing Machine.

Package

Fill in a specified number of fasteners in to the corresponding compartment.

Fasteners box

Plastic circular box with 8 identical compartments to store different types of fasteners. It has a diameter of $190 \pm 5\ mm$, and a height of $20 \pm 1\ mm$.

Compartment

Partitioned storage container inside of the fasteners box. Each compartment resembles the shape of a circular sector with 45 degrees.

Reservoir

The container of the machine to contain the pre-sorted fasteners prior to processing.

Feeder

The bottom of the ramp that directly feed the fasteners to the open compartment of the box.

2. Executive Summary

This proposal outlines the design features and construction planning for the automated fasteners packaging machine for AER 201 engineering design project. This machine accepts pre-sorted four types of fasteners, nuts, bolts, spacers, and washers, and discharge them into specified compartments of the fasteners box. The combination of fasteners and the compartments are specified by the users via the LCD interface.

In the problem formulation part of this proposal, the main design objectives, detailed metrics, and the constraints are framed as per design feature breakdown. The viability of the design is verified through sufficient background surveys, i.e. literature survey, idea survey and market survey. The design proposal is determined through a rigorous design making process, where alternative solutions are evaluated, using utility-based evaluation and Analytical Hierarchy Process.

The machine, in general, operates in three different modes. During the Standby mode, pre-sorted fasteners are loaded into the corresponding reservoirs. Then the machine enters the Packaging mode, dispensing the fasteners into the compartments via the ramps according to user's instructions. During the Post-packaging mode, the ramps redirect the remaining fasteners to the bottom reservoirs for recollection.

There are three main mechanisms designed to complete the task. The dispensing mechanism of the machine consists of four rotating reservoirs and ramps mounted with IR photoresistance sensor to count the number of the dispensed fasteners. The detecting mechanism detects the location of 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 (i.e. the feeder).

The overall budget to build the machine is around $191.44, including the raw materials, PIC microcontroller, and electrical components.

The three members in Team 34 are Yuxuan(Sherry) Chen, Yizhou (Philip) Huang, and Jiachen (Jason) Zhou. Yizhou is responsible for the electromechanical system, specifically the design, analysis and construction of the mechanical parts of the machine and actuators. Jiachen is the circuit member, who designs the circuit components of the machine to communicate between the microcontroller and the mechanical system. Yuxuan is the microcontroller member of the team, who is responsible for implementing the program and effectuating the logic of the machine.

3. Problem Formulation

3.1 Goals

A furniture manufacturer needs to autonomously pack various types of fasteners into a compartment box based on given instructions. The goal of the project is to design and construct the prototype of a machine that packs fasteners based on given instruction. The different types of fasteners are nuts, bolts, spacers and washers.

3.2 Objectives

3.2.1 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.

3.2.2 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 manufacturable (HO3)
- The machine should be able to operate with a low failure rate (HO3)

3.2.3 Constraints

- The machine must operate autonomously once the empty box and fasteners are loaded.
- The entire prototype must fit with 0.5*0.5*0.5 m^3.
- 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.

3.3 Functional Analysis:

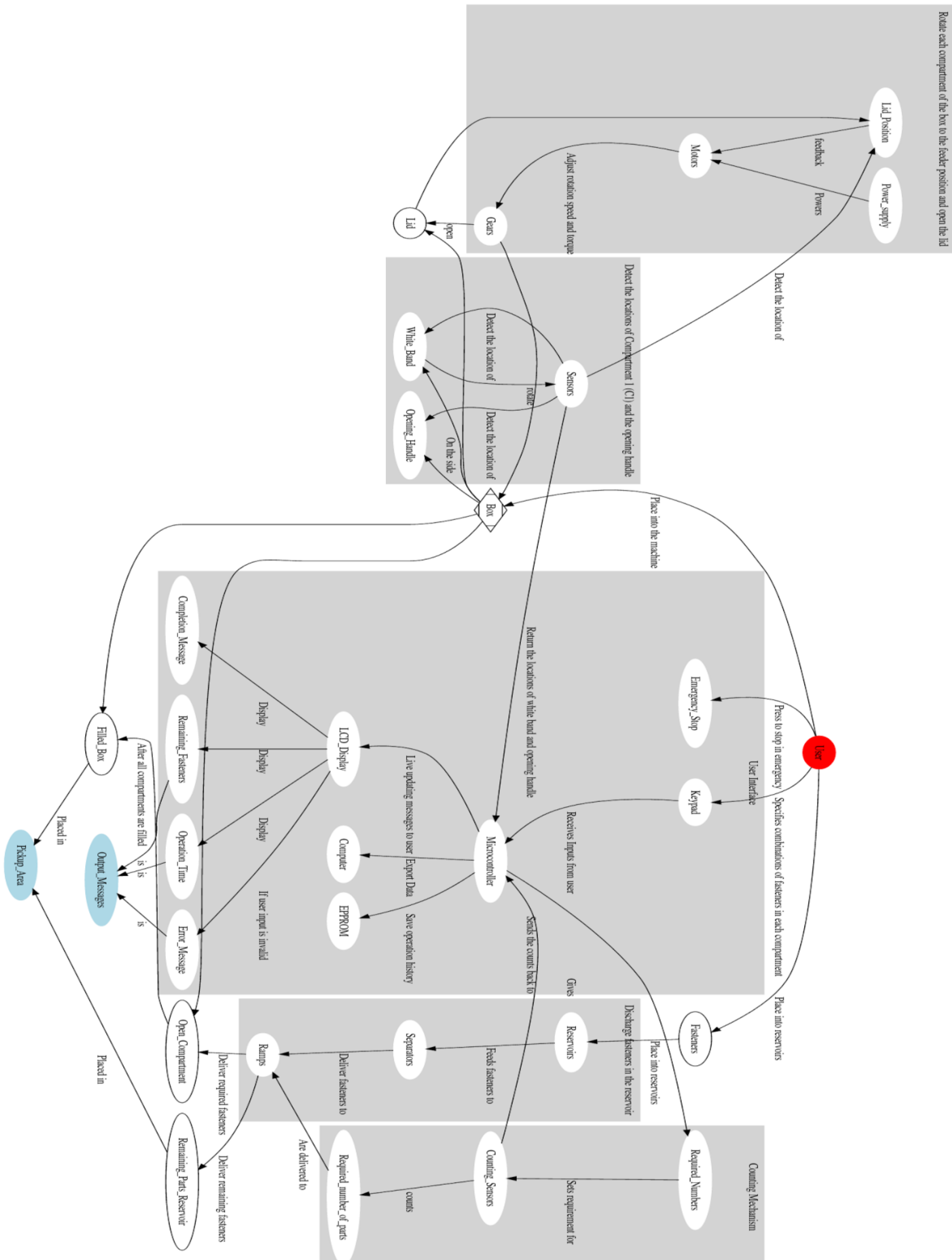


Figure 1 Functions Logic Flow Chart

3.3.1 Overview:

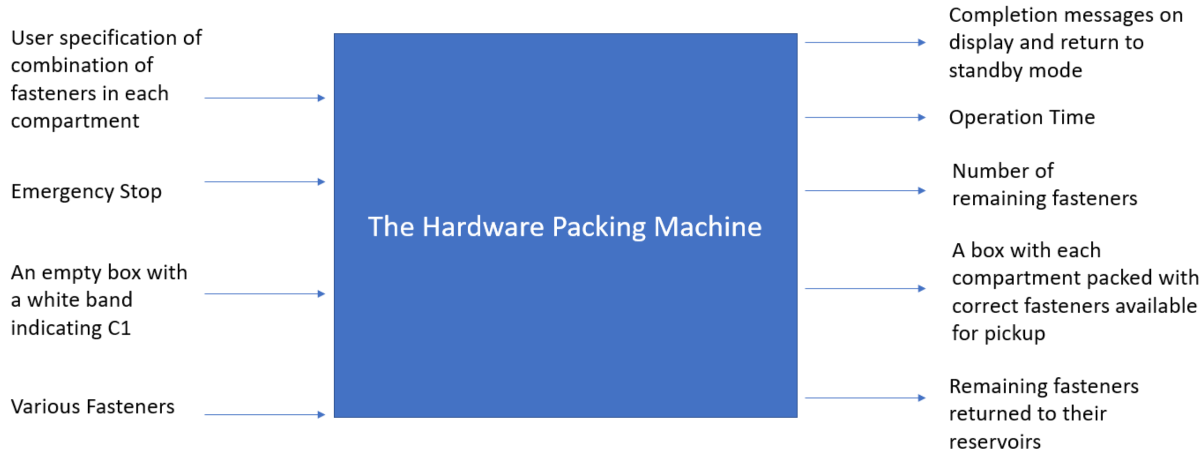


Figure 2 Overview Design (Glass Box Method)

3.3.2 Detailed Breakdown:

A. 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

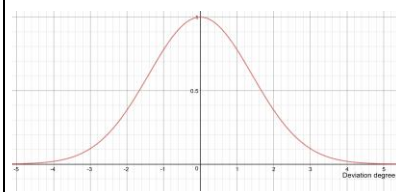
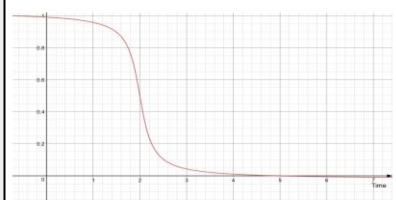
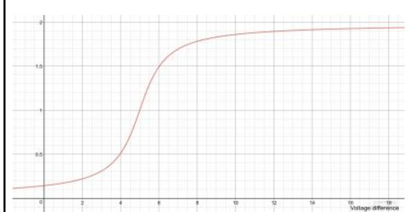
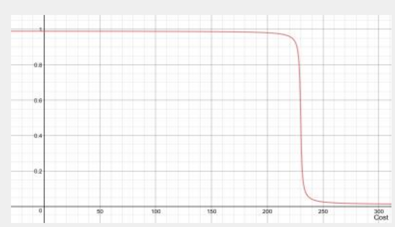
C3. Less time required as outlined in M4 is preferred

C4: Less power required in M5 is preferred

C5: Less cost as outlined in M6 is preferred

Utility Function 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	

B. 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)

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 complete "one rotation"	-Choice of materials does not violate client's constraints in the RFP -Machine can usually autonomous complete "one rotation". If not, the minor error can be fixed quickly (<20s)	-As per "Satisfactory", hardware parts rarely need to be replaced or rebuilt -Machine can always autonomously complete "one rotation". No human assistance is needed at all times	- As per "Good", minimal noise and vibration made during the rotation process

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

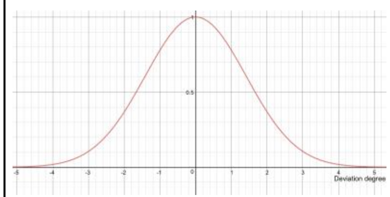
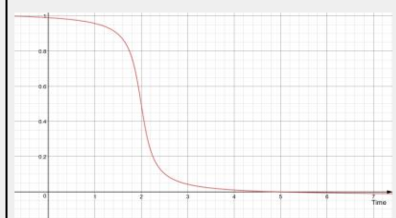
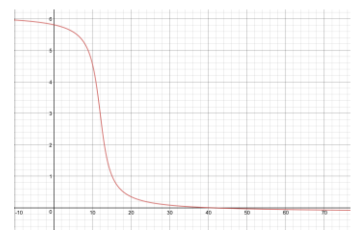
C4: Less percentage of power dissipation detailed in M6 is preferred

C5: Less cost outlined in M7 is preferred

C5: Higher grades of hardware components listed in M8 is preferred

Utility Function Table:

Table 2: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	

C. 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)

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)

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.

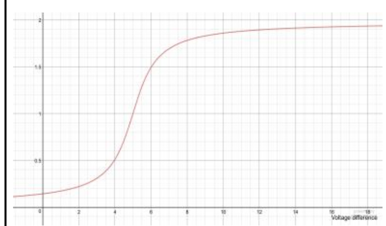
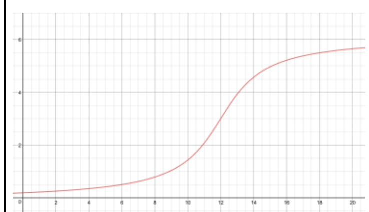
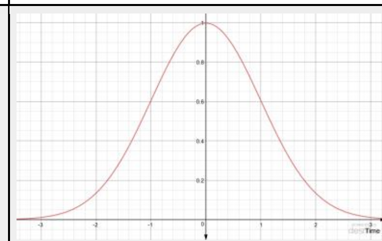
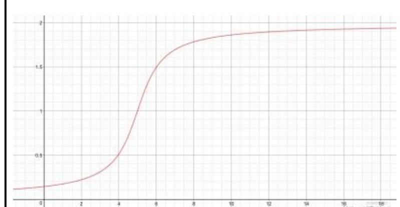
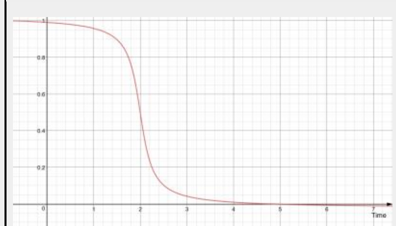
C3. Higher grade outlined in M4 is preferred.

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

C5. Higher grade in M4 is preferred

Utility Function Table:

Table 3: 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	

4. Background Survey

4.1 Literature Survey

4.1.1 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.

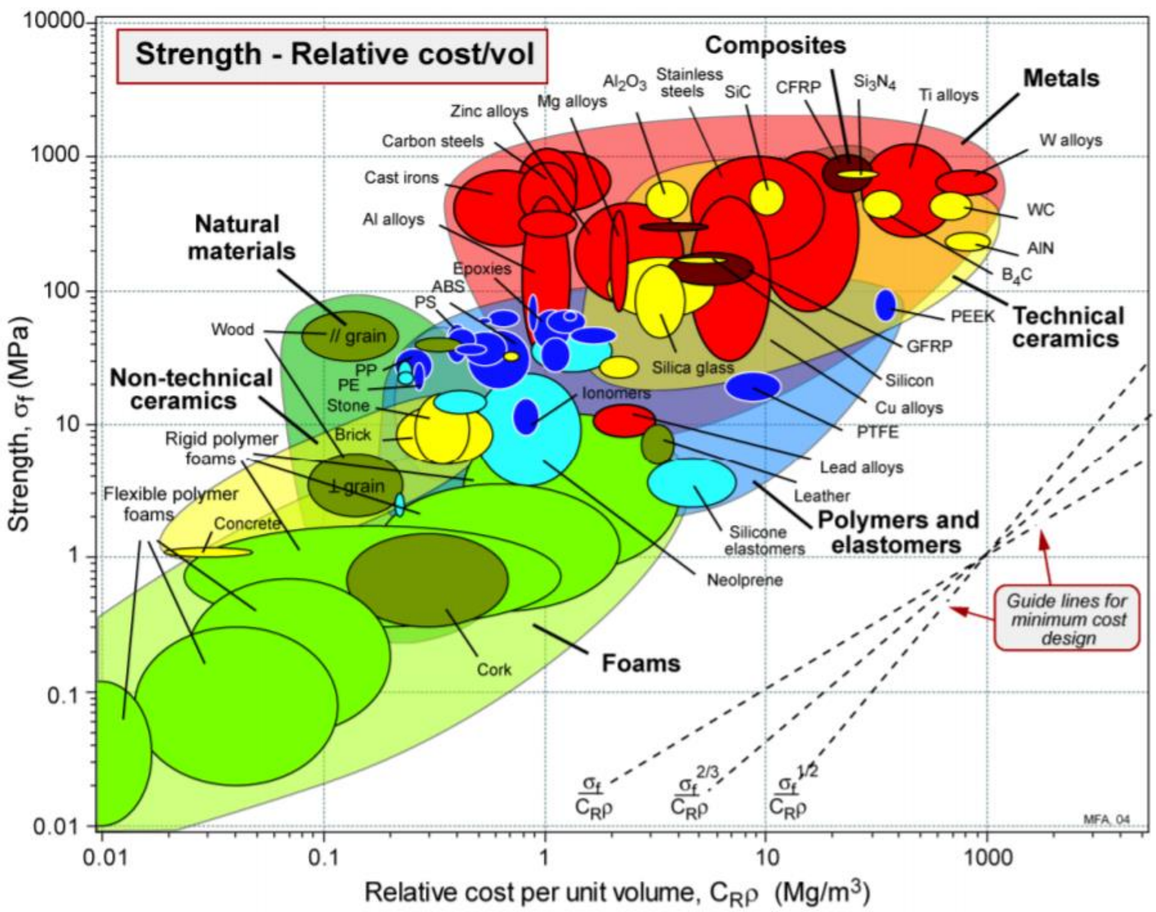


Figure 3 Strength of Various Materials versus Relative Cost (CES2010 Edupack)

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.

