DEDICATION

This project is dedicated to our parents and families who gives us the opportunity to study and raised us to become who we are now,

To our friends whom we shared this work with through this long road,

To our mentors who gave us the lucid knowledge and put us on the right road.

ACKNOWLEDGMENTS

First and foremost, we would like to thank God Almighty our creator, our source of inspiration, wisdom, knowledge and understanding. God has been the source of our strength throughout this project.

We would also like to express our gratitude and appreciation to Dr. Amin Danial and Dr. Olaa Mohamed, for all the help and guidance, they provided throughout our education.

We would like to thank our family, especially our parents, for their encouragement, patience, and assistance over the years.

"We are forever indebted to our parents."

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Abstract

Engineering is the creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination, or to construct or operate the same with full cognizance of their design, or to forecast their behavior under specific operating conditions, all as respects an intended function, economics of operation and safety to life and property.

And in engineering field we study in many fields to apply the scientific search that is done by scientist to physical form that is easy and suitable for normal people that will make their lives easier.

In our project we want to increase the quality of fruit that being export to the outside world by building a machine for sorting and classification of fruit by using high technology as image processing for sorting and classification the fruit by its shape through mechanical mechanism.

The aim of the project is to solve the problem of classification of good rotten fruits through image processing.

A system consists of sorting the fruit by image processing and classified the shape of fruit by mechanism with capacity one ton/hr. minimum.

LIST OF ABBREVIATION

Abbreviation	Definition	Chapter Section
PLC	Programmable Logic Control	2-2
CPU	Central Processing Unit	2-3
GPU	Graphical Processing Unit	2-3
GPIO	General-Purpose Input & Output	2-3
$v_{F.b}$	Feeding tank volume	3-2-1
$v_{F.b.q}$	Feeding tank volume of quadrant pyramid	3-2-1
$v_{F.b.t}$	Feeding tank volume of triple pyramid	3-2-1
L	normal length of feeding tank	3-2-1
L2	length of sheet metal	3-2-1
H	Hight of sheet metal	3-2-1
H2	normal Hight of feeding tank	3-2-1
W2	width of conveyer belt	3-2-1
W3	width of triple pyramid	3-2-1
W	Feeding tank Width	3-2-1
d_2	the diameter of large orange = 100mm	3-2-2
d_1	the diameter of small orange = 53mm	3-2-2
d	the diameter of sorting roller	3-2-2
l_1	the height of curved groove	3-2-2
l_3	the center-to-center length of curved groove	3-2-2
l_2	the minimum length between two rollers	3-2-2
C	the center-to-center length of two rollers	3-2-2
R_3	radius of curved groove	3-2-2
L	length of roller	3-2-2
P	chain pitch = 1.25 m = 31.75mm	3-2-2
t_2	thickness of attachment part of shaft	3-2-2
t_w	thickness of washer = 0.6mm	3-2-2
d_p	distance between two outer places of chain = 14 mm	3-2-2
$d_{o.o}$	distance between two oranges	3-2-2
$d_{c.c}$	center to center distance of two roller which the orange exits from camera room.	3-2-2
f_a	normal force due to orange	3-2-2
m_1	mass of orange	3-2-2
μ	friction coefficient between orange and steel	3-2-2
$\propto$	angle of conveyor	3-2-2
T_b	Tension of Belt	3-2-3
F	coefficient of friction belt with pulley	3-2-3
L	Length of the half of the conveyer	3-2-3
G	Gravitational Force	3-2-3
M_i	load due to idler	3-2-3

M_b	load due to belt	3-2-3
Mm	load due to conveyed material	3-2-3
α	angle of inclination of the belt	3-2-3
H	vertical height of the conveyer in meter	3-2-3
L	Nominal life (Millions of Revolutions)	3-2-4
c	Dynamic Capacity in (N)	3-2-4
n	Exponent of the life formula. [(*n=3) for Ball Bearing & (n=10/3) for Roller Bearing]*	3-2-4
L_h	Nominal life in working hours. ($L_h = Lyears \times LDays \times Lhours$)	3-2-4
N	Rotational Speed in rpm	3-2-4
p	Equivalent bearing load “Static Load” in (N)	3-2-4
x	Radial Factor	3-2-4
ρ_r	Actual Radial Load	3-2-4
y	Axial Factor	3-2-4
p_x	Actual Axial Load	3-2-4
T	Torque or Twisting Moment	3-2-5
Ip	polar moment of inertia of shaft	3-2-5
τ	Torsional shear stress	3-2-5
r	radius of shaft	3-2-5
θ	Angel of Twist	3-2-5
G	Modulus of rigidity	3-2-5
σb	normal stress due to bending moment	3-2-5
M	Maximum Bending moment acting on critical section	3-2-5
I	Second moment of inertia	3-2-5
Y	Distance from neutral axis to the outer	3-2-5
σ_y	yield stress of shaft material	3-2-5
w	width of key	3-2-6
d	diameter of shaft	3-2-6
H	height of key	3-2-6
τ	shear stress act on key	3-2-6
F	force act on key due to shaft torque	3-2-6
A	area in which stress act on it	3-2-6
σ	: crashing stress act on key	3-2-6
T	is torque act on key	3-2-6
τ'	shear stress on shaft	3-2-6
e	shaft strength factor	3-2-6
PCD	Pitch circle diameter of the sprocket in metric units.	3-2-7
T	number of teeth.	3-2-7
Cp	Chain pulls total (N)	3-2-7
L	Centre distance (m) - head- to tail-shaft	3-2-7
L_t	Total distance of the chain	3-2-7
Wc	Chain total mass per meter (kg/m) including attachments and fittings.	3-2-7

Wm	Mass of load/meter (kg/m)	3-2-7
V	Chain speed (m/sec)	3-2-7
μc	Coefficient of friction, chain on steel (sliding or rolling)	3-2-7
μm	Coefficient of friction, load on steel.	3-2-7
ρ	Load density (kg/m3)	3-2-7
α	Angle of inclination (degrees).	3-2-7
K	Power at head shaft (kW)	3-2-7
PB	Chain pulls at B (N)	3-2-7
P	pitch of chain equal	3-2-7
H	Hight of original link of chain	3-2-7
L_h	is the Hight of attachment part	3-2-7
d4	diameter equal 33 mm	3-2-7
T	number of teeth = 31	3-2-7
d1	d1: pin diameter = 5mm	3-2-7
d2	E-clips inner diameter and groove diameter.	3-2-7
m	groove width	3-2-7
n	length to the face of the pin	3-2-7
L_c	width of outer link chain	3-2-7
L_p	length of pin	3-2-7
At	from tables(8-1,8-1)	3-2-8
Eb	represents the modulus of elasticity of the bolt material	3-2-8
Kb	equivalent stiffness of the bolt in the grip zone	3-2-8
Kd	stiffness of unthreaded portion	3-2-8
Kt	stiffness of threaded portion	3-2-8
F	force of moving object in “Newton”	3-2-10
η	efficiency of motor	3-2-10
i	gear ration of mechanism	3-2-10
F_A	external force act on object in “Newton”	3-2-10
θ	angle of inclination of mechanism in “degree”	3-2-10
μ	friction of coefficient of sliding surface	3-2-10
J	total inertia of system in “$Kg.m^2$”	3-2-10
T_L	load torque act on system in “$N.m$”	3-2-10
T_a	accelerating torque act in acceleration of motor in “$N.m$”	3-2-10
T	total torque multiply by factor of safety in “$N.m$”	3-2-10
N	maximum speed	3-2-10
t_a	distance of accelerating speed	3-2-10
A	accelerating rate	3-2-10
N_L	required speed of load in “$\frac{m}{s}$”	3-2-10
D	distance in “meter”	3-2-10
T	time taken for object from start to reach end in “second”	3-2-10
N_m	speed of motor in “rpm”	3-2-10

$\boldsymbol{R}$	radius of roller used in belt in "meter"	3-2-10
t	time taken in accelerating rate in "s"	3-2-10
$\boldsymbol{J_0}$	moment of inertia of rotor in "$kg.m^2$"	3-2-10
$\boldsymbol{J_L}$	moment of inertia of load in "$kg.m^2$"	3-2-10
RPM	Revolution Per Minuit	3-2-10
L	length of rejection gate plate equal to 30 cm	3-2-10
m	maximum mass of orange equal to 0.5 kg	3-2-10
g	gravity acceleration equal to 9.81 $\frac{m}{s^2}$	3-2-10
$\boldsymbol{M}$	mass of orange.	3-2-12
$\boldsymbol{g}$	gravity acceleration	3-2-12
$\boldsymbol{N}$	normal force on orange	3-2-12
U	friction coefficient of steel	3-2-12
X	the slope angle of the stage	3-2-12
S	the total distance of slope	3-2-12
a	acceleration of orange	3-2-12
v	velocity of orange	3-2-12
$\boldsymbol{v_x}$	initial velocity of orange	3-2-12
t	total time has taken by orange to reach to last stage	3-2-12
$\boldsymbol{RE}$	encoder sensor resolution pulse / rev	9-1-2
$\boldsymbol{Ts}$	sampling period sec	9-1-2
$\boldsymbol{V}$	speed rev / sec	9-1-2
$\boldsymbol{Err}$	speed error rev / sec	9-1-2
$\boldsymbol{Jm}$	inertial of motor.	9-3-1
$\boldsymbol{Jl}$	inertial of conveyer.	9-3-1
$\boldsymbol{KE}$	constant gain.	9-3-1
$\boldsymbol{Ng}$	sprocket ratio.	9-3-1
$\boldsymbol{Bl}$	damping coefficient of conveyer.	9-3-1
$\boldsymbol{Bm}$	damping coefficient of DC motor.	9-3-1
$\boldsymbol{RA}$	resistance of DC motor.	9-3-1
$\boldsymbol{Eb(s)}$	back EMF of motor.	9-3-1
$\boldsymbol{Ia(s)}$	armature current.	9-3-1
$\boldsymbol{Wm(s)}$	speed of motor.	9-3-1
$\boldsymbol{Wl(s)}$	speed of conveyer.	9-3-1
$\boldsymbol{Tm}$	torque of motor.	9-3-1
$\boldsymbol{Tl}$	torque of conveyer transferred to motor.	9-3-1
$\boldsymbol{\alpha}$	angular acceleration.	9-3-1

Chapter 1
Introduction

Chapter 1: Introduction

The fruit and vegetable market are getting highly selective, requiring their suppliers to distribute the goods according to high standards of quality and presentation. Present sorting systems tend to include the development of an electronic weight system and a vision-based sorting and grading unit which also measures size, with a friendly user interface that enables definition of classification parameters, reconfiguration of the outputs and maintenance of production statistics.

Automation of fruit sorting industry is one of the important milestones in this market. Farmers and distributors do conventional quality inspection and handpicking to sort and grade food products. But these conventional methods have many drawbacks like time consuming, monotonous, slow and inconsistent etc. so automation in this area has greater advantage in terms of efficiency, accuracy, consistency etc. Computer vision systems provide rapid, economic, hygienic, consistent and objective assessment. Agriculturally efficient countries like Israel and Australia have manifested active use of this modern technology.

Fruit sorting machine is an indispensable equipment in fruit production line. Separating qualified fruits from defective ones are premise for making clean and tasty fruit. Fruit sorting and cleaning both belong to pre-treatment of fruits. It applies to all kinds of fruits and vegetables such as orange, apple, pear, peach, lemons, carrot, pineapple, mango, strawberry, blackberry, etc. Fruit sorting machine is efficient in transmitting, selecting and grading fruits, which can greatly relieve the labor intensity.

Sorting of agricultural products is accomplished based on appearance (color and absence defects), texture, shape and sizes. Manual sorting is based on traditional visual quality inspection performed by human operators, which is tedious, time-consuming, slow and non-consistent. It has become increasingly difficult to hire personnel who are adequately trained and willing to undertake the tedious task of inspection. A cost effective, consistent, superior speed and accurate sorting can be achieved with automated sorting.

The whole process of fruit production line is done in several steps as, first feeding the fruit in feeding tank then the first inspection from good fruit and rotten fruit after that the fruit enter the washing region then dry the fruit, the fruit will enter the process of waxing after the waxing process the fruit will enter the dry region one more then the fruit will be classified by its (weight, color, shape) “depend on fruit the three may not be used”, then the last process the package process where the fruit is put in boxes ready for exporting.