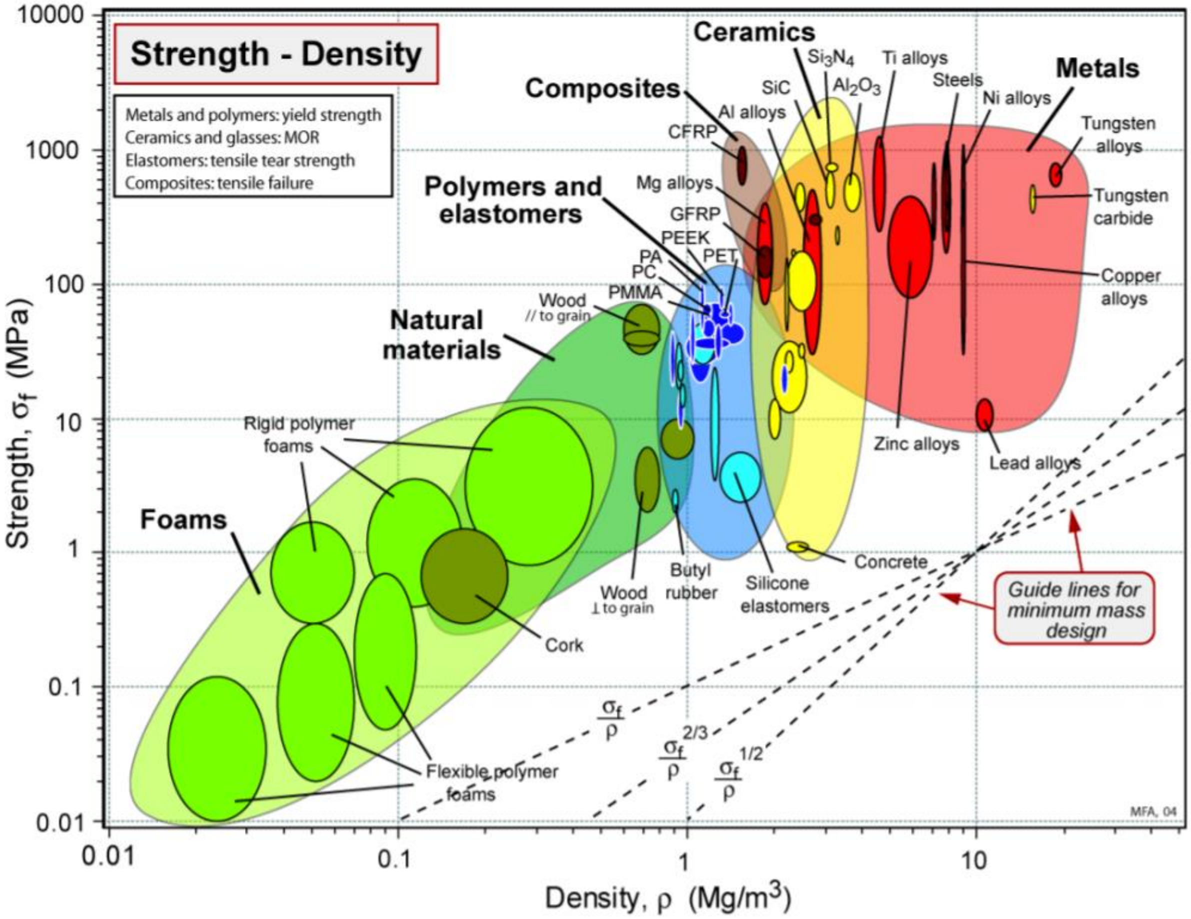


Figure 4 Strength of Various Materials versus Density (CES2010 Edupack)

4.1.2 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].

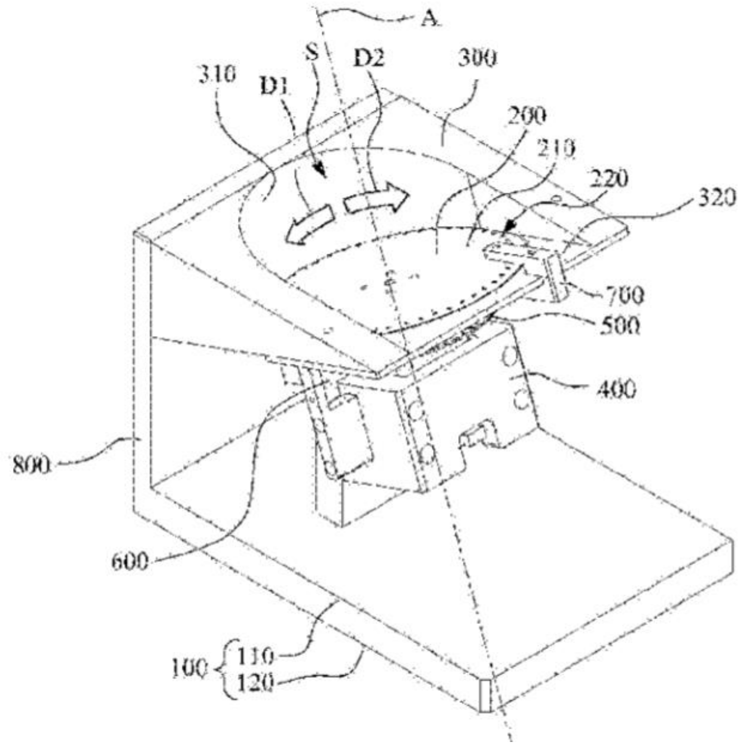


Figure 5 Patent Schematics of a Screw Feeding Device

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].

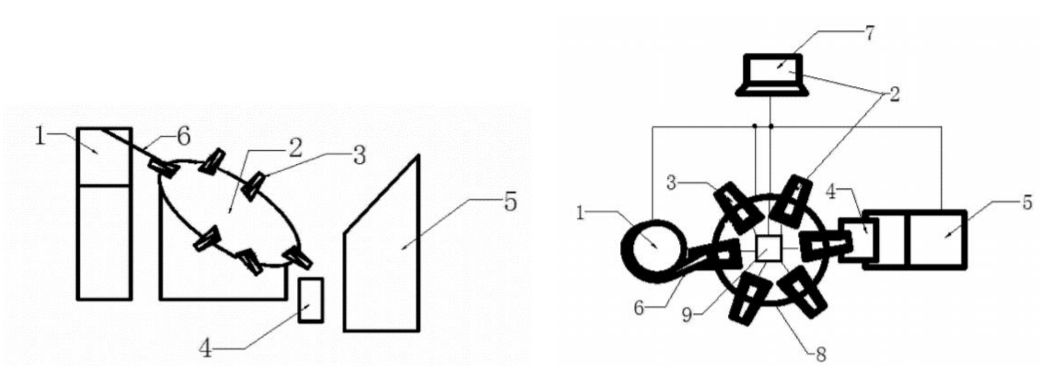


Figure 6 Patent Schematics of a Fasteners Automatic Packaging Device

4.2 Idea Survey

4.2.1 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. 7. 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.

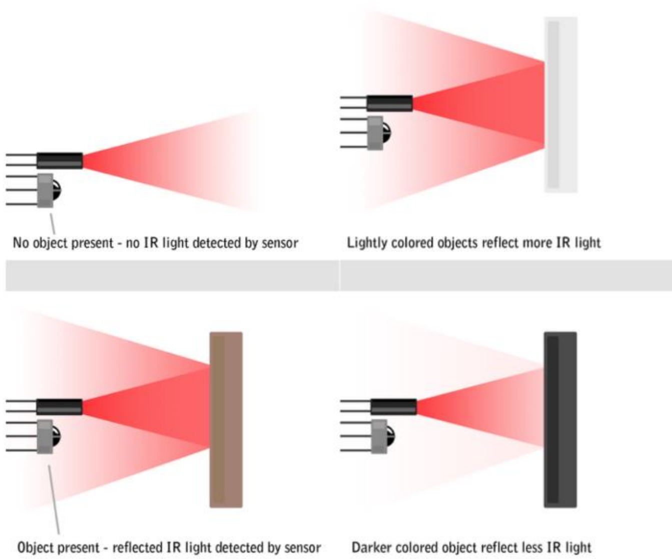


Figure 7 Demonstration of the Detection Mechanism of IR Reflective Sensor

4.2.2 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. 8. 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.

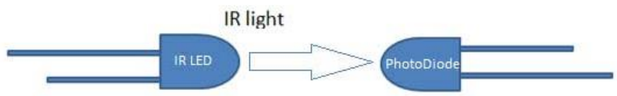


Figure 8 Mechanism of IR Beam Breaking

4.2.3 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. 9. 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 9 Vibratory Dispensing Machine [7]

4.2.4 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.

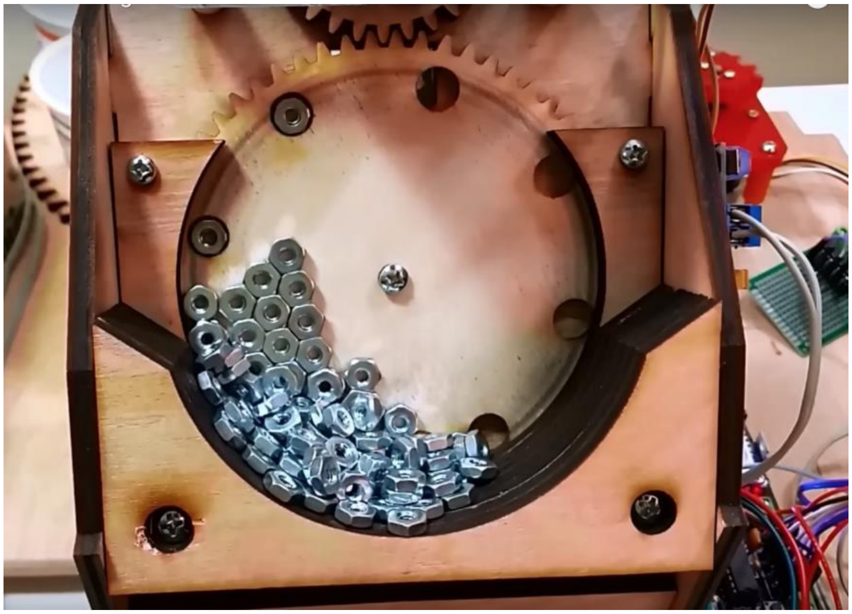


Figure 10 Automated Small Parts Counting Machine [8]

4.3 Market Survey

4.3.1 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. 11. 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 11 Vibratory Bowl Feeder

Centrifugal Feeders:

This device has a smooth and gentle operation. The parts are loaded to a rotating center disk mounted in the center 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. 12[10].

Figure 12 Centrifugal Feeders

4.3.2 Actuators

Solenoids:

Solenoids are electromagnets where wires are wrapped around. As current passes through the wires, a magnetic field will be generated and attracts Ferromagnetic materials (i.e. steel). When there are no more current, a spring will usually push/pull the attracted object back to its original position [11].

DC Motors:

DC motors, invented by Faraday in the mid-nineteenth century, generates a rotational torque when a current-carrying conductor is placed in a magnetic field. For DC brushed motors, the conductor will be connected to the rotor, and the stator provides a magnetic field which is fixed in place. For modern brushless DC motors, the permanent magnet is mounted on the rotor. The polarity of the electrically powered magnet will be switched according to the angular position to provide continuous rotations [11].

Stepper Motors:

The stepper motor is a special type of brushless DC motor that contains radially oriented electromagnets and permanent magnet that follows the magnetic field and rotates. This allows open-loop (without feedback) precise, radial position control, but has a relatively low torque, requires complex driving circuits and occupies many I/O resources [11].

Servo:

A servo is a special type of motor that utilizes linear feedback control to precisely control the rotor displacement. The desired position is set with the width of the "ON" position of the duty cycle of the PWM. However, one downside is that it usually cannot achieve continuous rotation [11].

Motor Encoder:

A motor encoder is a device that can convert the position of motors into digital signals. The regularly spaced lattice structure on the shaft will block or transmit light depending on the specific angular position as the motor spins. A light reflection or transmission sensor will then determine the detect the light signal and tell the angular speed from the frequency of light beams [11].

Motor Driver:

Motor drivers connect DC/stepper motors, signals, and power supply together on one board. Since a DC motor typically has two terminals (namely positive and negative), changing direction means swapping the two terminals and changing speed means adjusting the voltage across it. This function can be realized only through applying a motor driver, i.e. H-bridge. An H-bridge typically consists of four transistors as shown in the figure. By enabling two of them in diagonal direction, the motor is able to reverse its polarity. The motor can also be braked by setting either top two or bottom two transistors to be off [11].

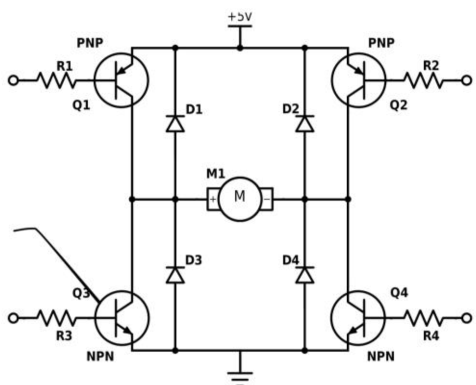


Figure 13 H-Bridge Circuit Schematics

5. Conceptualization:

5.1 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.

5.1.1 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 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.

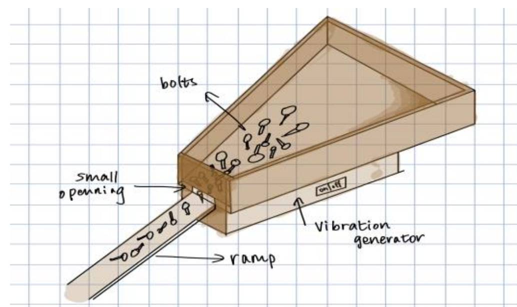


Figure 14 Vibratory Bowl Feeder

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.

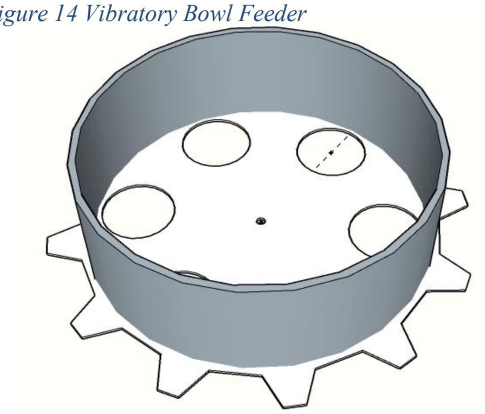


Figure 15 Vibratory Dispensing Mechanism

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

Utility based evaluation:

Table 4: 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 5: 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 6: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 7: 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 8: 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 9: Normalized Matrix

	A	B	C	Overall Preference
A	0.652	0.625	0.66	1
B	0.130	0.125	0.111	0.366
C	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.

5.1.2 Detecting Mechanism

Utility based Evaluation:

Table 10: 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 11: 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 12: 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.

5.2 Specification of Proposed Design

5.2.1 Design overview

The overall operation of the machine can be specified into three different modes: Standby mode, Packaging mode, and Post-packaging mode.

In **Standby mode**, all parts of the machine are idle. The machine has completed the previous operations and is waiting for the instructions from the user to proceed to perform the next operation. The machine enters the **Packaging mode** after user giving instructions via the interface and loading pre-sorted fasteners into the corresponding reservoirs. Fasteners are delivered to the specified compartments of the empty fasteners box based on the instructions. The rotating mechanism rotates the fasteners box relative to the lid to allow fasteners to be delivered into the designated compartments of the box. After the box is properly packaged, the machine will then enter the **Post-packaging mode**, where the rotating mechanism becomes idle, and the ramps redirect the remaining fasteners into the bottom reservoirs.

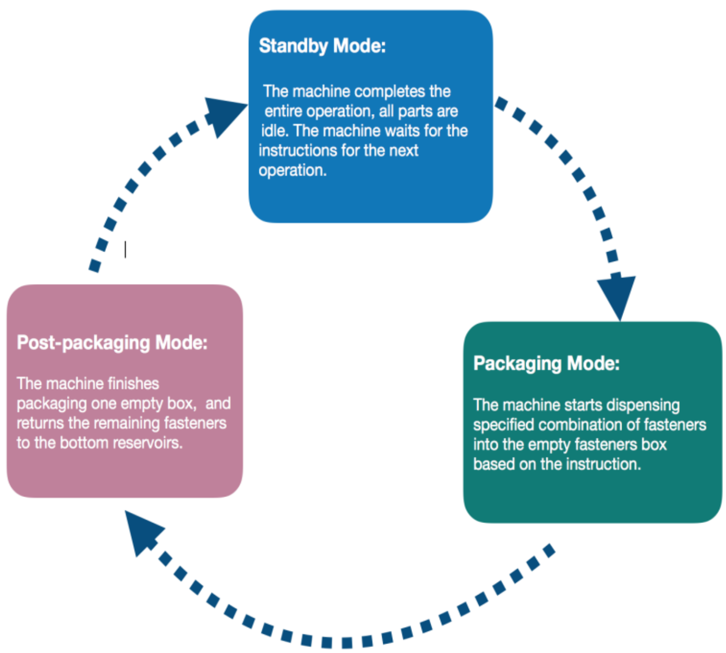


Figure 16 Three Operation Modes of the Machine

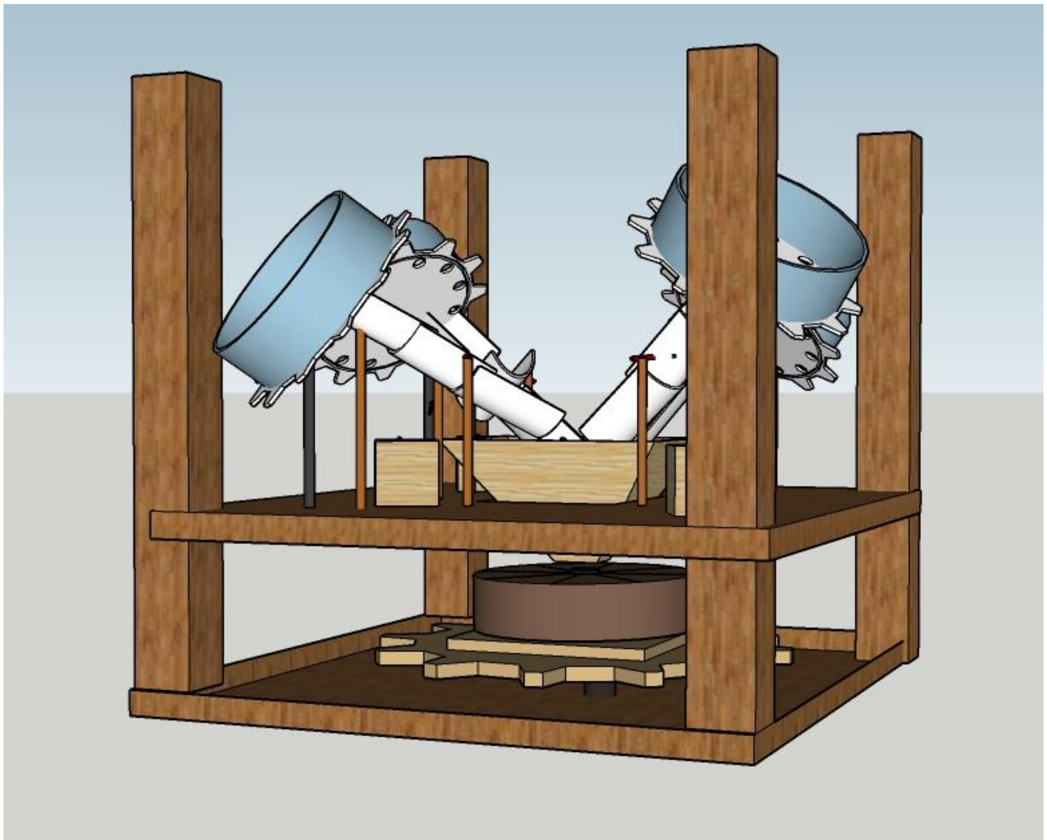


Figure 17 Design Overview

Reservoirs:

The machine includes four reservoirs, each of which consists of a top rotating circular disc and a fixated base disk. The top disc has a radius of 75 mm, and a width of 5 mm. For each reservoir, there are six identical holes drilled from the top disc that fit the geometrical shape of a specific type of fastener, such that only one can pass the hole each time (Fig. 18).

- For the **washers** reservoir, the holes are circular with a radius of 17 mm and a width of 1.2 mm.
- For the **spacers** reservoir, the holes are rectangular with dimensions 22.5 mm * 13.5 mm, and a width of 6mm.
- For the **nuts** reservoir, the holes are circular with a radius of 6.75 mm, and width of 4 mm.
- For the **Bolts** reservoir, the dimension of the hole is specified in the bottom right graph in figure 19.

The top disc is surrounded by a cylindrical shell with a radius of 75mm, width of 3mm, and height of 47mm. There are 12 teeth on the outer edge of the top disc, such that the speed of rotation can be easily controlled by gears.

The position of the base circular disc is fixed, with only one hole drilled at the top of the disc. The top rotating disc is stacked on top of the base disc. Pre-sorted fasteners would be loaded into the corresponding reservoirs by the user. Fasteners would fall into the holes during rotation until the hole reaches the hole on the base disc, where the fastener would be dispensed from the reservoir. A ramp is attached to the hole to catch and direct the discharged fasteners.

The reservoirs keep rotating during the packaging mode and the post-packaging mode until all of the fasteners are discharged from the reservoirs.

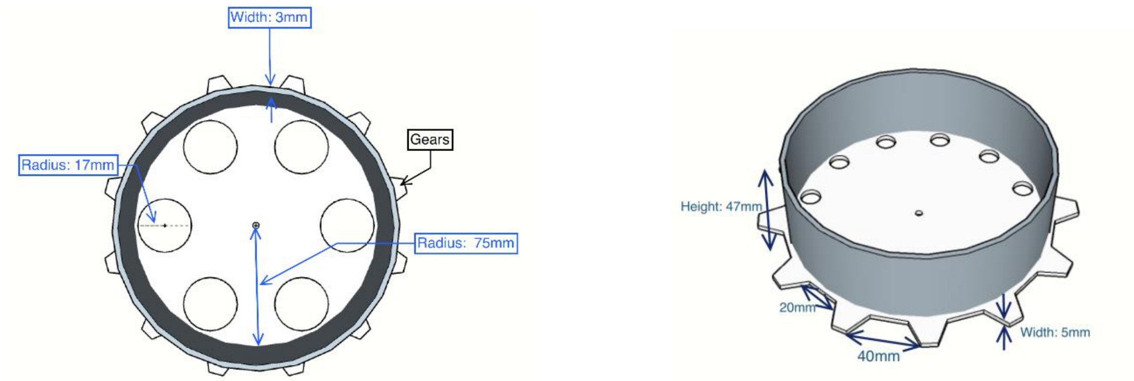


Figure 18 Top and 3D View of the Rotating Disc of the Reservoir (Example Shown in Washers)

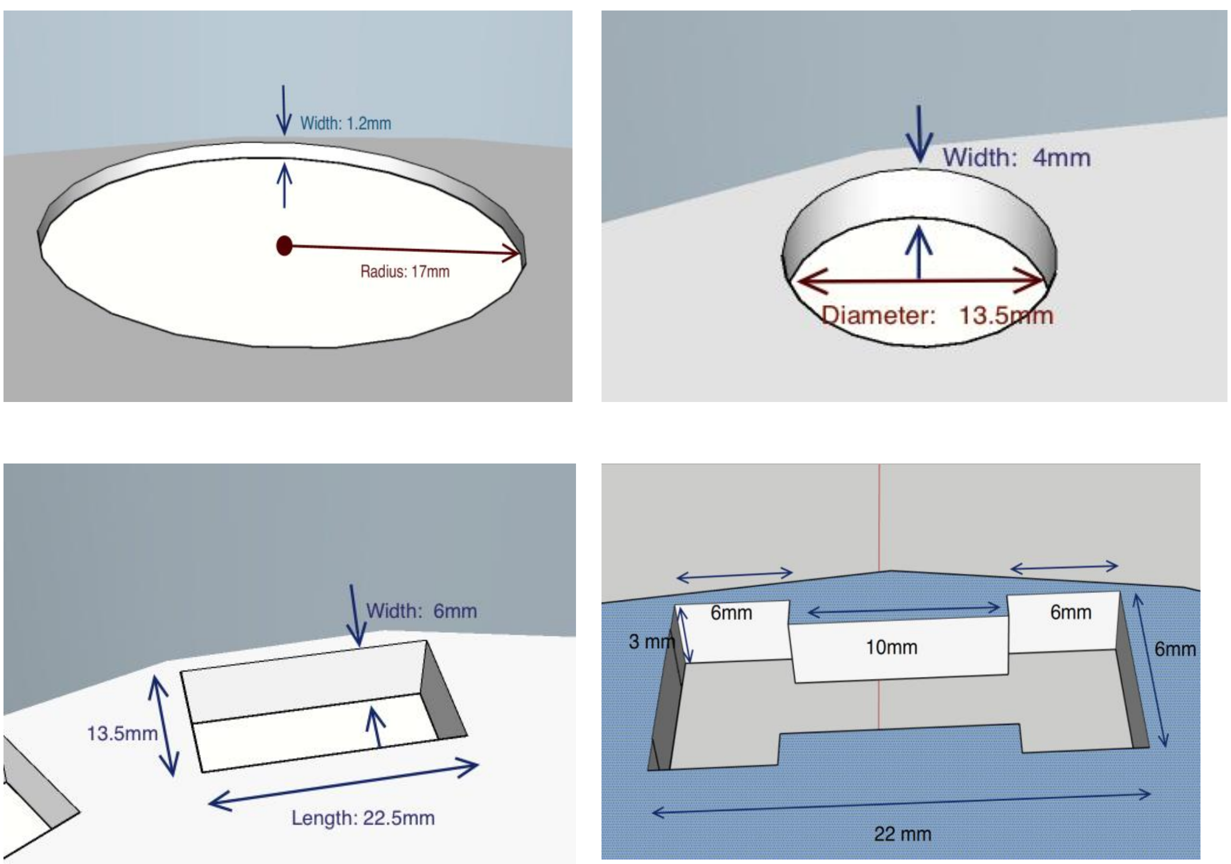


Figure 19 Four Different Shapes on the Rotating Disc

Ramps:

There are four ramps in total, each of which is attached to the base disc of the reservoir in order to catch and direct the dispensed fasteners.

Each ramp has three sections overlapping with each other, where the middle session can rotate around the hinge while the other two are fixed.

During the Packaging Mode, the ramps are stacked on top of each other, which direct the fasteners from the reservoirs downwards to the funnel, which then delivers the fasteners to the designated compartment.

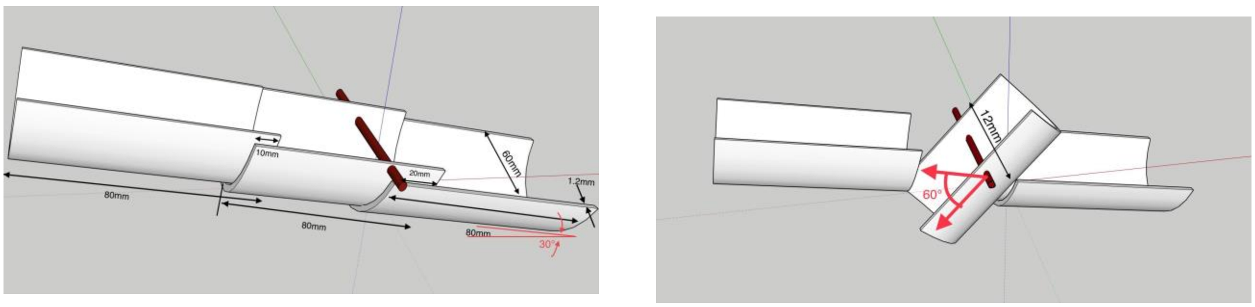


Figure 20 Ramp Design, and Opening Mechanism

Once the machine enters the Post-packaging mode, the middle section can rotate 60 degrees downward, such that all the remaining fasteners can be redirected to the bottom reservoirs via the ramps for recollection.

Funnel and Bottom Reservoirs:

All of the fasteners dispensed via ramps, during the packaging mode, would be collected by the funnel, which allows the fasteners to be delivered into the compartment accurately.

There are four bottom reservoirs that are located directly underneath each ramp. When the middle section of the ramp is rotated during the Post-packaging mode, all of the remaining fasteners are dispensed from the reservoirs and are redirected to the bottom reservoirs.