In our project the we will feed the fruit through feeding tank then the sorting of fruit from good and rotten, then we will classify the fruit by its shape, since the fruit is orange the different of color is used in sorting instead of classification.

Chapter 2

Literature Review

Chapter 2: Literature review

2-1: Mechanical:

2-1-1: Portable Smart Sorting:

The mechanical system is designed in the form of inclined and segmented plane to minimize the utilization of high-cost conveyor belt, by adopting the concept of LEGO toy building, this mechanical system is designed to be fast and easily mounted and separated.

The advantages of using this mechanical concept are low power, portable, and easy to arrange, by using this concept, the system is not only upgradable but also customizable according to the user's needs, the mechanical system is designed to be upgradable by adding the additional part.

The main system consists of two part as shown in FIG 2-1-1,

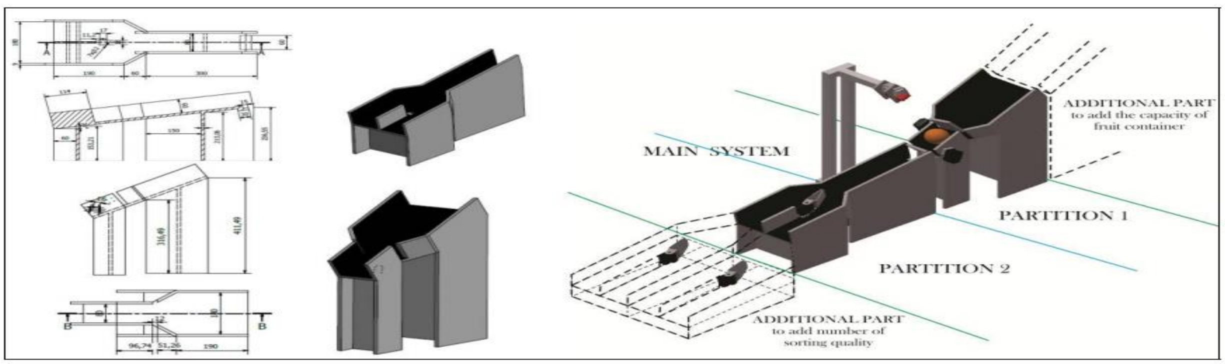


Figure 2-1- 1: Mechanical Design of Portable Smart Sorting and Grading Machine for Fruit

The first part for fruit to cheek either the fruit is rotten or not by camera as the main sensor with an angle of 60 degree, by making the mechanism simple, only the spherical fruit can pass as orange, tomato, apple, then after the fruit is classified as rotten or not it will pass through a gate by use servo motor to move fruit to next part.

The second part for sorting the fruit, for example if the fruit is rotten it goes left otherwise it go right or vice versa.

The main purpose of this mechanical design is to achieve the low-cost, low-power, and portable mechanical system for sorting and grading machine so that it can be employed flexibly by the user e.g., within a room, a moving truck container, a garden, etc.

Paper available at
https://www.researchgate.net/publication/271462101_Portable_smart_sorting_and_grading_machine_for_fruits_using_computer_vision/link/5940b385458515546l4ab8ce/download.

2-1-2: Construction design of apple sorter:

The apple sorting line design is based on a single, rectilinear separating path where the fruits are sorted and routed to separate trays. The device is equipped with a container of 200kg of fruit, the processing capacity of the entire sorting line is 1.5 tons of fruit per hour, the mechanism consists of five parts from the fruit in container to the classification of different condition of fruit as shown in FIG 2-1-2,

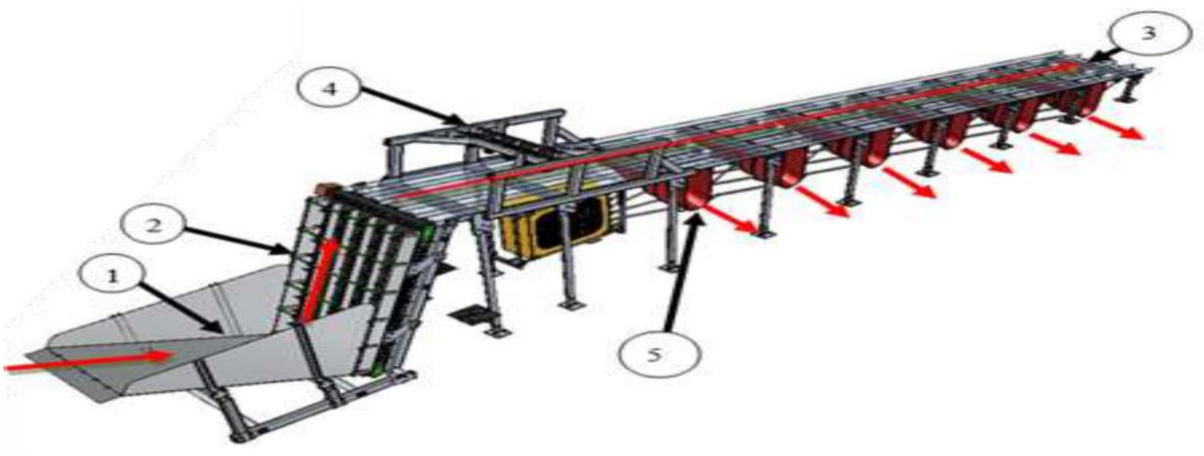


Figure 2-1- 2: Construction design of apple sorter

First part apples poured into the fruit container, then second part apple transported using the conveyor belt, third part apples onto the ramp at the angle 20 degree so that the fruit may roll over freely.

Over the upper part of the ramp are located cameras which is fourth part, camera take a series of photos of the ongoing fruit. Data from cameras are sent to the computer then special program analyses the pictures and classifies fruit in accordance with standard.

After sorting, the computer sends a signal to the driver of stepper motor, which opens the appropriate gate. When the gate opens, fifth par apples classified to the appropriate class fall down through the hole and roll down the gutters to the box below.

Article available at https://www.bioconferences.org/articles/bioconf/full_html/2018/01/bioconf_wipie2018_02025/bioconf_wipie2018_02025.html.

2-1-3: Classifier of tomatoes by color, size and weight:

The minimum number of variables of the fruit considered necessary to make an objective assessment of its quality, and of how precisely each should be sampled has been selected. In the case of tomatoes, these characteristics are size and color.

For the size the fruit classified into two category weight and diameter as for the color classification, it is necessary to distinguish between various levels going from green to red, through a series of intermediate green-red levels, these colors are indicative of the ripeness of the fruit depending on variety.

In this mechanism the tomato will be classified by weight, diameter, and color, the color and diameter will be done by computer vision, the whole mechanism will be classified into five section, which is mechanical elements of transport and support, weighing, vision, synchronization and ejection central, and monitoring subsystem as shown in FIG 2-1-3,

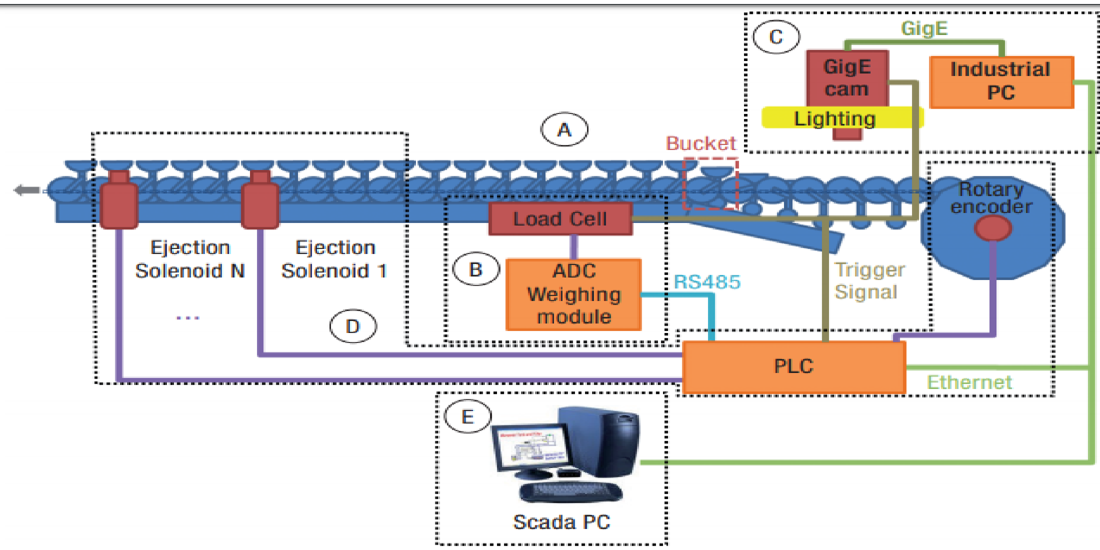


Figure 2-1- 3: General block diagram: A) transportation and support, B) weighing, C) vision, D) control of synchronization and ejection, E) monitoring.

The system has been developed on a mechanical chassis on which the product to be classified circulates in buckets deposited one by one. These are subjected to a mechanized chain that moves along the entire structure of the machine so that the product can be pushed out of the bucket at any point along its route.

The main design is built on bucket, the bucket has two function one which is rotation of fruit to get 360 degree of picture of fruit and the other function is the weighting which help to raise the tomatoes onto a platform with a single point of support on which the weight of the tomato support assembly rests, allowing the weighing process to be performed as it passes through the load cell.

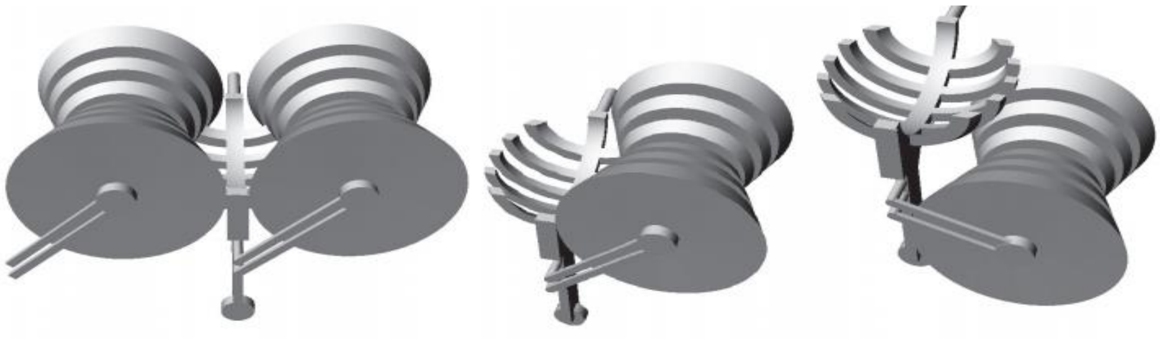


Figure 2-1- 4: Construction design of bucket for rotation and weight adjustment

The vision part consists of an industrial PC that performs the processing of images captured with a camera, in addition the PC will communicate via Ethernet with the rest of the control system, sending the calculated value of the diameter and color of tomato on request.

Synchronization and ejection central which the relation between input data and actuators the expulsion of the products is accomplished by a solenoid that will force the tilting of the bucket with a resulting tomato drop, and will be activated by the controller at the right time.

Monitoring subsystem is based on a custom-designed Scada in C++. Through this we have total control in real time of the central control subsystem for sync and expulsion, and therefore of any actuator or sensor of the machine.

Article available at https://dialnet.unirioja.es/descarga/articulo/3930620.pdf

2-1-4: Design of Grading Machine of Mandarin:

We discuss before different design but all of them use computer vision for diameter classification but in this mechanism the diameter classification will be mechanical.

The parts of machines are hopper to store and input the fruits to machine, drums with revolutionary motion having holes or sheaving screen and chute for exit of graded fruits, the dimensions of hopper are 100 cm in length, 60 cm in width and 35 cm in height.

The no. of revolving drums is 5, which are having holes along circumference of diameter 40mm, 50mm, 60mm, 70mm and 80mm. diameter of drum is between 40 and 50cm and length 100cm for more productivity are taken as shown in FIG 2-1.5.