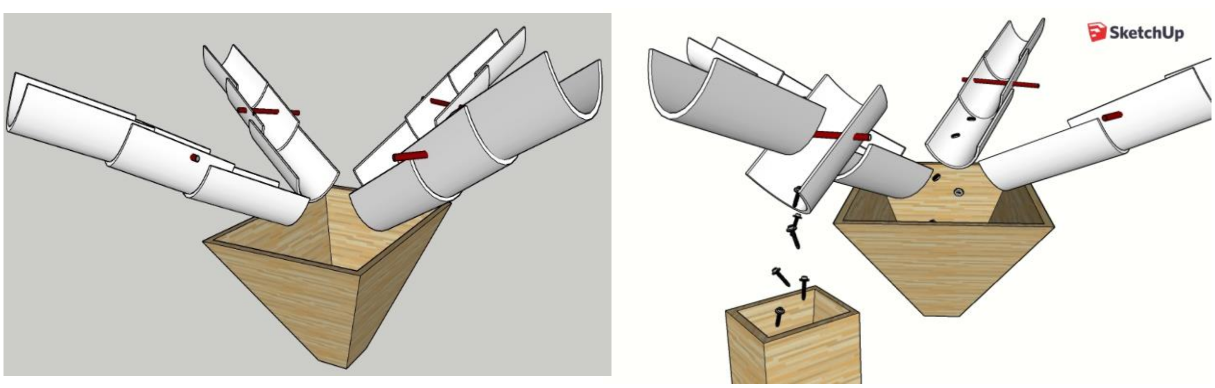


Figure 21 Funnel and Bottom Reservoirs

Rotating mechanism:

The fastener box can be rotated by a carousel. There is a 170mm*170mm*3.5mm square plate attached on top of the circular gear, and a 25mm * 30mm cylinder extended from the centre of square plate, such that the extension from the bottom of the fasteners box and the hollow structure of the box can be locked onto the square place.

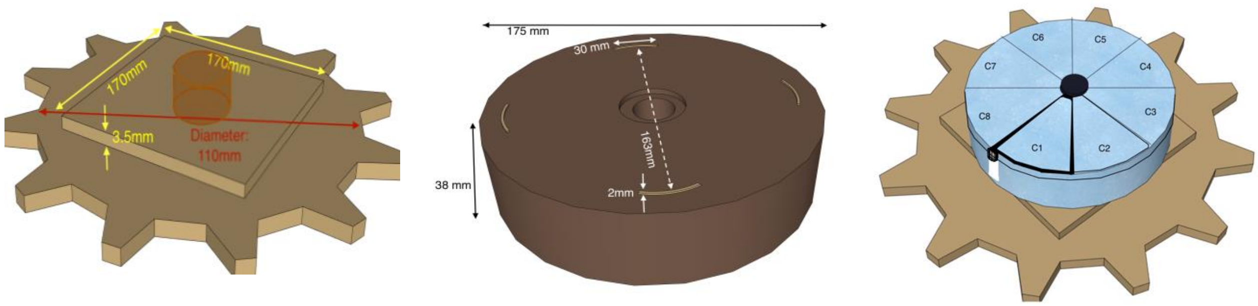


*Figure 22 Carousel Design (**right**: the rotating mechanism; **middle**: the bottom view of the fasteners box; **left**: the fasteners box is stuck on top of the square place)*

The circular gear at the bottom has 12 teeth on the edge, which can be rotated using a smaller gear.

After the first compartment is packaged, the carousel would rotate to a specific angle such that the exit of the funnel is pointing at the opening of the next compartment. The angle of rotation after packaging one compartment depends on the number of assembly steps, which is determined by the user.

- For a 4-step assembly, C1 (the compartment that is marked with a white band), C3, C5, C7 will be filled in.
- For a 5-step assembly, C1, C2, C4, C5, C7 will be filled in.
- For a 6-step assembly, C1, C2, C3, C5, C6, C7 will be filled in.
- For a 7 or 8-step assembly, Compartments will be filled in consecutively starting from C1.

The mechanism also includes a cap to interlock with the opening handle of the fastener box. The cap is fixed and does not rotate with the disc or the gears.

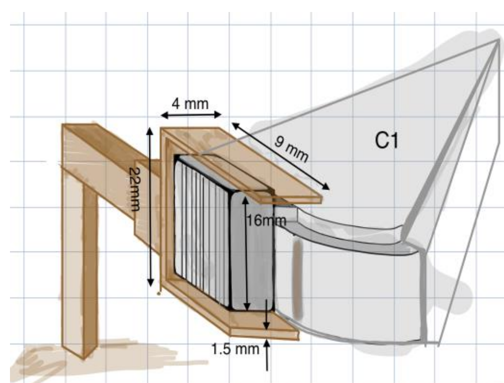


Figure 23 Opening Handle Mechanism

After the fasteners box is loaded, the carousel would rotate the box in clockwise direction until the opening handle snaps in the cap. The rotating torque from the gear applies onto the opening handle, which causes the slider to open until the opening angle reaches 45 degrees. After the slider is open, the cap acts as a mechanism to fixate the position of the lid, and the box rotates relative to the lid until the first compartment is aligned with the opening sector, which can be achieved by detecting the white band marked on the outer edge of compartment 1.

After packaging the first compartment, the box continues rotating while the lid remains fixed by the cap until all the compartments are properly packaged.

The last step is to rotate the box relative to the lid 360 degrees until the slider is completely closed and snapped. The machine finishes the packaging mode and enters the post-packaging mode.

5.2.2 Electromechanical Design:

Torque calculation:

An experiment was performed collaboratively with Nirmal Pol and Ameya Datta under the supervision of machine shop technologist Colin Harry (during the practical session on Tuesday, Jan 30th 2018 to determine the minimal amount of torque to overcome the static friction (between the lid and the box) to move the lid of the box. The experimental setup is shown follow:

Weight will be added in the rubber band at the bottom to increase the gravitational force being applied on the opening handle of the box. The result of the experiment indicates that at least **1kg** of needs to be added to the rubber band to rotate the lid.

Using the formula $\boxed{\text{torque} = \text{force} * \text{lever arm length} = 1\text{kg} * g * 0.1\text{m}}$, we can then estimate the minimal torque required scales with **1Nm.**

One thing worth noting is that the kinetic friction coefficient is less than the static friction coefficient between the lid and the box. This means that if the torque generated is larger than the minimal torque, the motor would generate more than enough torque to rotate the box with respect to the lid.

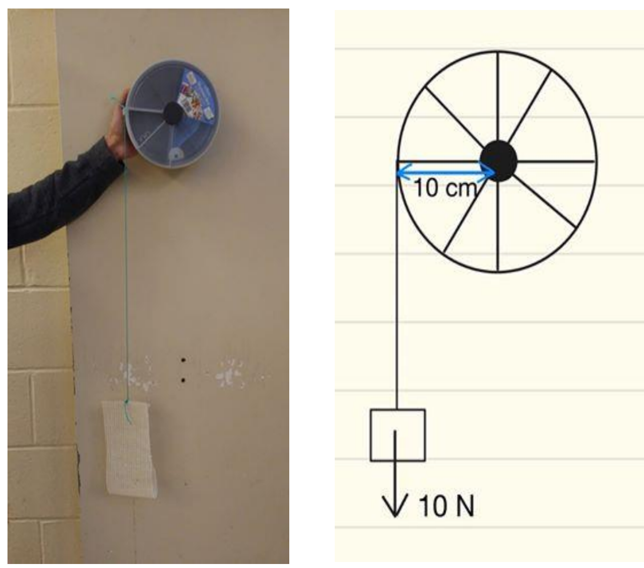


Figure 24 Torque Experiment and Free Body Diagram

Actuators:

As discussed in the market survey, there are mainly one type of linear actuator(solenoid) and three types of rotational motors (DC, stepper, servo). Considering the strengths and limitations of each type discussed previously, the electromechanical member has proposed the following selection of motors for the design:

1. Continuous servo motor will be used for the rotational motion of the carousel. Since the carousel directly controls the orientations of the compartments and the opening angle of the lid of the compartment under the box, servo motor is deemed suitable because of its ability to accurately control the angular position of the rotor. Continuous motor, on the other end, require more IO resources than the servo. The torque generated by a stepper motor is also less than the torque generated by a continuous servo motor as shown in the datasheet [12,13].
2. DC motor are used for the rotational motion of the reservoirs. Since the design only requires constant-speed continuous rotation of the reservoirs, DC motors are very sensible choices because of its easily implemented driver circuit and high torque given per dollar spent [14].
3. The servo motor will act as a controller for the rotation of the middle section of the ramp, which would act according to the microcontroller's command to determine the destination of each fastener. (Fig. 20) Since the angle of rotation is going to be less than 90 degrees, servo motors are chosen to control the angle of the ramp. Since there are four ramps in total, using a stepper motor would require significant amount of I/O resources on the PIC development board. (4 pins/ramp * 4 ramps = 16 pins!) This eliminate the possibility of using stepper motor for this purpose.

5.2.3 Circuits Design:

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. This section will introduce each electrical component and elaborate on their functions as well as the implementation. The data sheets of each electrical component is attached to this proposal in Appendix. Please note that for the entire machine, the uses +12V to drive actuators and +5V for logic high and low signals.

1. Power Supply

The machine is constrained to be plugged into a 120V 60Hz AC power directly from the wall outlet. Note that a typical AC/DC converter, which has 3 types of DC outputs: +12V 1A, +5V 4A, -12V 0.4A, is readily available on the market, see Appendix for a detailed data sheet [15]. In this project, the internal circuits are powered by 12V for the actuators and 5V for the rest signal transmission.

2. Emergency Stop

Design for Safety is always the first and foremost in terms of engineering design. In this project, since the machine is directly plugged in a wall outlet (120V, 60Hz) which is a lethal value for a human, an emergency stop as an acute protection mechanism must be installed to prevent electric shock or even electrocution. The schematic below shows that

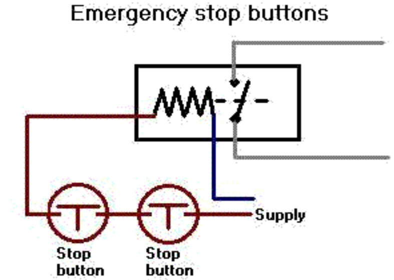


Figure 25 Emergency Stop Schematic

by pressing the emergency stop it cuts off the power from the power supply immediately [16].

3. Voltage Regulator

A voltage regulator is an electronic device that stabilize a DC voltage. It can also be used to filter the input and output noises by adding capacitors on both sides. A typical circuit schematic is shown below [11].

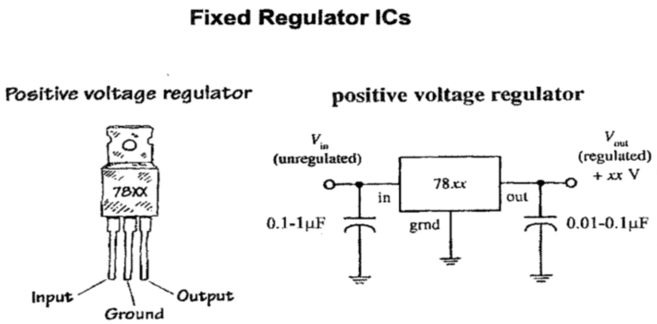


Figure 26 Circuit Schematic for Voltage Regulator

4. DC Motors

The DC motors are used to control the feeding gears that rotate the four reservoirs. For each reservoir, while the number of dispensed fasteners has not met the required amount, the gear is meant to keep rotating to dispense more, which is a proper scenario to use DC motors to drive. As explained in the previous section, a four-transistor H-bridge can be used to drive a DC motor and to control its direction of rotation. However, due to the nature of our feeding gear's function, the DC motors in this project are only required to run in one direction. This means, by modifying a H-bridge driver circuit, it is expected to use only one side of an H-bridge (two transistors) to control the DC motors from the microcontroller. The circuit schematic and its status table are shown below.

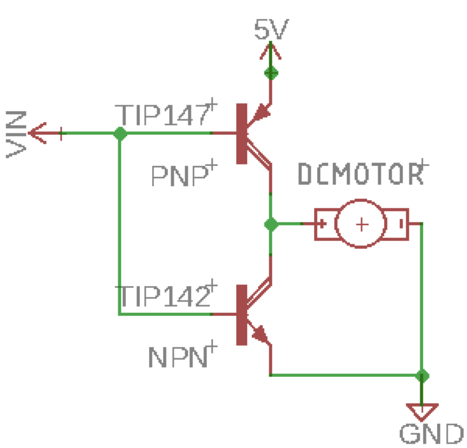


Figure 27 DC Motor Driver Circuit Half-H Bridge

Table 13:The DC Motor Control Status

V_{in}	TIP147Base	TIP147 State	TIP142Base	TIP142 State	Motor Status
1	1	0	1	1	Brake
0	0	1	0	0	Moves Clockwise (Current from "+" to "-")

5. Stepper Motors

The stepper motor is used to rotate the box with more precise and equally spaced angular increment, and even higher torque at low speeds without the involvement of a gear. Since the box is separated into 8 identical sector compartments, it is preferable to use a 45°-per-step stepper motor to rotate the box sector by sector. Another profound advantage a stepper motors has other than a DC motor is its ability to hold the torque i.e. hold the position firmly when not running. However, stepper motors do not respond to a typical clock signal, instead, the input signals need to be energized in the correct sequence that the motor's shaft can recognize. This procedure can be done by connecting to a translator, such as a ULN2003 series transistor-array ICs. Then, a ULN2003 will communicate with 4 pins on a microcontroller, such as an Arduino board shown below [17] [18].

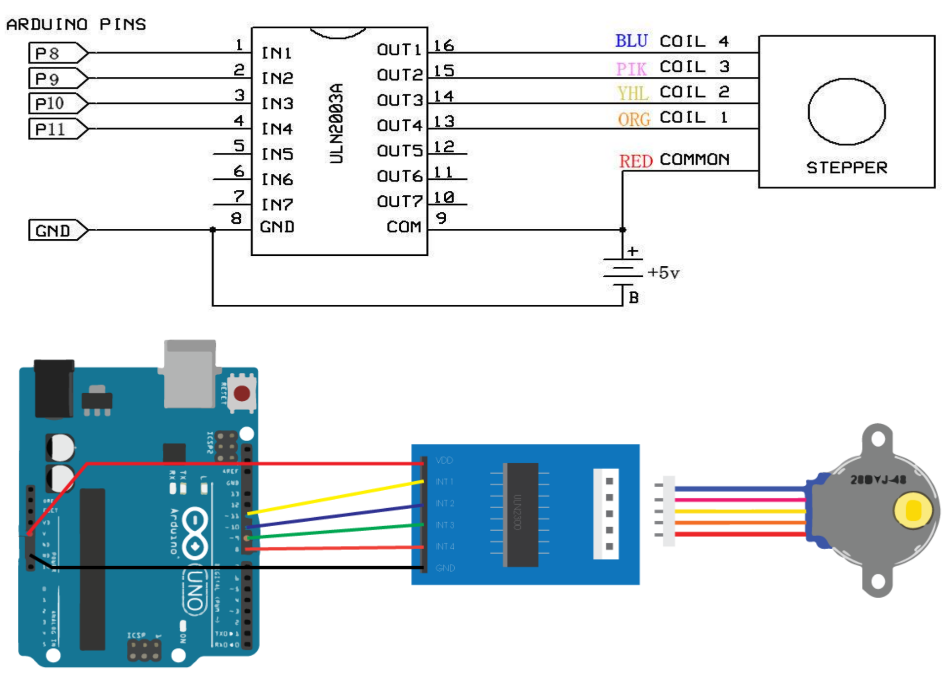


Figure 28 Stepper Motor Drive Schematics (Arduino Compatible)

6. Servo Motors

After the complete dispensation of fasteners, the remaining ones are designed to return to their recollection reservoirs. The mechanism will be done by rotating the middle section of the ramp 60° downwards to redirect the fasteners to the reservoirs placed below. Servo motors are mounted onto the hinges and controlled through the microcontroller. Each servo motor has three terminals, one +5V, one ground, and the other is the signal input from the microcontroller.

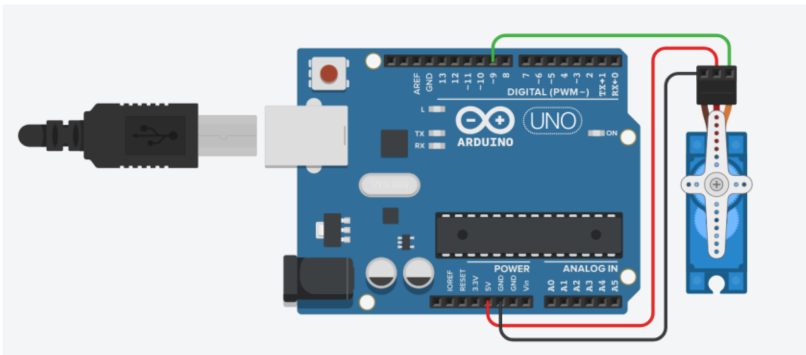


Figure 29 Circuit Schematic for Servo Motor (Arduino Compatible)

7. IR Sensors for Counting Mechanism

As introduced in the idea survey that a IR photodiode pair can form a beam-through mechanism to detect anything passing through, the following schematics of the circuit implementation utilizes an OpAmp to amplify the signal such that when nothing goes between the IR pair the output voltage can reach about +3.5V (a High signal input recognized by the microcontroller) while the output drops to about +0.02V (a Low signal) when the IR beam gets obstructed [19].

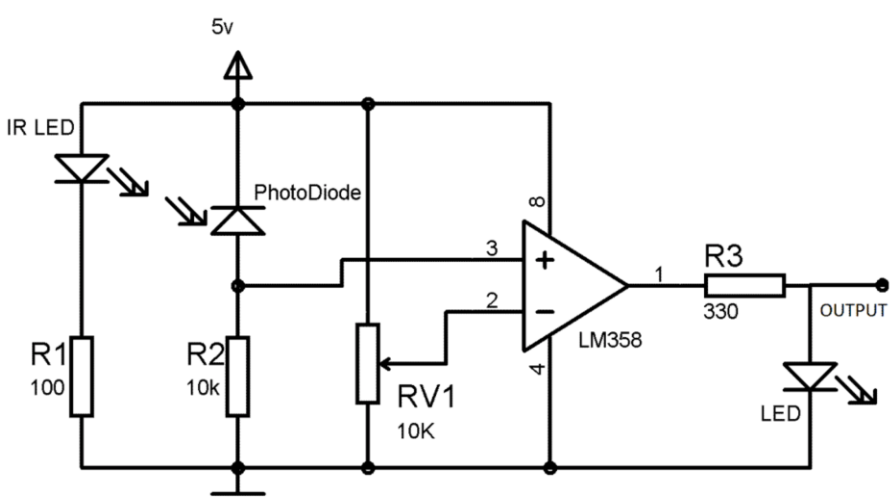


Figure 30 Circuit Schematic for IR Beam Through Pair LEDs

8. IR Reflective Sensor

IR reflective sensor is used to detect the white electrical tape which indicates the position of the first compartment. As explained in the previous section, an IR reflective sensor consists of an IR LED emitter and a phototransistor as a receiver and can be used to detect lightly colored object effectively. A sample circuit schematic is shown below that can output analog signal. As a matter of fact, an identical integrate circuit that can 1) output both analog and digital signals, 2) adjust sensitivity, and 3) is also Arduino compatible is readily available on the market [20].

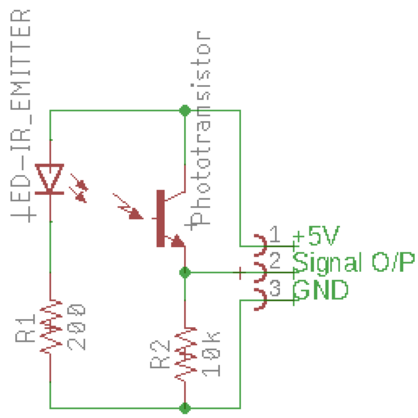


Figure 31 Circuit Schematic for IR Reflective Sensor

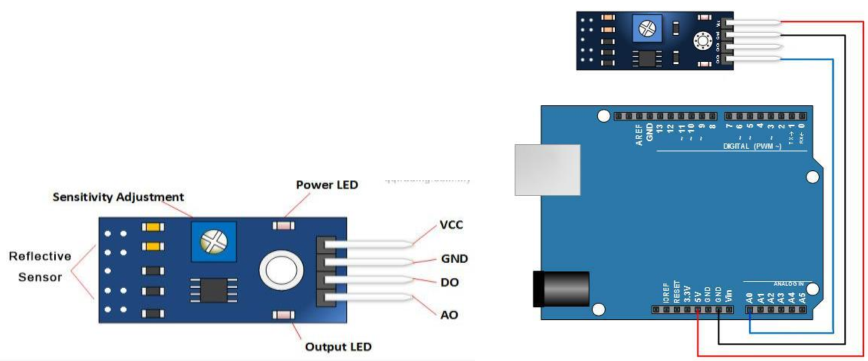


Figure 32 Circuit Schematics for IR Reflective Sensor (IC)

5.2.4 Microcontroller Architecture:

The selected microcontroller to use for this machine is PIC 18F4620. It is a better than the alternative microcontroller (i.e. Adruino nano/uno) due to large data and memory, high CPU speed, and greater number of I/O pins.

5.2.4.1 Pin assignment:

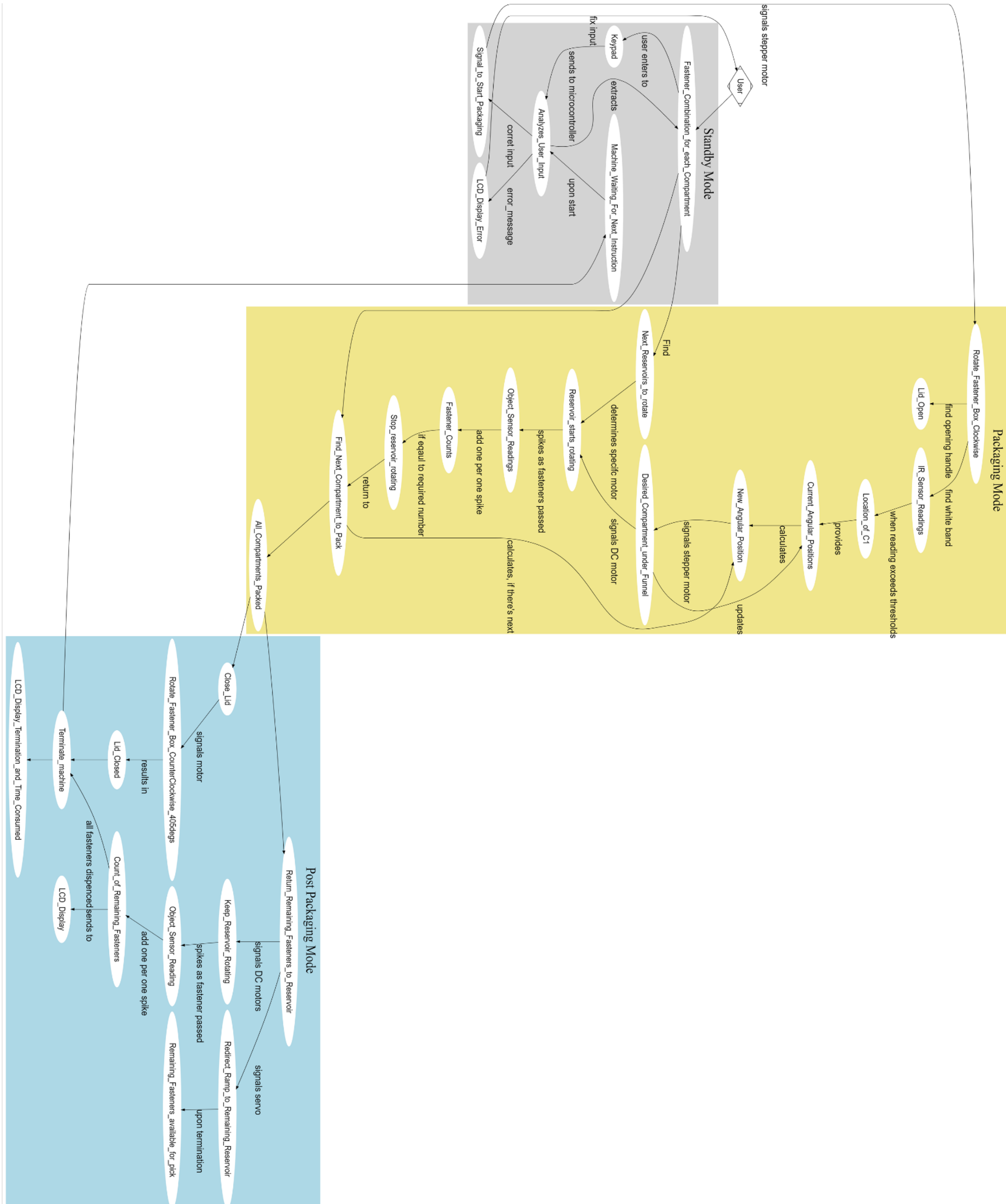
Table 14: PIC 18F4620 pin assignment

Pin	I/O	A/D	Function
RD2:RD7	Output	N/A	Interface with LCD display
RB1,RB4:RB7	Input	N/A	Interface with keypad
RC3:RC4	Input	N/A	Interface with RTC
RC6,RC7	Input/Output	N/A	USB
RD0,RD1,RC3,RC5	Output	N/A	GLCD
RA2,RA3	Input/Output	N/A	A2D
RB2	Output	Analog	Generate signals for servo to rotate the middle session of the ramp.
RB6	Output	Analog	Generate signals for Servo motor to rotate the fasteners box
RC0,RC1,RD3,RD4	Output	Digital	Generate signal for motor at reservoir 1-4
RA0,RA1, RE0,RE1	Input	Digital	Receive signal from IR photoresistence sensor 1-4 (one on each ramp)
RB5	Input	Digital	Receive signal from IR reflector sensor

The microcontroller subsystem serves as the as the bridge between the user and machine, as well as an overall controller of the autonomous packaging process. The overall flow of the software for the basic functionality is described in the following flowchart:

The additional features addressed in this document include real time Date/Time Display, PC interface and storing history to EEPROM. The implementations of these extra-design features are relatively independent from the main logic as they do not directly affect the performance of hardware packaging, thereby not included in the above flowchart. However, these features will although be designed, tested and delivered in the final design as an improvement to the overall user friendliness of the machine.

5.2.4.2 Flowchart



6. Project management

6.1 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

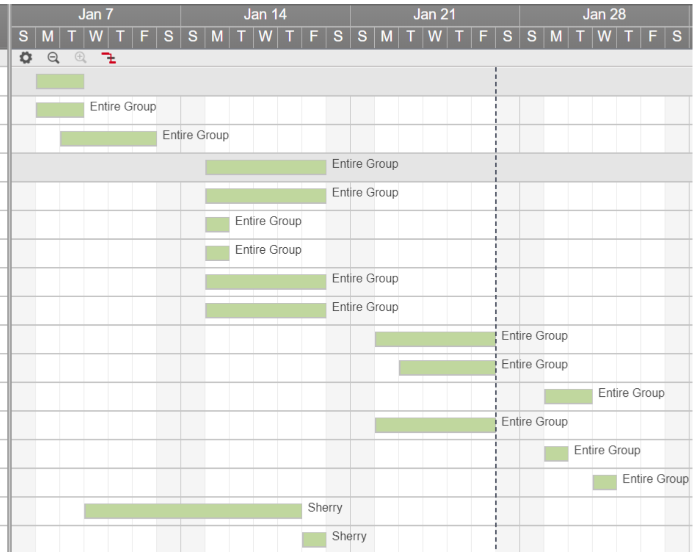
The circuit member is responsible for designing and implementing the overall structure of the circuits that drives the motors, connects the sensors, the power supply and the microcontrollers. The circuit member should prototype each individual circuit and sensor components and verify their functionality, 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

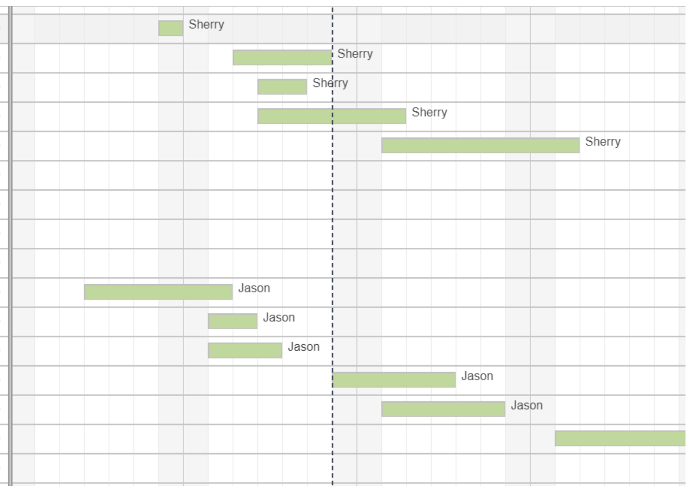
The microcontroller member is responsible for designing user interface and the overall microcontroller system. The user should be able to communicate its needs easily with the machine by sending commands through the keypads and retrieving feedbacks from the machine through the LCD. Another important 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.