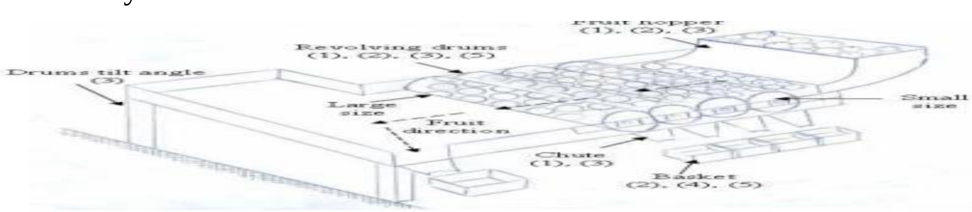


Figure 2-1- 5: Construction design of mandarin grading machine

Article available at http://www.ijies.net/finial-docs/finial-pdf/01041720172511.pdf.

2-1-5: Machine Vision Based Autonomous Fruit Inspection and Sorting:

The system consists of one phase, which is if the fruit is rotten or not, this phase will cut into two section inspection section and sorting section as shown in FIG 2-1 6.

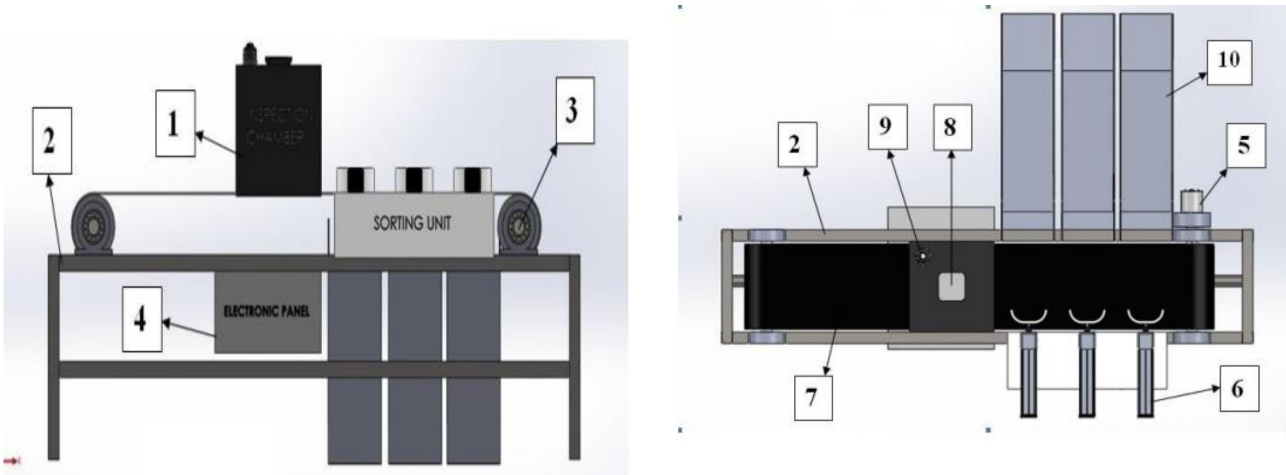


Figure 2-1- 6: Construction design of lemon sorting machine

Numbers in above diagrams denote:

1. Inspection Chamber
2. Frame
3. Shaft assembled with bearings
4. Electronic Panel
5. Drive motor
6. Actuators
7. Conveyer belt
8. HD Webcam
9. Guide ways

Fruits are placed on conveyer at regular position intervals by fruit placer, they move from left to right on the conveyer belt, fruits are retained in their place by cup shaped minute indentations.

As they move into illuminated inspection chamber, overhead webcam captures their image which is processed in computer-based MATLAB software and proper decision is drawn after processing the image in the pre-fed algorithm regarding activation of linear actuators to sort the fruit forward, as per the output, linear actuator actuates and pushes fruit into proper guide way sorting the fruit as defected into Guide way-1, raw into Guide way-2 and small mature fruit into Guide way-3, while large mature fruits are sorted undisturbed at the end of the conveyer travel.

Article available at https://www.irjet.net/archives/V3/i7/IRJET-V3I781.pdf.

2-2: Controller:

Programmable Logic Control (PLC), is industrial computer that use in industrial application by monitor the input devices to make decision depend on the software program.

2-2-1: PLC History:

In the past the control used for industrial applications was relay logic systems, the control systems us timers, relays, and drum sequencers.

Drum sequencers is mechanical mechanism consist of multiple switches opens and closed depend on movement of cams, the cam move by motor speed, so the whole process was complicated and can't add any external feature in the future.

So, the advantage of PLC over the relay logic systems is the availability of editing or adding feature in the system and also the communication to other devices with or different operating systems.

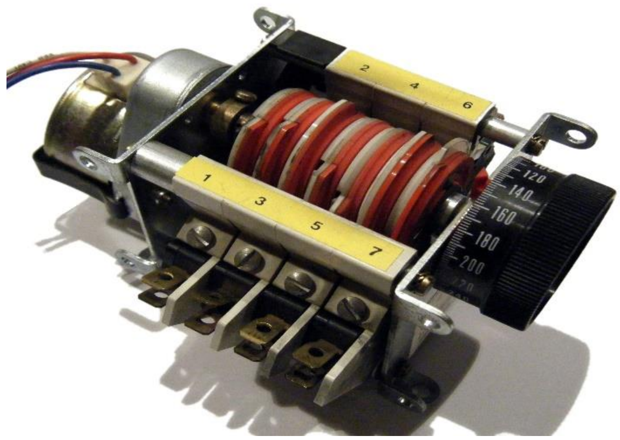


Figure 2-2-1 1: Cam/drum Sequencer

PLC introduced in 1968 by GM hydraulic, in 1969 the PLC was sold in the market by the name Mod icon, then in 1977 Mod icon sold to Gould electronics to current owner Schneider

For software Program it starts in early stage by logic as Boolean algebra, then after a while ladder diagram was represented then function block and statement text, but still the ladder is still more common.

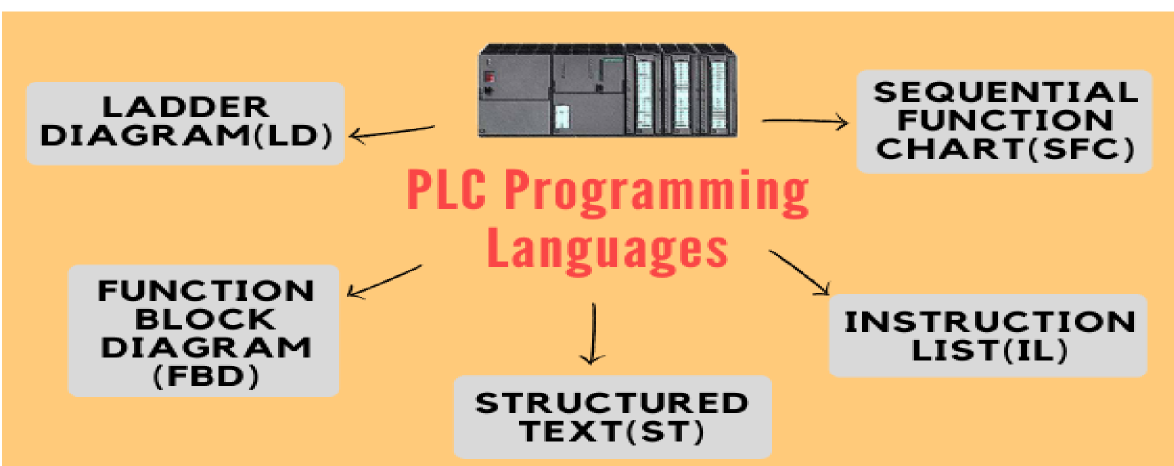


Figure 2-2-1 2: Different Programming Languages

2-2-2: PLC Architecture:

PLC consist of 5 element, CPU, Power Supply, memory, I/O, and communication modules as shown in FIG 2-2-2- 1.

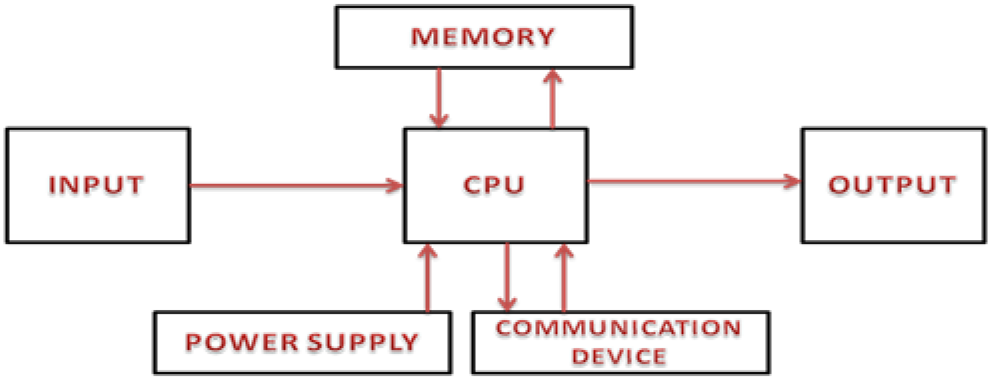


Figure 2-2-2- 2: PLC Architecture

1. **Power Supply:** The one responsible for supplying PLC main unit it takes 110/220 AC volt and give the DC volt for PLC modules.

2. **CPU:** The Central Processing Unit responsible for making decision needs for I/0 modules for example input when press the output will make decision.

3. **I/O:** Input and Output modules is the way for PLC to interface with the outer environment and it can be analogue or digital example for input as sensors and switch, for output as actuators, valves, …etc.

4. **Memory:** is responsible for save the software program and also give each I/o address, the type of memory is nonvolatile so the program, will not be lost after power off.

5. **Communication modules:** is away for mor than PLC or more than one device with different operating systems to communicate with each other.

The cable use in communication is three types Fiber optic cabling, twisted pair cabling, and Coaxial as shown in FIG 1.4, the comparison between three types as shown in TABLE 2-2-2-1.

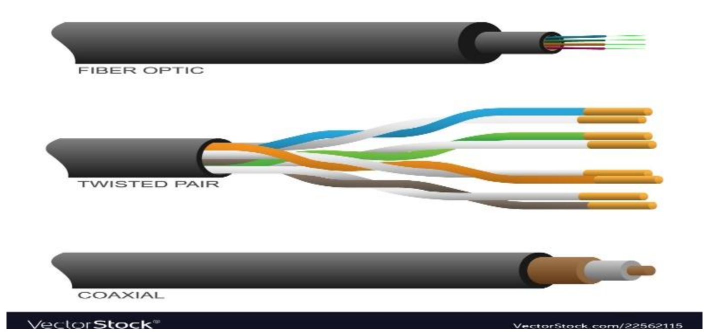


Figure 2-2-2- 3: Cable Type

Cable Type	Speed	Bandwidth	Distance
Fiber optic cable	10/100/1000 Mbps, 10/40/100/200 Gbps	Up to 4700 MHz	Up to 80km
Twisted pair cable	Up to 10 Gbps	Up to 4700 MHz	Up to 100m
Coaxial cable	—	750 MHz (default)	Up to 500m

Table 2-2-2- 1: Cable Types Comparison

Communication is either serial or parallel communication, for serial communication as RS – 232c, RS – 422/485, for parallel as IEEE – 488.

2-2-3: Areas where programmable logic controllers are applied:

PLCs are used in various applications in industries such as the steel industry, automobile industry, chemical industry and the energy sector. The scope of PLCs dramatically increases based on the development of all the various technologies where it is applied.

1. **Glass industry:**
   PLCs controllers have been in use in the glass industry for decades. They are used largely to control the material ratio as well as to process flat glasses. The technology has been advancing over the years and this has created an increased demand for the PLC control mode for use in the glass industry.
   The production of glass is an elaborate and sophisticated process so the companies involved often use PLCs with the bus technology in its control mode.
   Overall, the PLC is applied in both analogue data recording in the glass production, and in digital quality and position control.

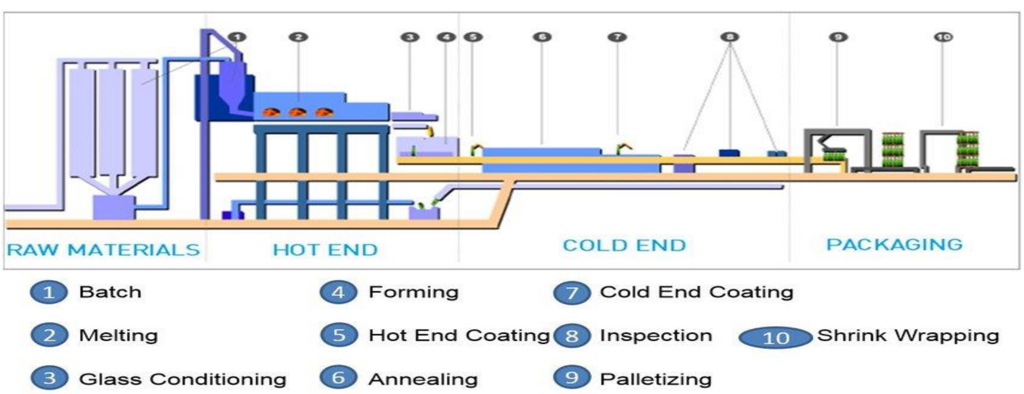


Figure 2-2-3- 1: Glass industry

2. **Paper industry:**

   In the paper industry, PLCs are used in various processes. These include controlling the machines that produce paper products at high speeds.
   For instance, a PLC controls and monitors the production of book pages or newspapers in offset web printing.