6.2 Gantt Charts

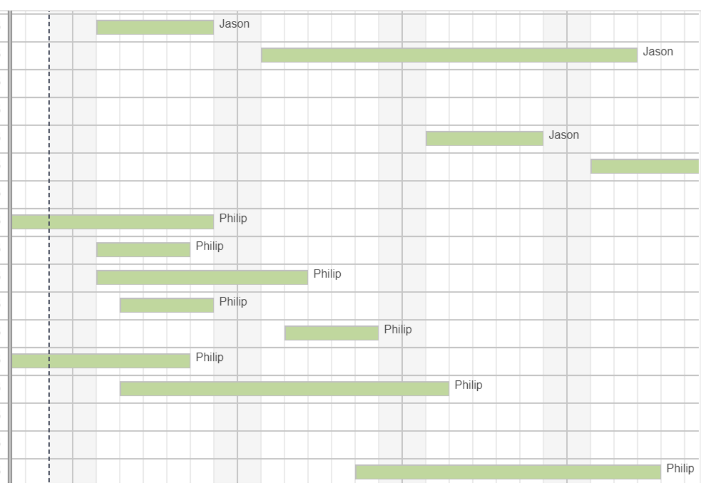
	Task Name	Start	Finish
1	Group Design	01/08/18	01/09/18
2	Discussing RFP	01/08/18	01/09/18
3	Brainstorming	01/09/18	01/12/18
4	Conceptual Design	01/15/18	01/19/18
5	Market Survey	01/15/18	01/19/18
6	Literature Survey	01/15/18	01/15/18
7	Idea Survey	01/15/18	01/15/18
8	Rotation Mechanism Prototyping	01/15/18	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

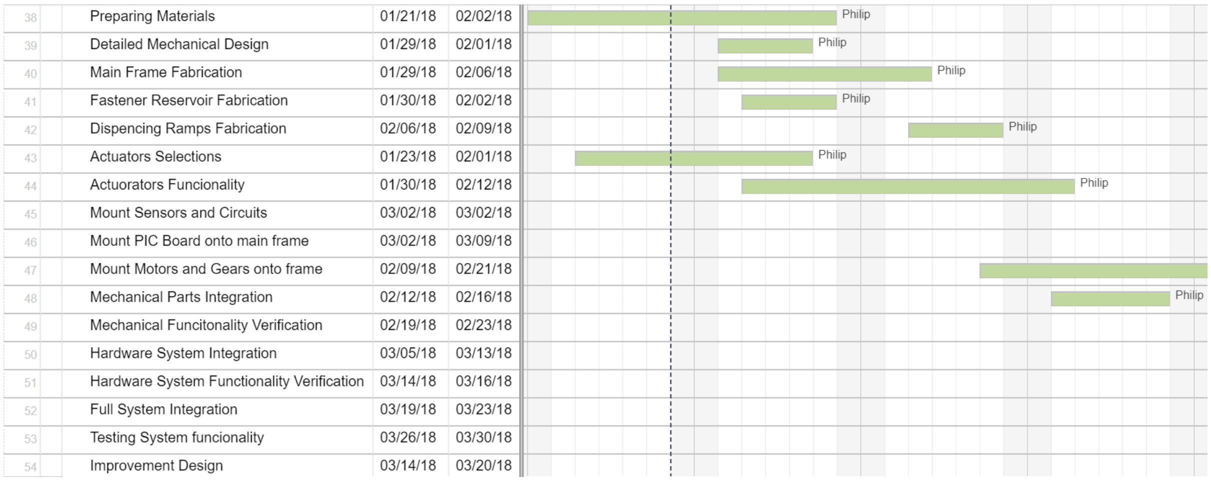


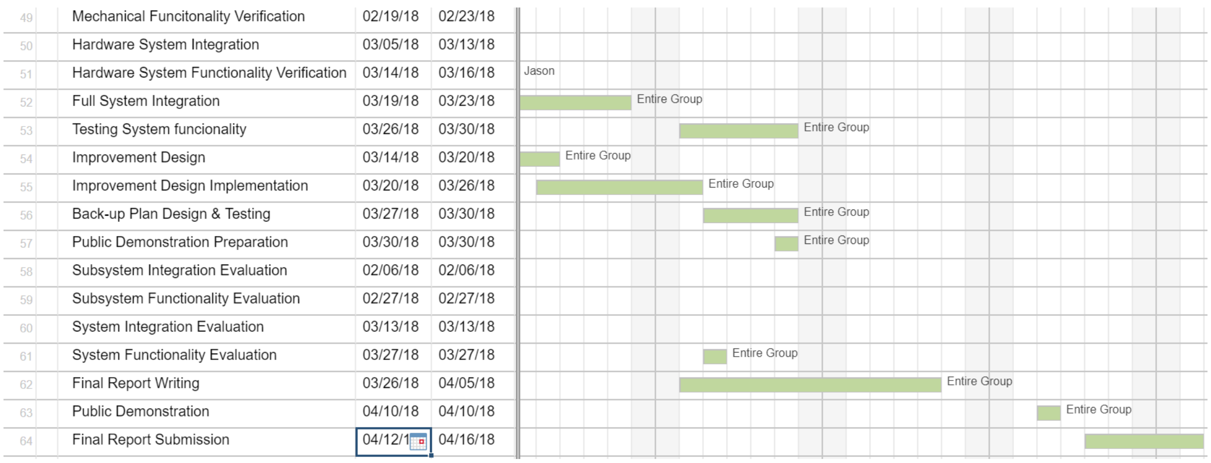
	Task Name	Start	Finish
18	Software High-level Structure Design	01/20/18	01/20/18
19	LCD Interface Design	01/23/18	01/26/18
20	Keypad Interface Design	01/24/18	01/25/18
21	Write Pseudo Code	01/24/18	01/29/18
22	Software Logic Development	01/29/18	02/05/18
23	Software-sensor interface	02/12/18	02/16/18
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



	Task Name	Start	Finish
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







Note that in the above Gantt chart, the task assignment is indicated beside the timeline bar. The name of the electromechanical member, circuit member and microcontroller member are Philip, Jason and Sherry respectively.

The Gantt chart is created using Smartsheet [21].

6.3 Budget

Item	Unit Price ($)	Quantity	Total Price ($)	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	4	9.04	Home Depot
Wood or Metal screws (26 pieces)	2.97	1	2.97	Home Depot
Everbilt Corner Bruce	2.98	1	2.98	Home Depot
Continuous Servo	16	1	16	YourDuino.com
9g Micro Servo Motor	2.43	4	9.72	Hobbyking
Shenzhen DC Gearhead Motor	4.00	5	20.00	Prof. Emami
Electromechanical Subtotal:			76.33	

Item	Unit Price ($)	Quantity	Total Price ($)	Sources
Power Supply (AC->DC)	11.95	1	14.75	JAMECO Electronics
Transistor TIP142	1.53	4	6.12	DiGiKey
Transistor TIP147	1.59	4	6.36	DiGiKey
ULN2003 Transistor Array	0.92	1	0.92	DiGiKey
IR emitter	0.35	4	1.40	DiGiKey
IR Phototransistor	0.33	4	1.32	DiGiKey

Jumper Wires + Solder	8.00	1	8.00	DiGiKey
IC OpAmp LM358	0.61	4	2.42	DiGiKey
Breadboard (Solderable)	1.59	4	6.36	DiGiKey
Resistors (various)	0.058	20	1.16	DiGiKey
Capacitors (various)	0.45	8	3.60	DiGiKey
IR Reflective Sensor	1.70	1	1.70	Creatron
Circuit and Sensors Subtotal			54.11	

Item	Unit Price ($)	Quantity	Total Price ($)	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
Microcontroller Subtotal			61.00	

Total Budget: $ CAD 191.44

7. Conclusion

This document presents the design of the hardware packing machine by team 34 in AER201. The proposed design addresses the challenge raised in the RFP as well as overall team goal outlined in the beginning of this document.

The main feature of this proposal can be summarized as follow: 1) a detailed formulation of the problem with objectives, metrics, constraints and functions is provided 2) a survey of related literatures, ideas and market products is conducted 3) Many alternative design solutions are explored and AHP-aided or Utility-based decision-making process is practiced 4) Specific design is proposed and broken down into individual subsystems. 5) Statement of work, Gantt charts and budgets are included in the end to demonstrate our planning.

However, we acknowledge our team does not have the full resources to devise a plan for industry-level, market-ready machines for mass production. Therefore, the team is willing to seek further opportunities to improve the capability of the proposed design in the future.

8. References

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9. Appendices

9.1 Data Sheet

The data sheets of the following devices will be presented in this section:

- RD-35 Power Supply [15]
- TIP142T/147T [22]
- 43R Servo Specification [13]
- LTE-4208 IR Emitter and detector [5]
- SG90C Micro Servo [23]
- 24BYJ48/28BYJ48/30BYJ46 stepper motor [12]
- E-stop [16]
- TCRT5000(L) Reflective Optical Sensor [6]
- ULN200x [24]
- ZGA25RP DC motor [14]

9.2 Code Used to generate Flowchart

MEAN WELL

35W Dual Output Switching Power Supply **RD-35 series**

■ Features :

- Universal AC input / Full range
- Protections:Short circuit/Over load/Over voltage
- Cooling by free air convection
- LED indicator for power on
- 100% full load burn-in test
- All using 105℃ long life electrolytic capacitors
- Withstand 300VAC surge input for 5 second
- High operating temperature up to 70℃
- Withstand 5G vibration test
- High efficiency, long life and high reliability
- 3 years warranty

SPECIFICATION

MODEL		RD-35A		RD-35B		RD-3513	
OUTPUT	OUTPUT NUMBER	CH1	CH2	CH1	CH2	CH1	CH2
	DC VOLTAGE	5V	12V	5V	24V	13.5V	-13.5V
	RATED CURRENT	4A	1A	2.2A	1A	1.3A	1.3A
	CURRENT RANGE	0.3 ~ 4A	0.2 ~ 1A	0.3 ~ 4A	0.2 ~ 1.3A	0.3 ~ 2A	0.2 ~ 1.5A
	RATED POWER	32W		35W		35.1W	
	RIPPLE & NOISE (max.) Note.2	80mVp-p	120mVp-p	80mVp-p	120mVp-p	120mVp-p	120mVp-p
	VOLTAGE ADJ. RANGE	CH1: 4.75 ~ 5.5V		CH1: 4.75 ~ 5.5V		CH1: 11.5 ~ 15.5V	
	VOLTAGE TOLERANCE Note.3	±2.0%	±6.0%	±2.0%	±5.0%	±4.0%	±4.0%
	LINE REGULATION Note.4	±0.5%	±1.5%	±0.5%	±1.0%	±0.5%	±0.5%
	LOAD REGULATION Note.5	±0.5%	±3.0%	±0.5%	±2.0%	±3.0%	±3.0%
	SETUP, RISE TIME	500ms, 30ms/230VAC 1200ms, 30ms/115VAC at full load					
	HOLD TIME (Typ.)	80ms/230VAC 16ms/115VAC at full load					
INPUT	VOLTAGE RANGE	88 ~ 264VAC 125 ~ 373VDC (Withstand 300VAC surge for 5sec. Without damage)					
	FREQUENCY RANGE	47 ~ 63Hz					
	EFFICIENCY (Typ.)	79%		82%		80%	
	AC CURRENT (Typ.)	0.8A/115VAC 0.55A/230VAC					
	INRUSH CURRENT (Typ.)	COLD START 36A/230VAC					
	LEAKAGE CURRENT	<2mA / 240VAC					
PROTECTION	OVER LOAD	110 ~ 150% rated output power					
		Protection type : Hiccup mode, recovers automatically after fault condition is removed					
	OVER VOLTAGE	CH1: 5.75 ~ 6.75V				CH1: 16.87 ~ 19.57V	
		Protection type : Hiccup mode, recovers automatically after fault condition is removed					
ENVIRONMENT	WORKING TEMP.	-25 ~ +70℃ (Refer to output load derating curve)					
	WORKING HUMIDITY	20 ~ 90% RH non-condensing					
	STORAGE TEMP., HUMIDITY	-40 ~ +85℃, 10 ~ 95% RH					
	TEMP. COEFFICIENT	±0.03%/℃ (0 ~ 50℃)on CH1 output					
	VIBRATION	10 ~ 500Hz, 5G 10min./1cycle, period for 60min. each along X, Y, Z axes					
SAFETY & EMC (Note 6)	SAFETY STANDARDS	UL60950, TUV EN60950 Approved					
	WITHSTAND VOLTAGE	I/P-O/P:3KVAC I/P-FG:1.5KVAC O/P-FG:0.5KVAC					
	ISOLATION RESISTANCE	I/P-O/P, I/P-FG, O/P-FG:100M Ohms/500VDC					
	EMI CONDUCTION & RADIATION	Compliance to EN55022 (CISPR22) Class B					
	HARMONIC CURRENT	Compliance to EN61000-3-2,-3					
	EMS IMMUNITY	Compliance to EN61000-4-2,3,4,5,6,8,11; ENV50204, EN61000-6-2 (EN50082-2) heavy industry level, criteria A					
OTHERS	MTBF	179Khrs min. MIL-HDBK-217F (25℃)					
	DIMENSION	99*82*36mm (L*W*H)					
	PACKING	0.3Kg; 45pcs/14Kg/0.83CUFT					
NOTE	1. All parameters NOT specially mentioned are measured at 230VAC input, rated load and 25℃ of ambient temperature. 2. Ripple & noise are measured at 20MHz of bandwidth by using a 12" twisted pair-wire terminated with a 0.1uf & 47uf parallel capacitor. 3. Tolerance : includes set up tolerance, line regulation and load regulation. 4. Line regulation is measured from low line to high line at rated load. 5. Load regulation is measured from 0% to 100% rated load. 6. The power supply is considered a component which will be installed into a final equipment. The final equipment must be re-confirmed that it still meets EMC directives.						

TIP142T
TIP147T

Complementary power Darlington transistors

Features

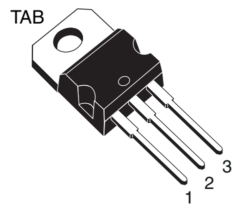
- Monolithic Darlington configuration
- Integrated antiparallel collector-emitter diode

Application

- Linear and switching industrial equipment

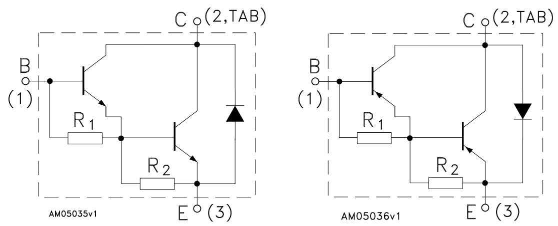
Description

The devices are manufactured in planar technology with “base island” layout and monolithic Darlington configuration. The resulting transistors show exceptional high gain performance coupled with very low saturation voltage.



TO-220

Figure 1. Internal schematic diagrams



R_1 typ. = 5 kΩ
R_2 typ. = 60 Ω

R_1 typ. = 8 kΩ
R_2 typ. = 100 Ω

Table 1. Device summary

Part number	Marking	Polarity	Package	Packaging
TIP142T	TIP142T	NPN	TO-220	Tube
TIP147T	TIP147T	PNP		

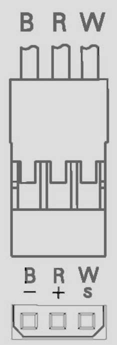
SPRINGRC®
www.springrc.com

43R Servo(360° Rotation) Specification

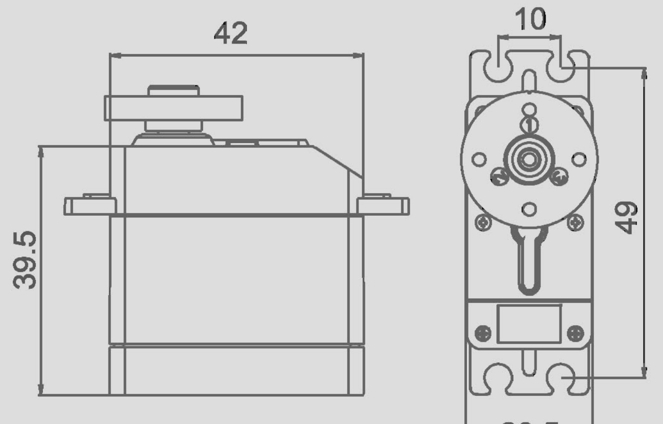
Thank you for choosing Spring Model's product

MODEL	TYPE	WEIGHT		4.8V			6V			DESCRIPTION	
		g	oz	SPEED	TORQUE		SPEED	TORQUE		GEAR	BEARING
				r/min	kg.cm	oz.in	r/min	kg.cm	oz.in		
SM-S4303R	Analog	44	1.55	60	3.3	45.8	70	4.8	66.7	1Metal Gear+ 4Plastic Gear	2
SM-S4306R		44	1.55	60	5.0	69.4	50	6.2	86.1	1Metal Gear+ 4Plastic Gear	2
SM-S4309R		60	2.12	58	7.9	109.7	49	8.7	120.8	Metal Gear	2
SM-S4315R		60	2.12	62	14.5	201.4	53	15.4	213.9	Metal Gear	2

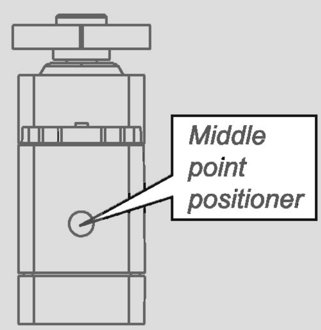
▲ 43R Robot series servo controled via analog signal(PWM),stopped via middle point positiner.
▲ Standard interface(like JR)with 30cm wire.
▲ Rotation and Rest Point Adjustment:when analog signal inputs,servo chooses orientation according to impulse width.when intermediatevalue of impluse width is above 1.5ms, servo is clockwise rotation,conversely,anticlockwise.Rest point need use slotted screwdriver to adjust the positioner carefully.Servo stopped rotation when the input signal is equivalent to impluse width.
▲ Please choose correct model for your application.
Caution: Torque over-loaded will damage the servo's mechanism.
▲ Keep the servo clean and away from dust, corrosive gas and humid air.
▲ Without further notification when some parameters slightly amend for improving quality.



BLACK(B) – NEGATIVE POLE
RED(R) – POSITIVE POLE
WHITE(W) – SIGNAL



Dimension（Unit：mm）

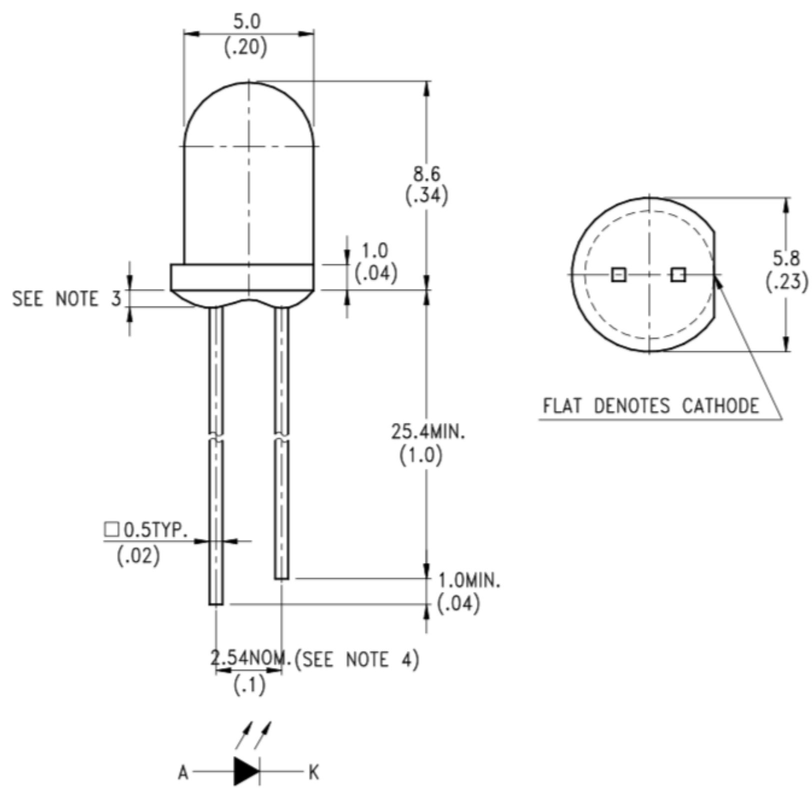


Rest Point Adjustment

FEATURES

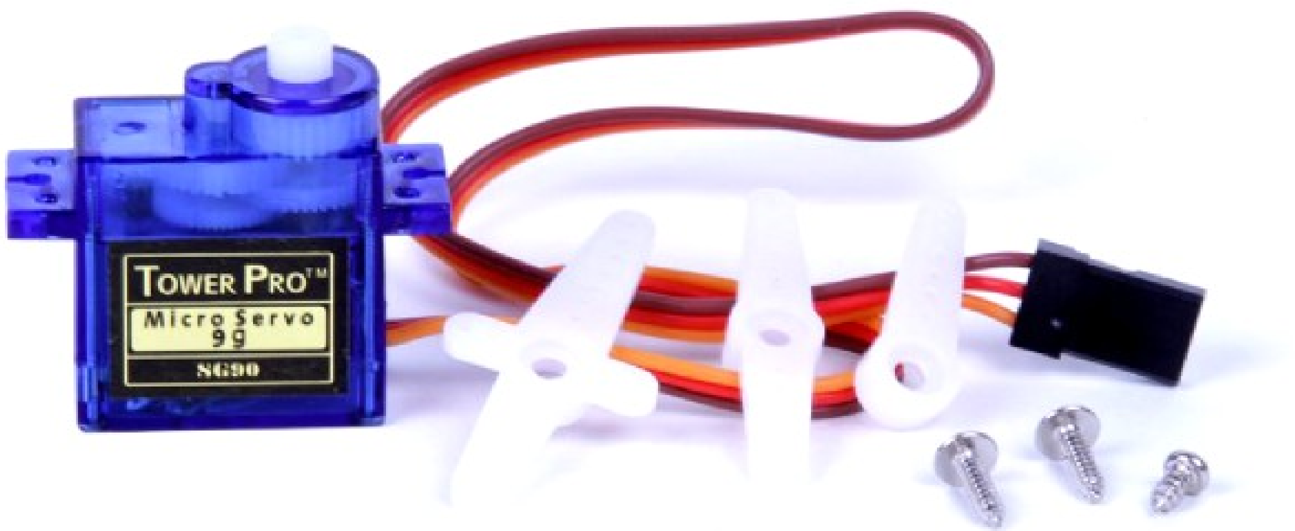
* SELECTED TO SPECIFIC ON-LINE INTENSITY AND RADIANT INTENSITY RANGES
* LOW COST MINIATURE PLASTIC END LOOKING PACKAGE
* MECHANICALLY AND SPECTRALLY MATCHED TO THE LTR-3208 SERIES OF PHOTOTRANSISTOR
* CLEAR TRANSPARENT COLOR PACKAGE

PACKAGE DIMENSIONS

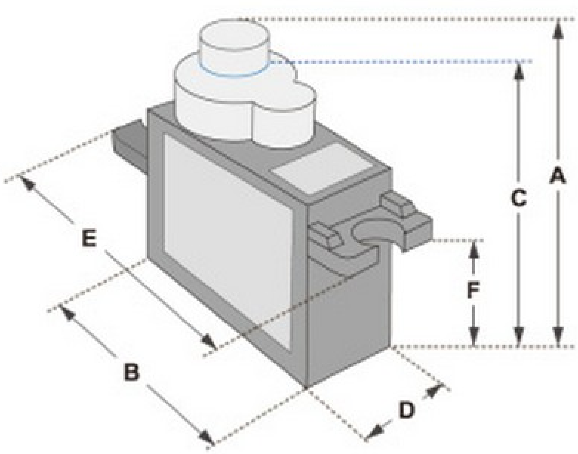


NOTES:
1. All dimensions are in millimeters (inches).
2. Tolerance is ±0.25mm(.010") unless otherwise noted.
3. Protruded resin under flange is 1.0mm(.039") max.
4. Lead spacing is measured where the leads emerge from the package.
5. Specifications are subject to change without notice.

SERVO MOTOR SG90 DATA SHEET

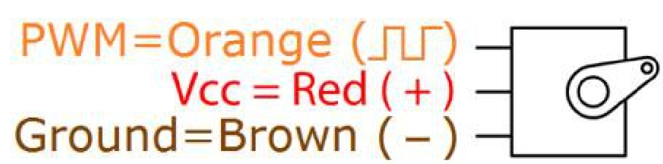


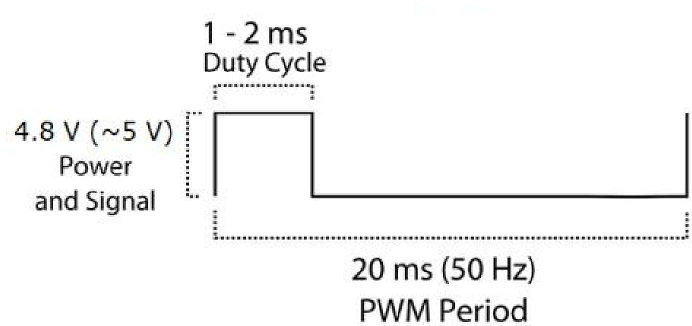
Tiny and lightweight with high output power. Servo can rotate approximately 180 degrees (90 in each direction), and works just like the standard kinds but smaller. You can use any servo code, hardware or library to control these servos. Good for beginners who want to make stuff move without building a motor controller with feedback & gear box, especially since it will fit in small places. It comes with a 3 horns (arms) and hardware.



Dimensions & Specifications
A (mm) : 32
B (mm) : 23
C (mm) : 28.5
D (mm) : 12
E (mm) : 32
F (mm) : 19.5
Speed (sec) : 0.1
Torque (kg-cm) : 2.5
Weight (g) : 14.7
Voltage : 4.8 - 6

Position "0" (1.5 ms pulse) is middle, "90" (~2ms pulse) is middle,
is all the way to the right, "-90" (~1ms pulse) is all the way to the left.

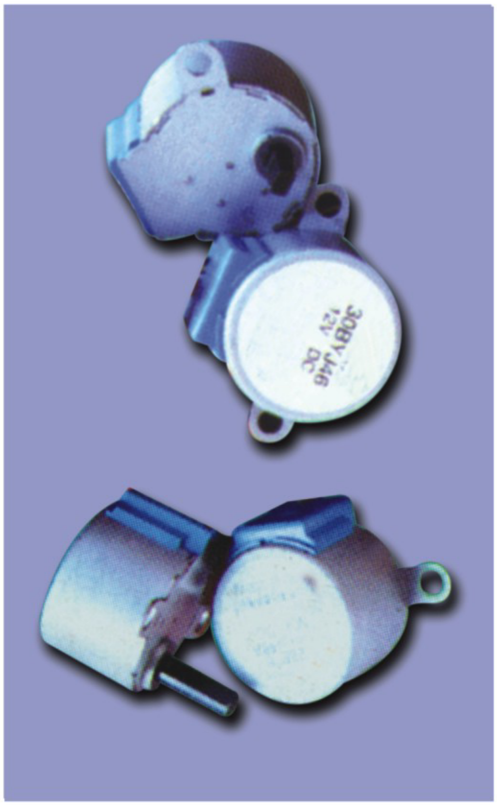




HuaNing MOTOR

24BYJ48 28BYJ48 30BYJ46 type stepping motor

24BYJ48/28BYJ48/30BYJ46



Applicatim:
mainly used
for air-conditioners...

24BYJ48 Motor Specification

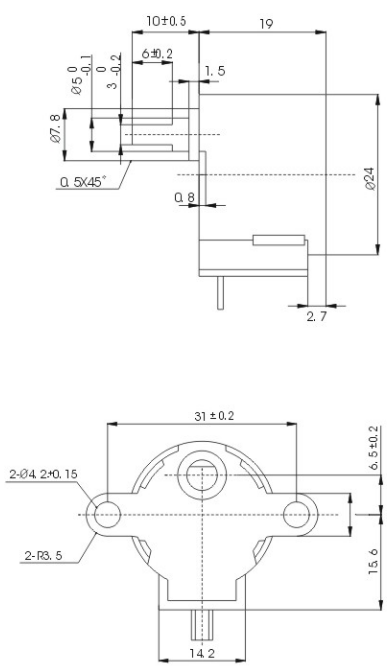
No.of phases	4	Voltage	12VDC
Current	40mA	Resistance	300Ω
Step angle	5.625	Reduction Ratio	1:64
No-load pull-out frequency	1000pps	No-load pull-in frequency	500pps
Pull-in torque	≥29.4 mN . m		
Wiring indications	A (orange) , B (yellow) , C (blue) D (grey) , E (red,min-point)		

28BYJ48 Motor Specification

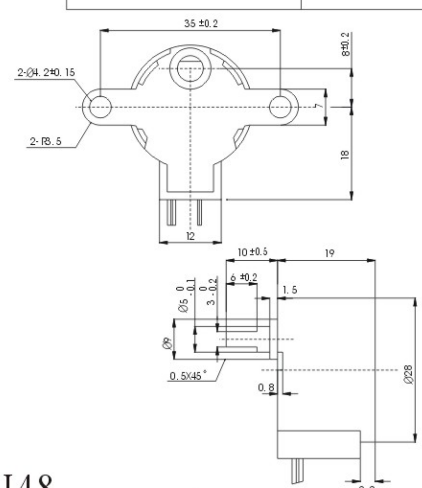
No.f phases	4	Voltage	12VDC
Current	40mA	Resistance	300Ω
Step angle	5.625	Reduction Ratio	1:64
No-load pull-out frequency	1000pps	No-load pull-in frequency	500pps
Pull-in torque	≥29.4 mN . m		
Wiring indications	A (orange) , B (yellow) , C (blue) D (grey) , E (red,min-point)		

30BYJ46 Motor Specification

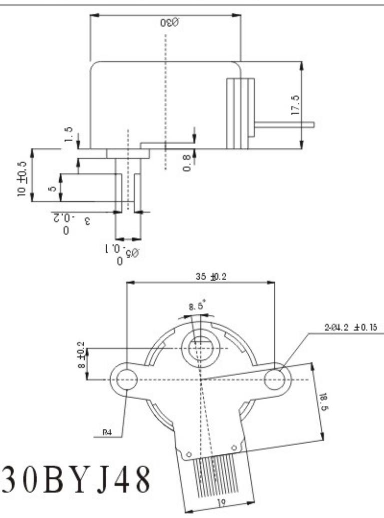
No.f phases	4	Voltage	12VDC
Current	40mA	Resistance	300Ω
Step angle	5.625	Reduction Ratio	1:85.25
No-load pull-out frequency	800pps	No-load pull-in frequency	500pps
Pull-in torque	≥34.3 mN . m		
Wiring indications	A (orange) , B (black) , C (white) D (yellow) , E (red,mid-point)		



24BYJ48



28BYJ48



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A01ES-D

Emergency stop switches

Distinctive features and specifications

A01ESD1701A-R1

- ❑ **Approved to EN 60947-5-5**
- ❑ **5 prominent red actuator styles**
- ❑ **Locked/unlocked status indicator**
- ❑ **AC15 1,5A 250VAC, 6A 250VAC**
- ❑ **Panel sealed to IP65**

ENVIRONMENTAL SPECIFICATIONS

- Sealing options : front panel IP65, rear panel IP40 according to EN60947-5-5
- Operating temperature : -20°C to +55°C

ELECTRICAL SPECIFICATIONS

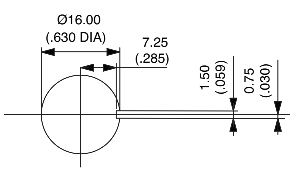
- Electrical function : push to shut off, twist to release
- Current/voltage rating : AC-15 1,5A 250VAC, 6A 250VAC
- Electrical life : 6.050 cycles
- Contact gap : > 3mm
- Insulation resistance : 50MΩ min
- Dielectric test voltage : 2900V

GENERAL SPECIFICATIONS

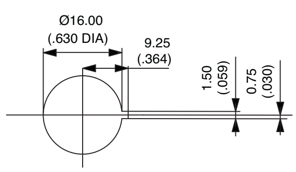
- Panel thickness : 6mm (.236) max.
- Mechanical life : 6050 cycles
- Operating force : 18 to 20N
- Torque : 0.8Nm
- Soldering : 350C, 5 seconds (IEC 68-2-2-20Tb, method 2)
- Switch terminals : solder/ quick-connect 2.8mm (.110) (IEC 68-2-20)

PANEL CUT-OUT

A01ES-DM - A01ES-DSP3



A01ES-D - A01ES-DF1- A01ES-DF2



MATERIALS

- Operator case : polyetherimide
- Actuator : polycarbonate
- Switch block : PBT
- Panel seal : neoprene

AGENCY APPROVAL

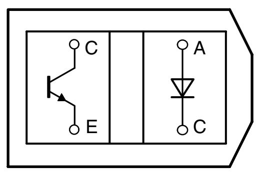
Switch block approved to
UL 1054 / VDE / EN 61058-1

D

The company reserves the right to change specifications without notice.