Figure 2-2-3- 2: Paper industry

3. **Cement manufacturing:**

   Manufacturing cement involves mixing various raw materials in a kiln. The quality of these raw materials and their proportions significantly impact the quality of the final product. To ensure the use of the right quality and quantities of raw materials, the accuracy of data regarding such process variables is of the essence.
   A distributed control system comprised of PLC in its user mode and a configuration software are used in the industry's production and management processes. The PLC in particular, controls ball milling, coal kiln and shaft kiln.

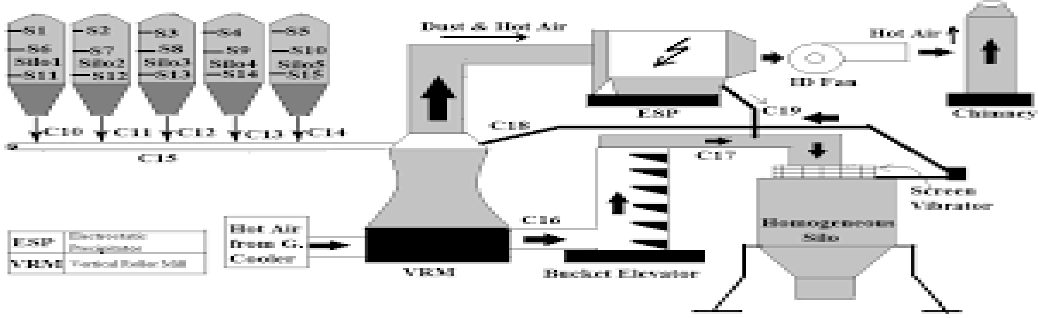


Figure 2-2-3- 3: Cement Manufacturing

2-2-4: PLC Operation:

There are four basic steps: input scan, program scan, output scan, and house-keeping, as shown in FIG 2-2-3-4

1. **Input Scan:** Detect all state of input devices connect to plc
2. **Program Scan:** Execute the software program
3. **Output Scan:** Do action to all output devices connect to PLC
4. **House-Keeping**: communication of program terminals basically is cleaning before and after the process from unnecessarily variables as temporally variable.

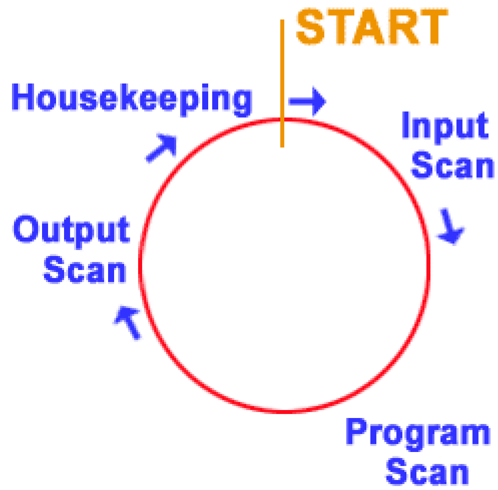


Figure 2-2-3- 4: Operating Speed

2-3: Computer Vision:

- **What is raspberry pi**

The Raspberry Pi is a low cost, **credit-card sized computer** that plugs into a computer monitor or TV, and uses a standard keyboard and mouse. It is a capable little device that enables people of all ages to explore computing, and to learn how to program in languages like Scratch and Python.

- **A Little History of the Raspberry Pi**

Back in 2006, while Eben Upton, his colleagues at University of Cambridge, in conjunction with Pete Lomas and David Braben, formed the Raspberry Pi Foundation. Early prototypes of the Raspberry Pi were based on the 8-bit Atmel ATMega644 in order to reduce cost. Following prototypes utilized an ARM processor similar to what was used in the release version of the Raspberry Pi.
In 2012, the team started its first production run consisted of 10,000 Raspberry Pi unites manufactured by foundries in China and Taiwan. Unfortunately, there was a manufacturing issue where the ethernet jack on the Raspberry Pi. This incident caused some minor shipping delays It took the team six years of hardware development to create the Raspberry Pi makers and electronics enthusiasts adore today.

- **Raspberry Pi Architecture**

- CPU (Central Processing Unit)**:**

The Central processing unit is the brain of the raspberry pi board and that is responsible for carrying out the instructions of the computer through logical and mathematical operations. The raspberry pi uses ARM11 series processor

- GPU (Graphics Processing Unit):

The GPU is a specialized chip in the raspberry pi board and that is designed to speed up the operation of image calculations. This board designed with a Broadcom video core IV and it supports OpenGL.

- Ethernet Port**:**

The Ethernet port of the raspberry pi is the main gateway for communicating with additional devices. The raspberry pi Ethernet port is used to plug your home router to access the internet.

- GPIO Pins**:**

  The general-purpose input & output pins are used in the raspberry pi to associate with the other electronic boards. These pins can accept input & output commands based on programming raspberry pi. The raspberry pi affords digital GPIO pins. These pins are used to connect other electronic components. For example, you can connect it to the temperature sensor to transmit digital data.

- XBee Socket:

  The XBee socket is used in raspberry pi board for the wireless communication purpose.

- Power Source Connector:

  The power source cable is a small switch, which is placed on side of the shield. The main purpose of the power source connector is to enable an external power source.

- UART:

  The Universal Asynchronous Receiver/ Transmitter is a serial input & output port. That can be used to transfer the serial data in the form of text and it is useful for converting the debugging code.

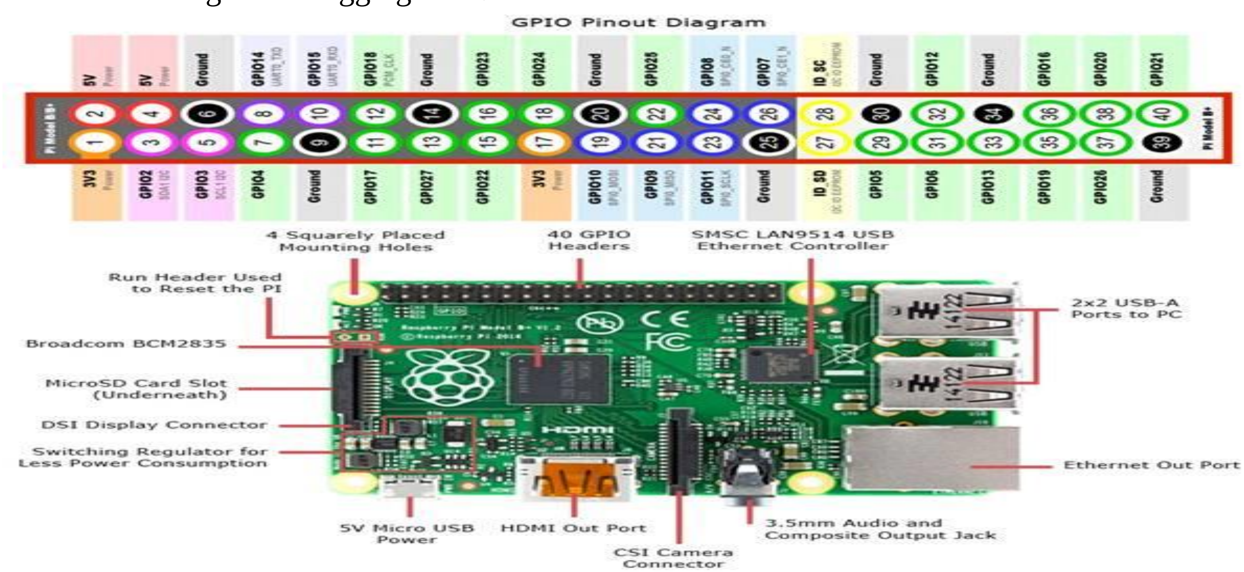


Figure 2-3- 1: Raspberry Pi

- **Specifications:**

  - Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz
  - 2GB, 4GB or 8GB LPDDR4-3200 SDRAM (depending on model)
  - 2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE
  - Gigabit Ethernet
  - 2 USB 3.0 ports; 2 USB 2.0 ports.
  - Raspberry Pi standard 40 pin GPIO header (fully backwards compatible with previous boards)
  - 2 × micro-HDMI ports (up to 4kp60 supported)
  - 2-lane MIPI DSI display port
  - 2-lane MIPI CSI camera port
  - 4-pole stereo audio and composite video port
  - H.265 (4kp60 decode), H264 (1080p60 decode, 1080p30 encode)
  - OpenGL ES 3.0 graphics
  - Micro-SD card slot for loading operating system and data storage
  - 5V DC via USB-C connector (minimum 3A*)
  - 5V DC via GPIO header (minimum 3A*)
  - Power over Ethernet (PoE) enabled (requires separate PoE HAT)
  - Operating temperature: 0 – 50 degrees C ambient

Chapter 3
Mechanical Design

Chapter 3: Mechanical Design

Our main project will be categorized into two stages, first the orange fruit will be fit into the feeding tank that can hold 8 kilo of orange then the mechanism will move forward with angle of 15 degrees upward that will help the fruit to be put into its position then it will pass through the camera room to know either the fruit is good or rotten, this is done by using computer vison it will discussed more in Chapter 5, the camera room will have 4 photo sensor when sensor detect the orange the camera will take shoot, after 4 shoots the camera will take decision either the fruit is good or rotten, the it will send the signal to controller, then for first stage second part will be the rejection part if the fruit is good it will be as its if not then the rejection plate will rotate 90 degrees counter clockwise where the fruit go to waste box, for the good fruit it will go to the second stage, which will classify the fruit by its size according to international standards.

3-1: Design of mechanism

3-1-1: First Stage First part

The first stage first part for sorting the orange fruit, at first the feeding tank will take 8kg of orange and by the use of sorting roller only one fruit will be between the two rollers to ensure only one orange will be in the camera room, when the orange enter the camera room, the camera will take different shoot and compare the current orange to the date of different orange, to know if orange fruit is good or rotten, the orange will rotate between the sorting roller due to the base is fixed and the roller is moving upward, so the orange will rotate.

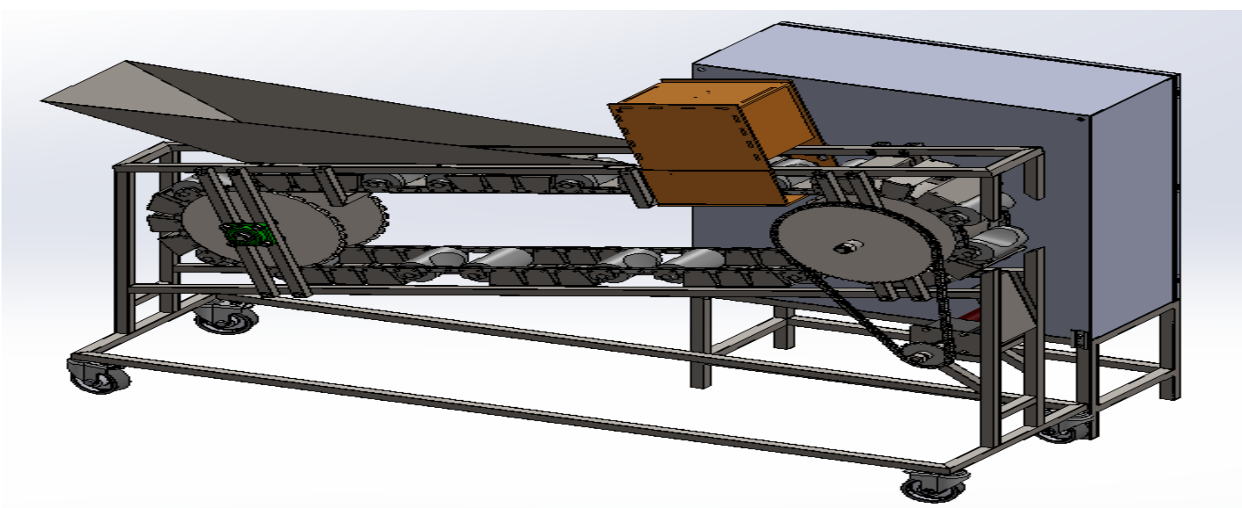


Figure 3-1-1- 1: Isometric View

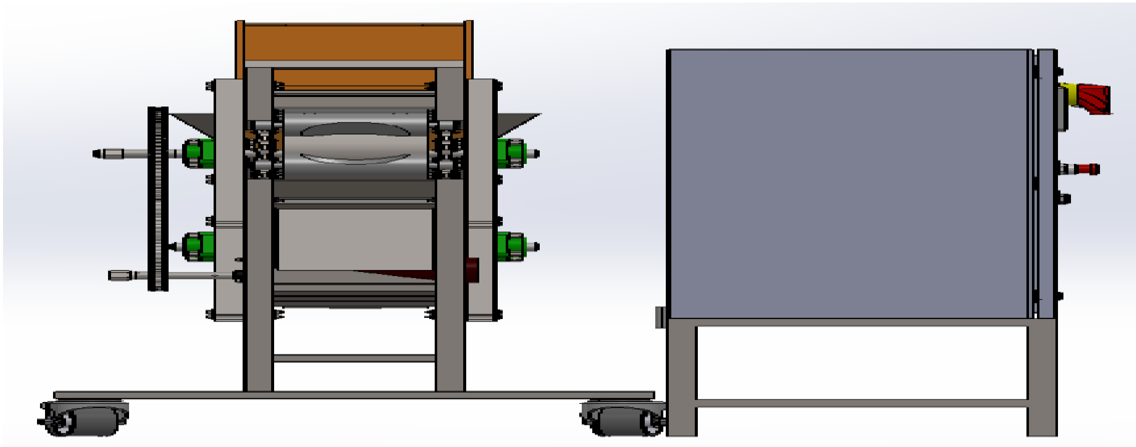


Figure 3-1-1- 4: Side View

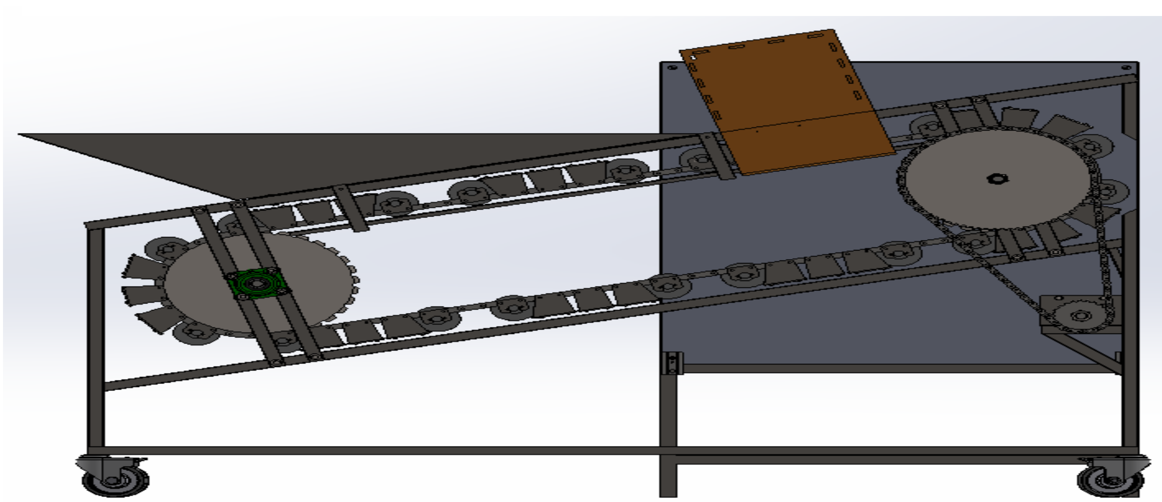


Figure 3-1-1- 2: Front View

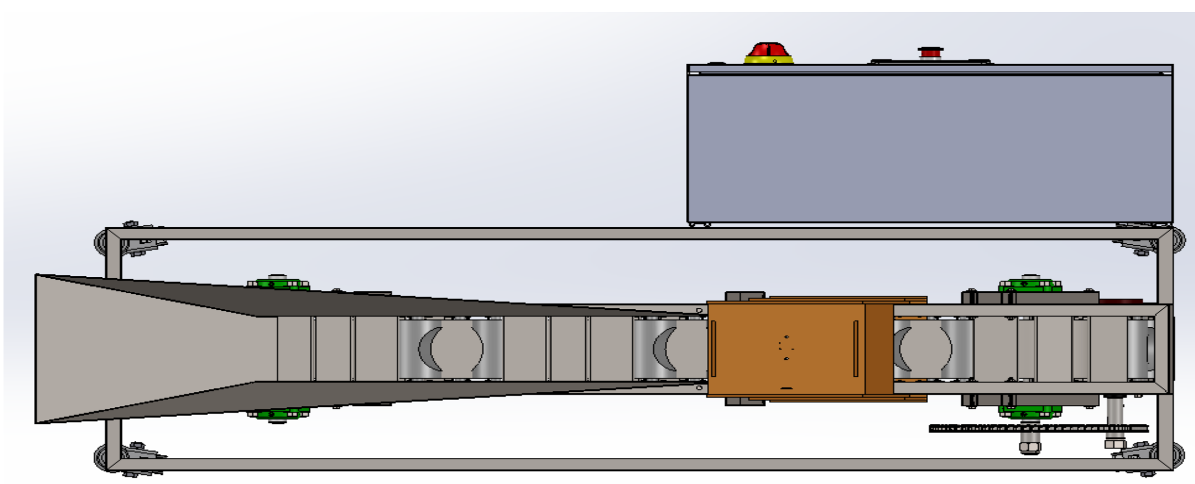


Figure 3-1-1- 3: Top view

3-1-2: First stage Second part

The first stage second part, when the orange exits the camera room the camera will take decision either the fruit is rotten or good, so before the fruit go to the next stage, the rotten fruit will be dropped into waste box and the good fruit will go to the next stage.

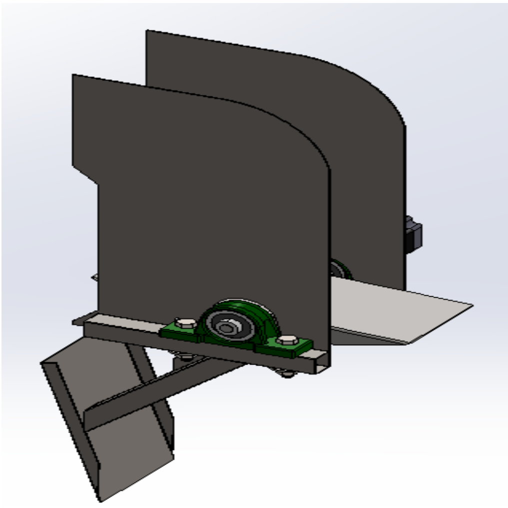


Figure 3-1-2- 2: Isometric View

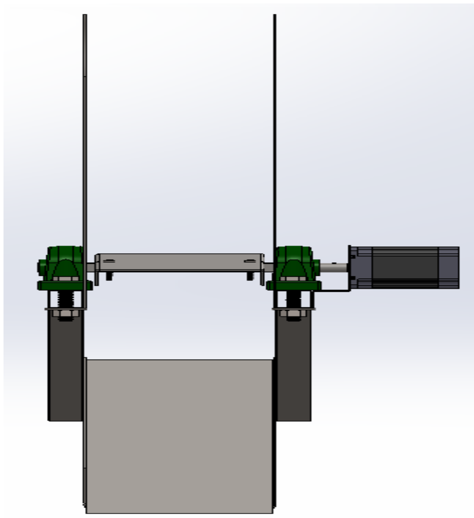


Figure 3-1-2- 1: Side View

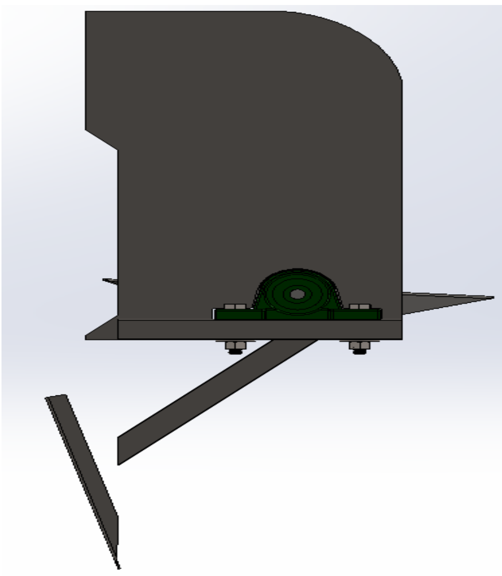


Figure 3-1-2- 3: Front view

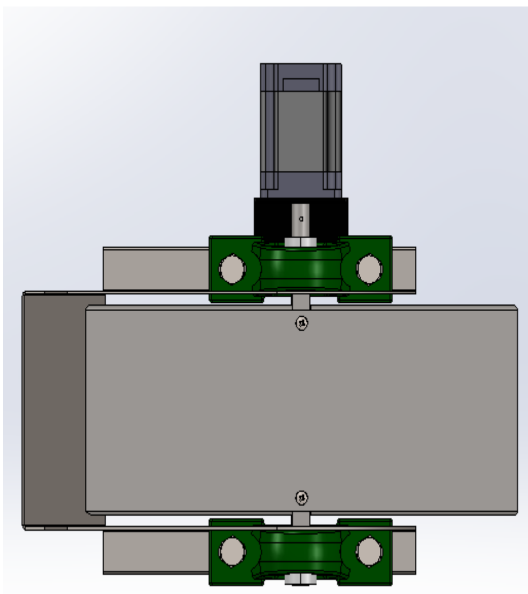


Figure 3-1-2- 4: Top View

3-1-3: Second Stage

Second Stage is for classifying good oranges into several sizes according to international standards as shown in Table 3-1-3-1.

The classification is divided into five stages:

- The first stage was designed on the basis of extracting oranges with size less than 53 mm.
- The second stage is designed to extract oranges from 53 mm to 68 mm.
- The third stage is designed to extract oranges from 70 mm to 76 mm.
- The fourth stage is designed to extract oranges from 80 mm to 88 mm.
- The fourth stage is designed to extract oranges from 92 mm to 96 mm.

Size code	Diameter (mm)	Fruits in 15kg box (pcs.)
0	92-110	30
1	87-100	36
2	84-96	40
3	81-92	48
4	77-88	64
5	73-84	72
6	70-80	80
7	67-76	88
8	64-73	100
9	62-70	113
10	60-68	125
11	58-66	138
12	56-63	150
13	53-60	162

Table 3-1-3- 1: Standard Size of Oranges

Note:

When the oranges are larger than 96 mm, they are extracted in a separate box after the last stage.