Reflective Optical Sensor with Transistor Output

19156_2



Top view 19156_1

FEATURES

- Package type: leaded
- Detector type: phototransistor
- Dimensions (L x W x H in mm): 10.2 x 5.8 x 7
- Peak operating distance: 2.5 mm
- Operating range within > 20 % relative collector current: 0.2 mm to 15 mm
- Typical output current under test: I_C = 1 mA
- Daylight blocking filter
- Emitter wavelength: 950 nm
- Lead (Pb)-free soldering released
- Compliant to RoHS directive 2002/95/EC and in accordance to WEEE 2002/96/EC

Pb-free

e2

RoHS
COMPLIANT

DESCRIPTION

The TCRT5000 and TCRT5000L are reflective sensors which include an infrared emitter and phototransistor in a leaded package which blocks visible light. The package includes two mounting clips. TCRT5000L is the long lead version.

APPLICATIONS

- Position sensor for shaft encoder
- Detection of reflective material such as paper, IBM cards, magnetic tapes etc.
- Limit switch for mechanical motions in VCR
- General purpose - wherever the space is limited

PRODUCT SUMMARY

PART NUMBER	DISTANCE FOR MAXIMUM CTR_{rel} (1) (mm)	DISTANCE RANGE FOR RELATIVE I_{out} > 20 % (mm)	TYPICAL OUTPUT CURRENT UNDER TEST (2) (mA)	DAYLIGHT BLOCKING FILTER INTEGRATED
TCRT5000	2.5	0.2 to 15	1	Yes
TCRT5000L	2.5	0.2 to 15	1	Yes

Notes

(1) CTR: current transfere ratio, I_{out}/I_{in}

(2) Conditions like in table basic charactristics/sensors

ORDERING INFORMATION

ORDERING CODE	PACKAGING	VOLUME (1)	REMARKS
TCRT5000	Tube	MOQ: 4500 pcs, 50 pcs/tube	3.5 mm lead length
TCRT5000L	Tube	MOQ: 2400 pcs, 48 pcs/tube	15 mm lead length

Note

(1) MOQ: minimum order quantity

ABSOLUTE MAXIMUM RATINGS (1)

PARAMETER	TEST CONDITION	SYMBOL	VALUE	UNIT
INPUT (EMITTER)				
Reverse voltage		V_R	5	V
Forward current		I_F	60	mA
Forward surge current	$t_p \leq 10$ µs	I_{FSM}	3	A
Power dissipation	$T_{amb} \leq 25$ °C	P_V	100	mW
Junction temperature		T_j	100	°C

ULN200x, ULQ200x High-Voltage, High-Current Darlington Transistor Arrays

1 Features

- 500-mA-Rated Collector Current (Single Output)
- High-Voltage Outputs: 50 V
- Output Clamp Diodes
- Inputs Compatible With Various Types of Logic
- Relay-Driver Applications

2 Applications

- Relay Drivers
- Stepper and DC Brushed Motor Drivers
- Lamp Drivers
- Display Drivers (LED and Gas Discharge)
- Line Drivers
- Logic Buffers

3 Description

The ULx200xA devices are high-voltage, high-current Darlington transistor arrays. Each consists of seven NPN Darlington pairs that feature high-voltage outputs with common-cathode clamp diodes for switching inductive loads.

The collector-current rating of a single Darlington pair is 500 mA. The Darlington pairs can be paralleled for higher current capability. Applications include relay drivers, hammer drivers, lamp drivers, display drivers (LED and gas discharge), line drivers, and logic buffers. For 100-V (otherwise interchangeable) versions of the ULx2003A devices, see the SLRS023 data sheet for the SN75468 and SN75469 devices.

The ULN2002A device is designed specifically for use with 14-V to 25-V PMOS devices. Each input of this device has a Zener diode and resistor in series to control the input current to a safe limit. The ULx2003A devices have a 2.7-kΩ series base resistor for each Darlington pair for operation directly with TTL or 5-V CMOS devices.

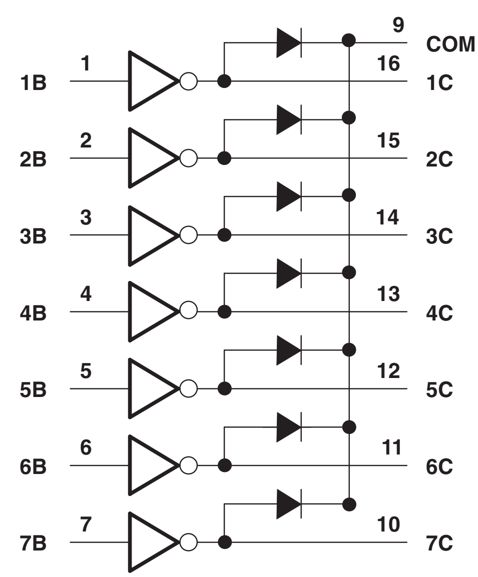
The ULx2004A devices have a 10.5-kΩ series base resistor to allow operation directly from CMOS devices that use supply voltages of 6 V to 15 V. The required input current of the ULx2004A device is below that of the ULx2003A devices, and the required voltage is less than that required by the ULN2002A device.

Device Information(1)

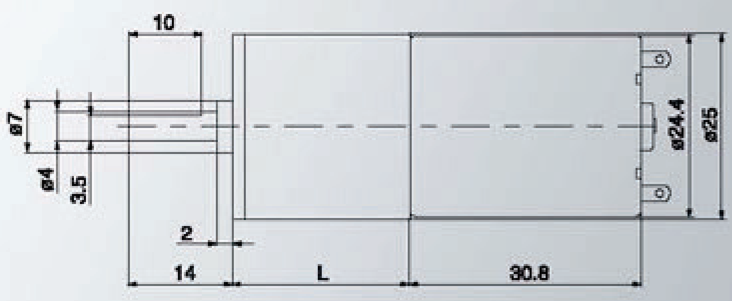
PART NUMBER	PACKAGE	BODY SIZE (NOM)
ULx200xD	SOIC (16)	9.90 mm × 3.91 mm
ULx200xN	PDIP (16)	19.30 mm × 6.35 mm
ULN200xNS	SOP (16)	10.30 mm × 5.30 mm
ULN200xPW	TSSOP (16)	5.00 mm × 4.40 mm

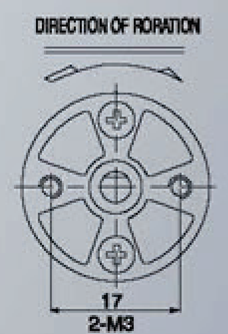
(1) For all available packages, see the orderable addendum at the end of the data sheet.

Simplified Block Diagram



ZGA25RP





■ Technical Data

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

Software Architecture Flow Chart

```
digraph G{
    node [ fontname=Arial, fontcolor=black, fontsize=24];
    edge [ fontname=Helvetica, fontcolor=black, fontsize=20];
    subgraph cluster_0{
        style = filled;
        color = lightgrey;
        node [style = filled, color = white]
        label = <<FONT POINT-SIZE="20">Standby Mode</FONT>>
        Fastener_Combination_for_each_Compartment->Keypad[label = "user enters to"];
        Keypad->Analyzes_User_Input[label = "sends to microcontroller"];
        Machine_Waiting_For_Next_Instruction->Analyzes_User_Input[label = "upon start"]
        Analyzes_User_Input->LCD_Display_Error[label = "error_message"];
        Analyzes_User_Input->Fastener_Combination_for_each_Compartment[label = "extracts"];
        Analyzes_User_Input->Signal_to_Start_Packaging[label = "corret input"]
    }
    subgraph cluster_1{
        style = filled;
        color = khaki;
        node [style = filled, color = white]
        label = <<FONT POINT-SIZE="20">Packaging Mode</FONT>>
        Signal_to_Start_Packaging->Rotate_Fastener_Box_Clockwise
            [label = "signals stepper motor"]
        Rotate_Fastener_Box_Clockwise->Lid_Open[label = "find opening handle"]
        Rotate_Fastener_Box_Clockwise->IR_Sensor_Readings[label = "find white band"]
        IR_Sensor_Readings->Location_of_C1[label = "when reading exceeds thresholds"]
        Location_of_C1->Current_Angular_Positions[label = "provides"]
        Current_Angular_Positions->New_Angular_Position[label = "calculates"]
        Fastener_Combination_for_each_Compartment->Find_Next_Compartment_to_Pack
        Find_Next_Compartment_to_Pack->New_Angular_Position
            [label = "calculates, if there's next"]
        New_Angular_Position->Desired_Compartment_under_Funnel
            [label = "signals stepper motor"]
        Desired_Compartment_under_Funnel->Current_Angular_Positions
            [label = "updates"]
        Desired_Compartment_under_Funnel->Reservoir_starts_rotating
            [label = "signals DC motor"]
        Fastener_Combination_for_each_Compartment->Next_Reservoirs_to_rotate
            [label = "Find"]
        Next_Reservoirs_to_rotate->Reservoir_starts_rotating
            [label = "determines specifc motor"]
        Reservoir_starts_rotating->Object_Sensor_Readings
            [label = "spikes as fasteners passed"]
        Object_Sensor_Readings->Fastener_Counts[label = "add one per one spike"]
```

```
        Fastener_Counts->Stop_reservoir_rotating[label = "if eqaul to required number"]
        Stop_reservoir_rotating->Find_Next_Compartment_to_Pack[label = "return to"]
        Find_Next_Compartment_to_Pack->All_Compartments_Packed
    }
    subgraph cluster_2{
        style = filled;
        color = lightblue;
        node [style = filled, color = white]
        label =<<FONT POINT-SIZE="20"> Post Packaging Mode </FONT>>
        All_Compartments_Packed->Return_Remaining_Fasteners_to_Reservoir
        Return_Remaining_Fasteners_to_Reservoir->Keep_Reservoir_Rotating
            [label = "signals DC motors"]
        Return_Remaining_Fasteners_to_Reservoir->Redirect_Ramp_to_Remaining_Reservoir
            [label = "signals servo"]
        Redirect_Ramp_to_Remaining_Reservoir->Remaining_Fasteners_available_for_pick
            [label = "upon termination"]
        Keep_Reservoir_Rotating->Object_Sensor_Reading[label = "spikes as fastener passed"]
        Object_Sensor_Reading->Count_of_Remaining_Fasteners
            [label = "add one per one spike"]
        Count_of_Remaining_Fasteners->Terminate_machine
            [label = "all fasteners dispenced"]
        All_Compartments_Packed->Close_Lid
        Close_Lid->Rotate_Fastener_Box_CounterClockwise_405degs[label = "signals motor"]
        Rotate_Fastener_Box_CounterClockwise_405degs->Lid_Closed[label = "results in"]
        Lid_Closed->Terminate_machine
        Terminate_machine->LCD_Display_Termination_and_Time_Consumed
        Count_of_Remaining_Fasteners->LCD_Display[label = "sends to"]
        Terminate_machine->Machine_Waiting_For_Next_Instruction
    }

    User->Fastener_Combination_for_each_Compartment
    LCD_Display_Error->User[label = "fix input"];
    User[shape=Mdiamond]
}
```

Overall Functionality Decomposition

```
 subgraph cluster_ode used to Generate Flow ChartCode used to Generate Flow Chart
    style=filled;
    color=lightgrey;
    node [style=filled,color=white];
    Keypad -> Microcontroller[label = "Receives Inputs from user"]
    Microcontroller-> LCD_Display[label = "Live updating messages to user"];
    LCD_Display-> Completion_Message[label = "Display"]
```

```
  LCD_Display-> Remaining_Fasteners[label = "Display"]
  LCD_Display-> Operation_Time[label = "Display"]
  LCD_Display-> Error_Message[label = "If user input is invalid"]
  Microcontroller-> Computer[label = "Export Data"]
  Microcontroller-> EPPROM[label = "Save operation history"]
  Emergency_Stop
  label = "User Interface";
 }
 subgraph cluster_2{
    style = filled
    color = lightgrey;
    node[style=filled, color=white]
    Sensors->White_Band[label = "Detect the location of"]
    White_Band->Sensors
    Sensors->Opening_Handle[label = "Detect the location of"]
 subgraph cluster_3{
    style = filled
    color = lightgrey;
    node[style=filled, color=white]
    Power_supply->Motors[label = "Powers"]
    Motors->Gears[label = "Adjust rotation speed and torque"]
    Sensors->Lid_Position[label = "Detect the location of"]
    Lid_Position->Motors[label = "feedback"]
    label = "Rotate each compartment of the box to the feeder position and open the lid"
 }
 subgraph cluster_4{
    style = filled
    color = lightgrey
    node[style=filled, color=white]
    Reservoirs->Separators[label = "Feeds fasteners to"]
    Separators->Ramps[label = "Deliver fasteners to"]
    label = "Discharge fasteners in the reservoir"
 }

subgraph cluster_5{
    style = filled
    color = lightgrey
    node[style=filled, color=white]
    Microcontroller->Required_Numbers [label = "Gives"]
    Required_Numbers->Counting_Sensors [label = "Sets requirement for"]
    Counting_Sensors->Required_number_of_parts [label = "counts"]
    Required_number_of_parts->Ramps [label = "Are delivered to"]
    Counting_Sensors->Microcontroller [label = "Sends the counts back to"]
    label = "Counting Mechanism"
 }
 User -> Keypad [label = "Specifies combinations of fasteners in each compartment" ]
```

```
  User -> Box[label = "Place into the machine"];
  User -> Emergency_Stop [label= "Press to stop in emergency"]
  User -> Fasteners -> Reservoirs [label = "Place into reservoirs"]
  Gears-> Box [label = "rotate"]
  Gears-> Lid[label = "open"]
  Lid->Lid_Position
  Box->White_Band[label = "On the side"]
  Box-> Lid
  Box-> Opening_Handle
  Box-> Filled_Box
  Box-> Open_Compartment
  Ramps->Open_Compartment[label = "Deliver required fasteners"]
  Open_Compartment->Filled_Box[label = "After all compartments are filled"]
  Ramps->Remaining_Parts_Reservoir[label = "Deliver remaining fasteners"]
  Remaining_Parts_Reservoir->Pickup_Area[label = "Placed in"]
  Filled_Box-> Pickup_Area[label = "Placed in"]
  Error_Message ->Output_Messages [label = "is"]
  Operation_Time->Output_Messages [label = "is"]
  Remaining_Fasteners->Output_Messages[label = "is"]
  Box [shape=Mdiamond];
  User[style=filled, color=red]
  Pickup_Area[style=filled, color=lightblue]
  Output_Messages[style = filled, color=lightblue]
}
```