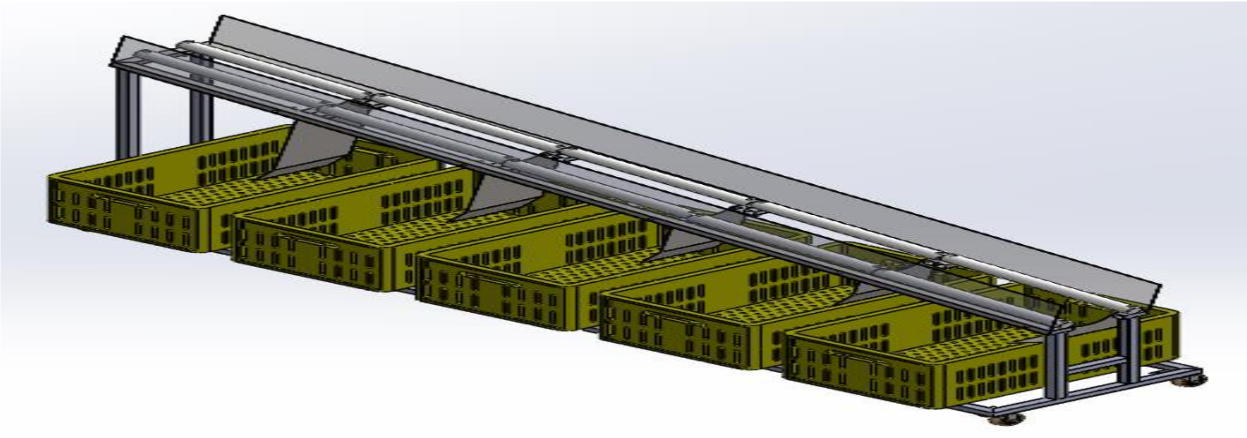


Figure 3-1-3- 1: Isometric View

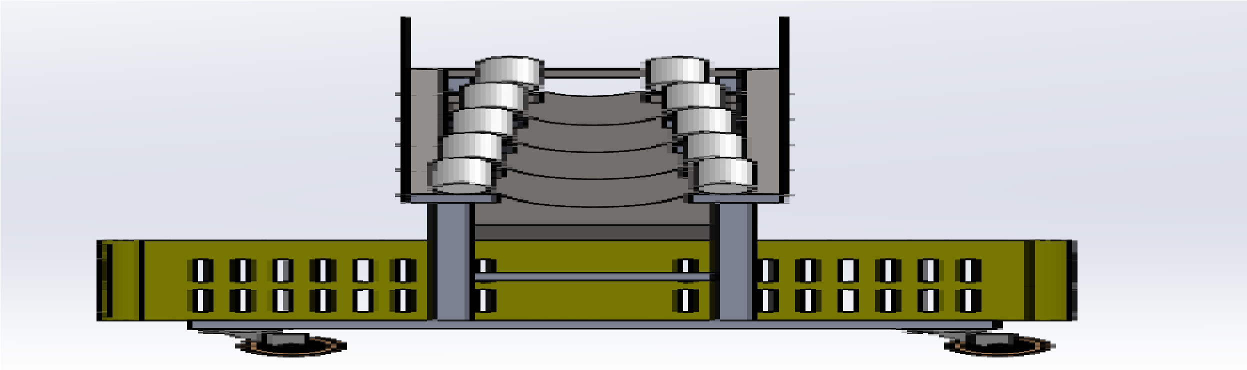


Figure 3-1-3- 3: Side View

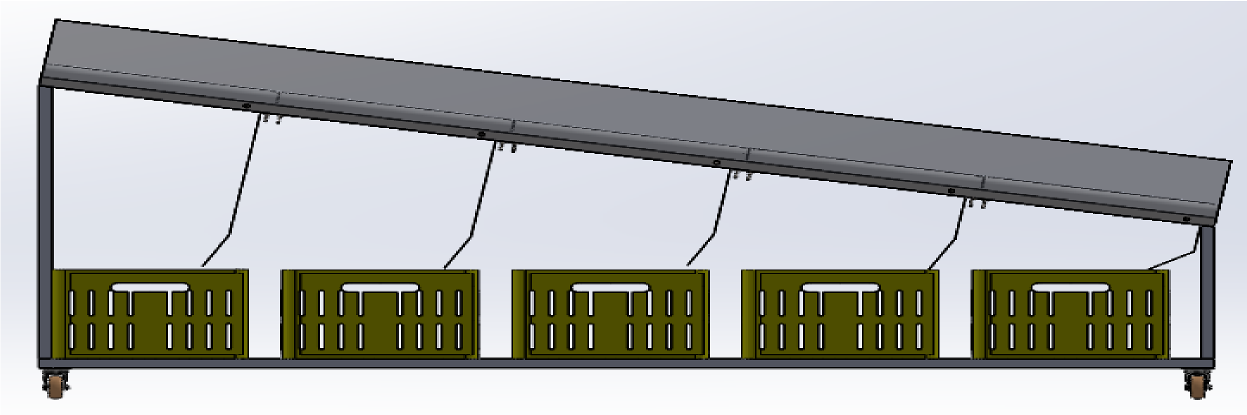


Figure 3-1-3- 4: Front view

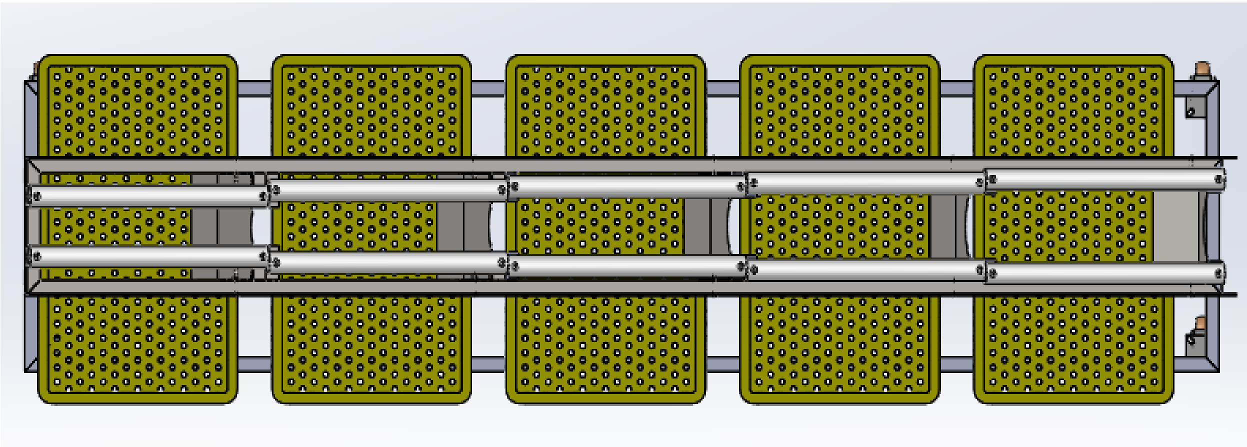
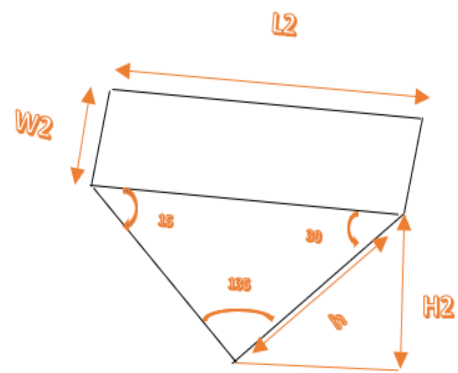


Figure 3-1-3- 2: Top View

3-2: Selection and Calculation of design part

Each part in the design is selected and calculated as, the tank, plastic shafts, boxes, steel shaft, keys, bolts, belts, motors, gears, and chain sprocket.

3-2-1: Feeding tank



Volume of feeding tank = 1.5*Volume of 8 kg box

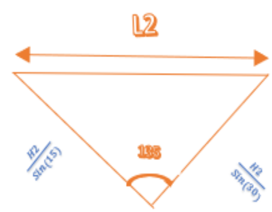
Volume of feeding tank = $1.5 * (40 * 35 * 10) = 21000\ cm^3$

$$v_{F.b} = 21000\ cm^3$$

The shape of feeding tank contain two triple pyramid and one quadrant pyramid.so,

$$v_{F.b} = 2 * \ v_{F.b.t} + \ v_{F.b.q}$$

- Calculation for quadrant pyramid:



$$v_{F.b.q} = \left(\frac{1}{2} * H2 * L2\right) * W2$$

$$L^2 = \left(\frac{H2}{\sin(30)}\right)^2 + \left(\frac{H2}{\sin(15)}\right)^2 - \left(2 * \left(\frac{H2}{\sin(30)}\right) * \left(\frac{H2}{\sin(15)}\right) * \cos(135)\right)$$

$$L = \sqrt{16 + 8\sqrt{3}} * H2$$

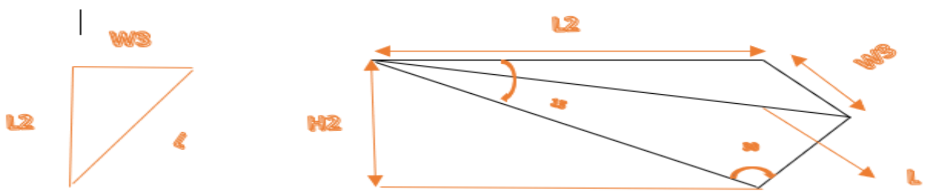
$$H2 = 20\ cm$$

$$L2 = 109.282\ cm$$

$$W2 = 13.5\ cm$$

$$v_{F.b.q} = \frac{1}{2} * 109.282 * 20 * 13.5 = 14753.07\ cm^3$$

- Calculation for triple pyramid:



$$v_{F.b.t} = \frac{1}{3} * \left(\frac{1}{2} * H2 * L2\right) * W3$$

$$v_{F.b.t} = 364.273 * W3$$

$$v_{F.b} = 2 * \ v_{F.b.t} + \ v_{F.b.q} = 21000 = (2 * 364.273 * w3) + 14753.07$$

$$W3 = 8.57\ cm$$

$$w\ = 2W3 + W2 = 30.64\ cm$$

$$L = \ \sqrt{l_2^2 + w_3^2} = 109.617\ cm$$

$$H = \frac{H2}{\sin(30)} = 40\ cm$$

Where,

$v_{F.b}$: is Feeding tank volume

$v_{F.b.q}$: is Feeding tank volume of quadrant pyramid

$v_{F.b.t}$: is Feeding tank volume of triple pyramid

L: normal length of feeding tank

L2: length of sheet metal

H: Hight of sheet metal

H2: normal Hight of feeding tank

W2: width of conveyer belt

W3: width of triple pyramid

W: is Feeding tank Width

From solid works simulation analysis:

- The material selected for feeding tank is steel AISI 1010, hot rolled, sheet metal with thickness of 2 mm.
- The maximum stress on the tank 15 MPa, the part is subjected to suddenly applied load with minor shock so the maximum stress become 1.5 * 15 equal to 22.5 MPa.
- The yield stress for AISI 1010, steel, hot rolled is 180 MPa.
- So, factor of safety is equal to 180/22.6 = 7.96, so the material is safe.
- The maximum displacement of tank is 0.3391 mm, this displacement is acceptable for tank

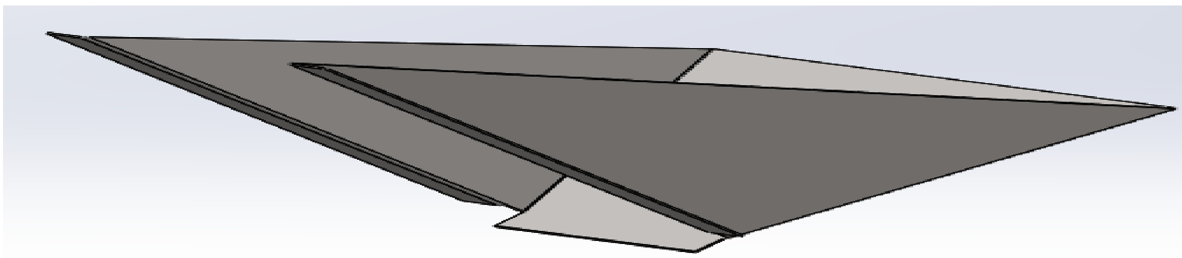


Figure 3-2-1- 1: Feeding tank

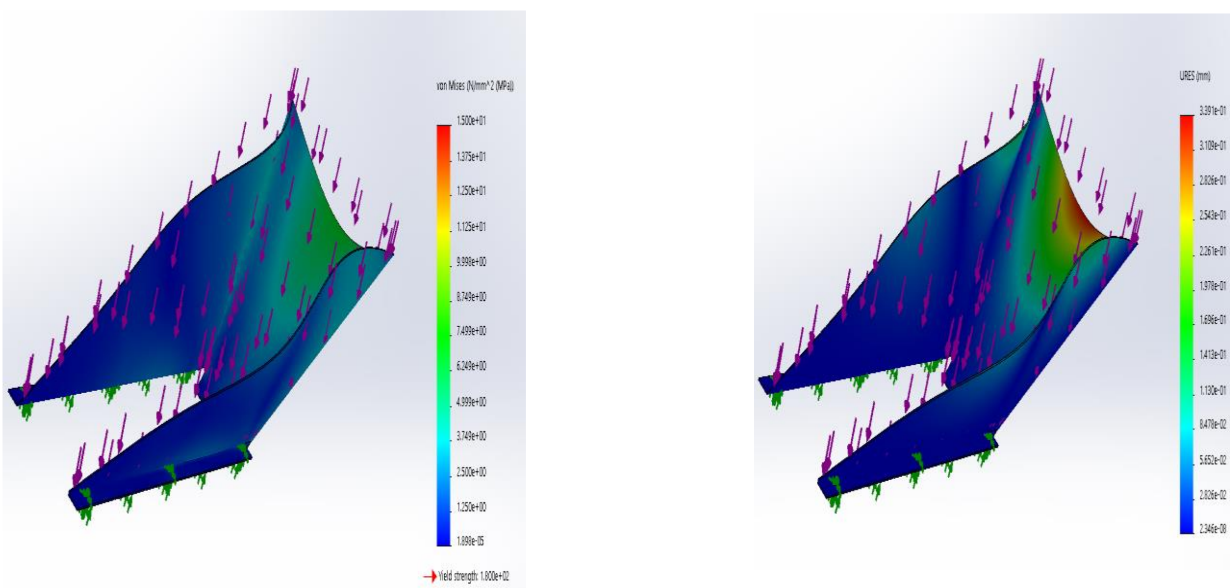
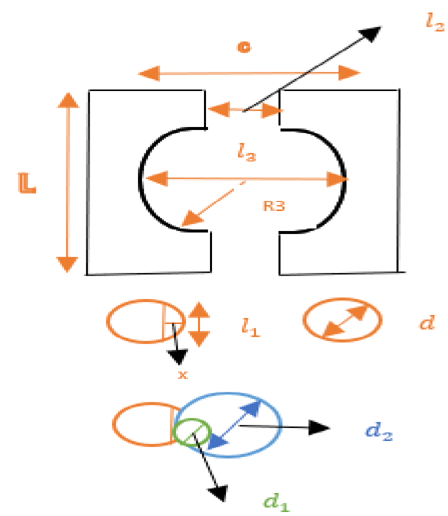


Figure 3-2-1- 2: Stress and displacement analysis for Feeding tank

3-2-2: Rollers

This is the rollers that is used for fruit place, to avoid dropping the orange it should push from the center so,



l_1 *must be grater than* $\left(\frac{d_2}{2}-\frac{d_1}{2}\right)$

$l_1 > \left(\frac{d_2}{2}-\frac{d_1}{2}\right)$

$l_1 > \left(\frac{100}{2}-\frac{53}{2}\right) > 23.5$

To avoid small orange or two small oranges enter between two rollers the l_2 must be less than diameter of smallest orange so,

$l_2 < d_1$

$l_2 < 53$

l_3 must be greater than diameter of largest orange and smaller than the diameter of two small orange so,

$$d_2 < l_3 < 2 * d_1 \quad , \quad 100 < l_3 < 106 \text{ ,let } l_3 = 103 \text{ mm}$$

C must be multiple of (2*p) and greater than l_3

$$C > l\_3 \quad , \quad C > 103 \text{ ,} 2 * p * n > 103$$

$$2 * 31.73 * n > 103 \quad , n > 1.6$$

$$n = 2 \ , \ C\ 2 * 31.73 * 2 = 127mm\ (4\ pitch)$$

$$R_3 > \frac{d_2}{2} \quad , \quad R_3 > 50 \quad , \ let\ R_3 = 52\ mm$$

$$C = d + l_2 \ , \quad l_2 = 127 - d \ , \quad l_2 < 53$$

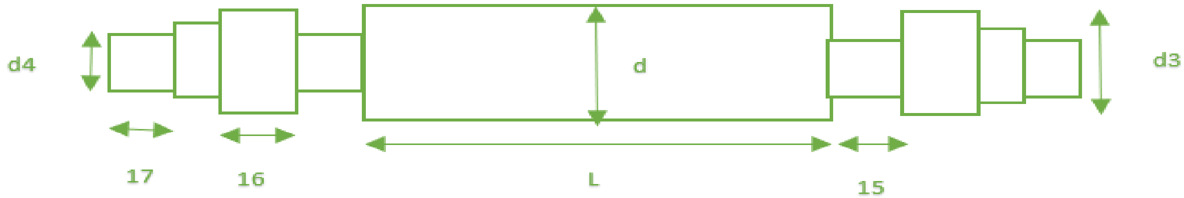
$$127 - d < 53 \quad , \ d > 127 - 53 > 74$$

$$d = 75\ mm \ , \quad l_2 = 127 - 75 = 52mm$$

$$l > d2 \ , l > 100 \ , let\ l = 120mm$$

$$x = \frac{d}{2} - \frac{c - l_3}{2} = \frac{75}{2} - \left[\frac{127 - 103}{2}\right] = 25.5\ mm$$

$$l_1 = 65.757 > 23.5\ mm \quad , so\ acceptable$$

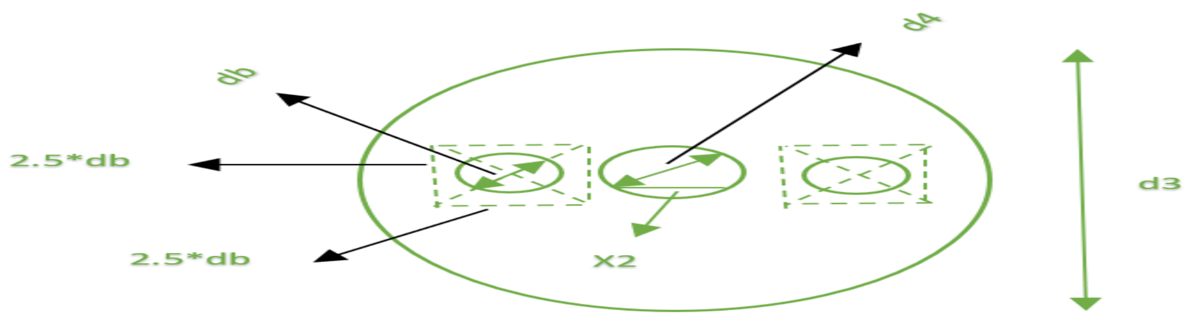


$$l_7 > t_a \;,\; l_7 > 2\,mm\,, let\ l_7 = 3\,mm$$

$$l_6 = d_p = 14\,mm$$

$$l_5 \geq l_t - [t_a + l_6], l_5 \geq 25 - [2 + 14]\,, l_5 > 9\,, let\ l_5 = 9\,mm$$

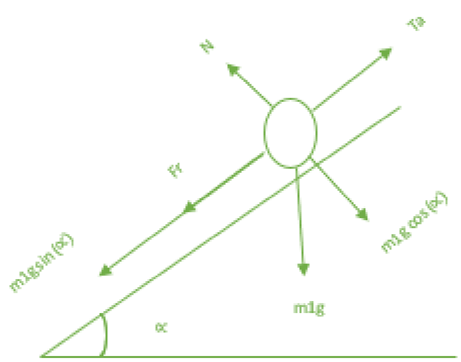
$$d_4 = 17\,mm$$

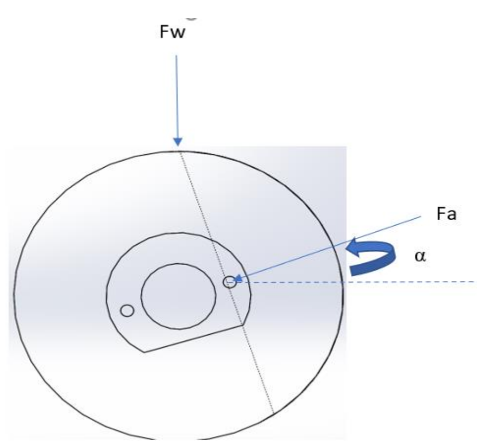


$$d_3 > 2 * (2.5 * d_p) + d_4 > 32\,, let\ d_3 = 33\,mm$$

The roller connected with 4 attachment parts with 2 screw M3 with length of 25 mm

$$f_w = mg = 8 * 9.81 = 78.48\,N$$





$$f_a = m_1 g \sin(\alpha) + f_r = m_1 g \sin(\alpha) + \mu N$$

$$N = \ m_1 g \cos(\alpha)$$

Where,

$$m_1 = 0.5 \ kg$$

$$\mu = 0.37$$

$$\propto = 15\ ^\circ$$

$$f_a = \ [0.5 * 9.81 * \sin(15)] + [0.5 * 9.81 * \cos(15)]$$

$$f_a = 3.03 \ N$$

From solid works simulation analysis

- The maximum stress act on roller is 6.187 MPa, the sudden applied load the maximum stress will be 1.5*6.187 equal to 12.374 MPa.
- The roller material must be selected with low friction to not reduce the quality of orange, with light mass, so the material selected is Artellon HDPE with 75 mm diameter.
- In the worst case the roller is applied to two types of loads one due to the weight of orange and the other due to force of pushing orange.
- The yield stress of HDPE is 15MPa, so the factor of safety is 15/12.374 equal 1.22, so the material is safe.
- The maximum displacement of roller is 0.169 mm, this displacement is acceptable for roller.

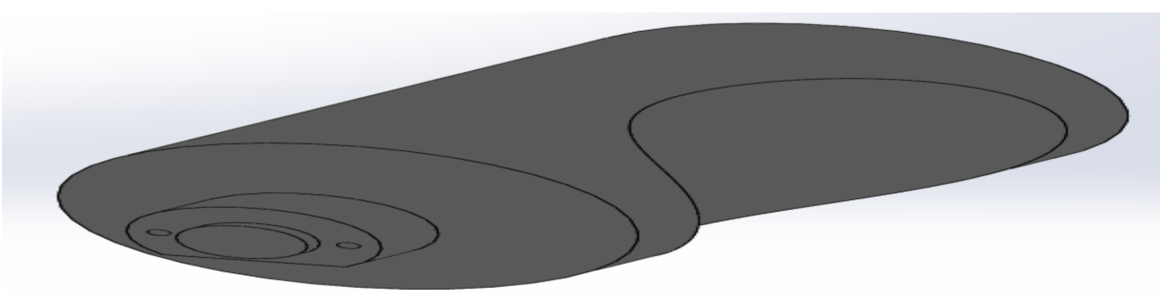


Figure 3-2-2- 1: Roller

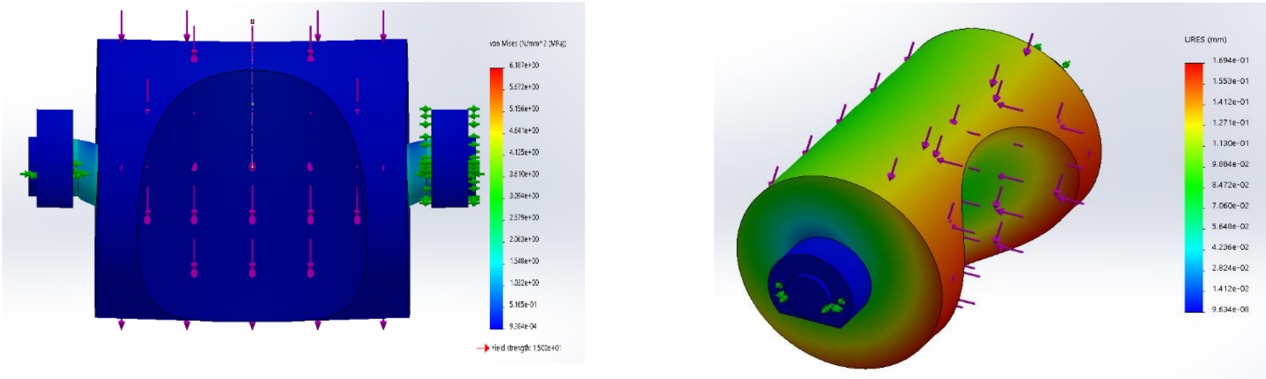


Figure 3-2-2- 2: Stress and displacement analysis for Feeding tank

Where,

d_2 : is the diameter of large orange = 100mm

d_1 : is the diameter of small orange = 53mm

d: is the diameter of sorting roller

l_1: is the height of curved groove

l_3: is the center-to-center length of curved groove

l_2: is the minimum length between two rollers

C: is the center-to-center length of two rollers

R_3 : is radius of curved groove

L: is length of roller

P: is chain pitch = 1.25 m = 31.75mm

t_2 : is thickness of attachment part of shaft

t_w: is thickness of washer = 0.6mm

d_p: is distance between two outer places of chain = 14 mm

$d_{o.o}$: is distance between two oranges

$d_{c.c}$: is center to center distance of two roller which the orange exits from camera room.

f_a : is normal force due to orange

m_1: mass of orange

μ: is friction coefficient between orange and steel

$\propto$: is angle of conveyor

3-2-3: Belts

The belt system is the most common piece of the mechanical handling equipment.

The belt system has two types

1. Flat &V - belt: that transport torque and speed in the inner parts of machines, that's due to the system application.

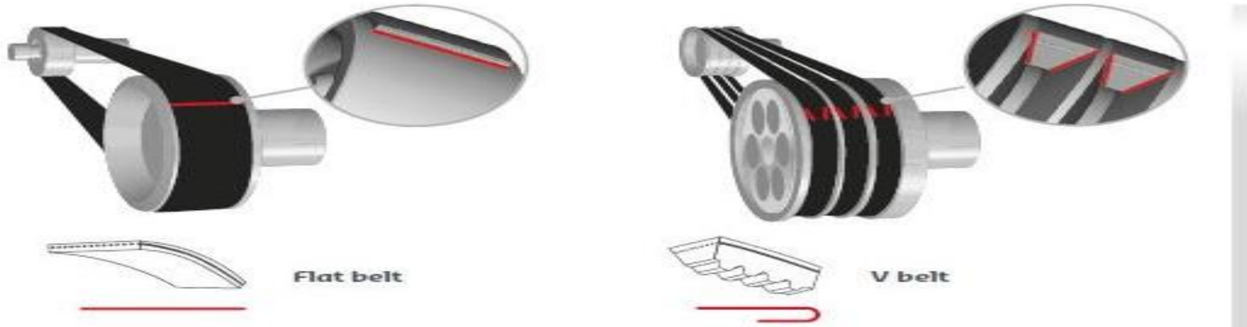


Figure 3-2-3- 1: Flat and V type belt

2. Conveyer belt: the carry and moves materials from one location to another.

Figure 3-2-3- 2: Conveyer belt

A conveyor is the convenient carrying medium consists of two or more pulleys or rollers rotating about their axis for transformation of material or product.

The conveyor belt plays more and more important role in economic construction and development since it connects one industrial department with another department. In the industrial production, conveyor belt is used for continuity and automation of vast production line and improve the production efficiency and reduce the working strength.

The conveyor belt is mainly composed of machine frame, two rollers or pulley; one of them is driving pulley which is also called as powered pulley (roller), other pulley which is not connected with any electric power which is known as driven pulley (roller).

Furthermore, the machine body is connected by high-quality steel plate and on the machine body; there are belt roller and carrier roller to drive and support the conveying belt.

Design of the belt in our project:

To start design in belts ... we must consider three things (Load-Size-Material)

1) Material
   We take in consideration the first thing about the belt material. because it makes a difference of the applied load and the specification of the material that be conveyed by belt.
   In our project Material of the Belt will carry Oranges, and oranges come under the food source so the material will be P.V.C Belt.
   P.V.C belt advantage that made from polymers that won't react with any kind of food source

Figure 3-2-3- 3: PVC conveyer belt

2) Size
   We have the size available in every belt … size won't be a trouble
3) Load
   The given load that the belt must carry is about 8 Kilograms

$$T_b = \left[1.37 * F * L * G * [\, 2 * M_i + (2 + \; M_b + \; Mm\,)]\right] * \cos(\alpha) + [H * G * \; Mm\,]$$

$$F: 0.3$$

$$L: 25.4x10^{\wedge}-2\ m$$

$$G: 9.81$$

$$M_i: we\ don't\ need\ idler\ =\ 0$$

$$M_b: 4.6 * (130x10^{\wedge}-3)\ Kg/m$$

$$Mm: 8/(25.4x10^{\wedge}-2)\ Kg/m$$

$$\alpha: 15\ degree$$

$$H: 0.245\ *\ Sin\ (15)$$

$$T_b = 1.37\ *\ (0.3)\ *\ (25.4x10^{-2})\ *\ (9.81)\ *\ (2\ *\ 4.6 * (130x10^{-3})\ *\ 8/\ (25.4x10^{-2}))\ *\ Cos\ (15)\ +\ [0.254\ *\ sin\ (15) *\ 9.81 * \frac{8}{25.4x10^{-2}} =\ 53.14\ N$$

$$In\ the\ Table\ of\ P.V.C\ belt\ I\ Choose$$

$$Type\ (F-31)$$

$$The\ tension\ of\ the\ belt\ type\ (F-31)\ is\ =\ 20N/Cm$$

$$N =\ factor\ of\ safety$$

$$N =\ 20 * 25.4/53.15\ =\ 9.5$$

Where,

T_b: Tension of Belt

F: coefficient of friction belt with pulley

L: Length of the half of the conveyer

G: Gravitational Force

M_i: load due to idler

M_b: load due to belt

Mm: load due to conveyed material

α: angle of inclination of the belt

H: vertical height of the conveyer in meter

But after that I had a major problem, that the belt must be a dark black with no reflection color, with the P.V.C belt it comes with the white color and its integration.

So, I decided to make instead of the P.V.C belt a sheet metal that will provide the load and the color.

The sheet metal will be 2mm thickness and 2 Meters long with the bending of its ends to take the shape of the conveyer belt and wielded in to the housing of stage 1.

On the same idea we decided to change the P.V.C belt between the Artellon with separated sheet metals on every peach of the chain to provide also the right color needed for the photo of the camera.

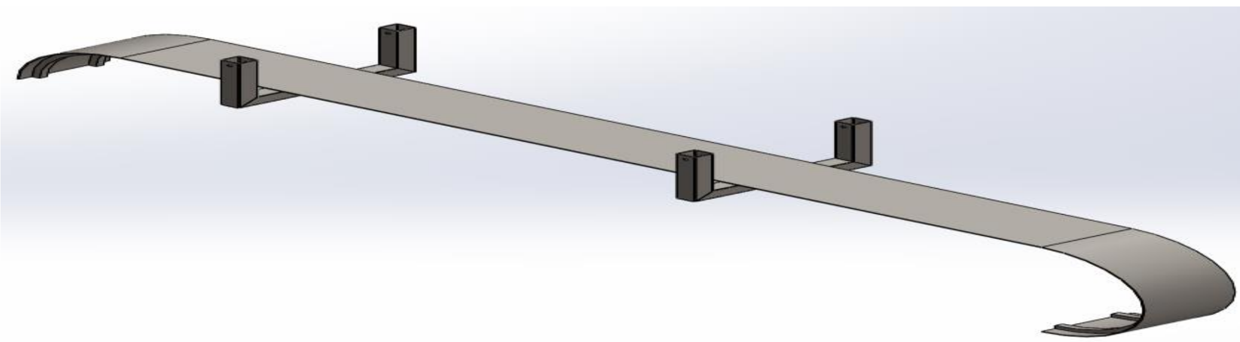


Figure 3-2-3- 4: Fixed base

3-2-4: Bearings

The term “bearing” typically refers to contacting surfaces though which load is transmitted. Bearings may roll or slide or do both simultaneously. The range of bearing types available is extensive, although they can be broadly split into two categories: sliding bearings also known as plain surface bearings, where the motion is facilitated by a thin layer or film of lubricant, and rolling element bearings, where the motion is aided by a combination of rolling motion and lubrication is often required in a bearing to reduce friction between surfaces and to remove heat.

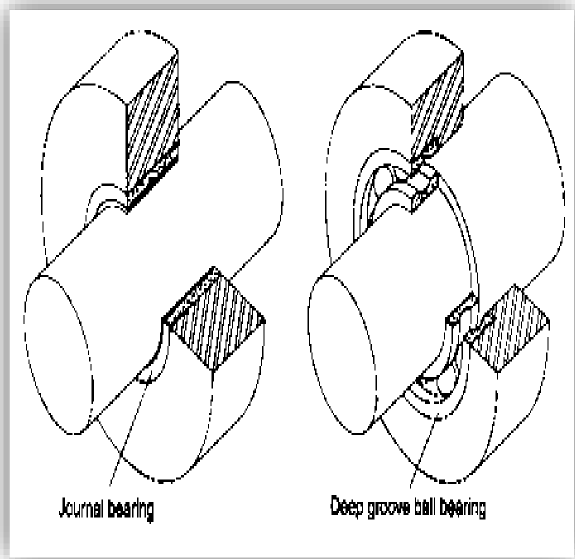


Figure 3-2-4- 1: Types of bearing

Sliding bearings:

The term ‘sliding bearing’ refers to bearings where two surfaces move relative to each other without the benefit of rolling contact.

Rolling contact bearings:

The term ‘rolling contact bearings’ encompasses the wide variety of bearings that use spherical balls or some type of roller between the stationary and moving elements. Most common type of bearing supports a rotating shaft resisting a combination of radial and axial (or thrust) loads. Some bearings are designed to carry only radial or only thrust loads.

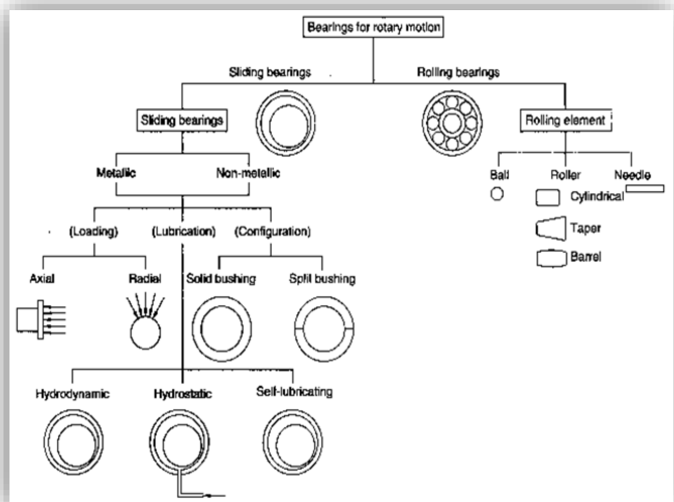


Figure 3-2-4- 2: Bearing for rotary motion

<u>Selection Bearing:</u>

- **Load Capacity (Dynamic & Static).**
- **Normal Life.**
- **Cost.**
- **Size (Outer Diameter &Inner Diameter).**

<u>Rules:</u>

$$L = \left(\frac{c}{P}\right)^{n}$$

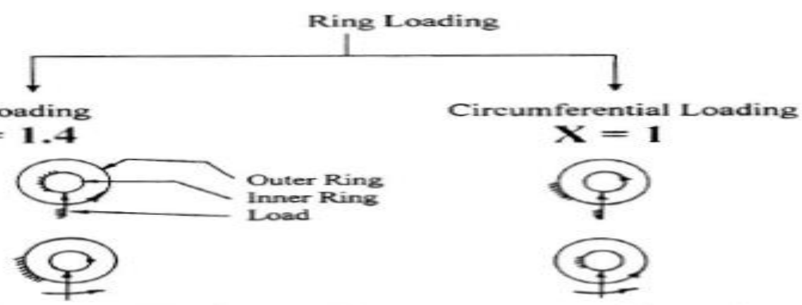
$$L = \frac{L_h * 60 * N}{10^6}$$

$$p = x * \ \rho_r + y * p_x$$

Where,

L *:* Nominal life (Millions of Revolution).
c *:* Dynamic Capacity in (N).
n *:* Exponent of the life formula. [*(n=3) for Ball Bearing & (n=10/3) for Roller Bearing]*
L_h *:* Nominal life in working hours. ($L_h = Lyears \times LDays \times Lhours$).
N *:* Rotational Speed in rpm.
p *:* Equivalent bearing load "Static Load" in (N).
x*:* Radial Factor.
ρ_r *:* Actual Radial Load.
y *:* Axial Factor.
p_x*:* Actual Axial Load.

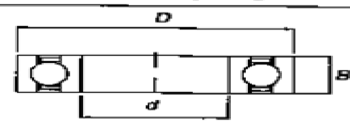
<u>The radial factor (X) is determined according to the following :</u>



<u>The axial factor (Y) depends on the type of bearing used :</u>

1. Deep Groove Ball Bearings	C/Pa :	5	10	20	40
	Y :	1.4	1.6	1.8	2.0
2. Angular contact ball bearings	single	0.7			
	double	1.3			
3. Self - Aligning ball bearings		1.5 → 4.5			
4. Taper Roller Bearings		1.4 → 1.8			
5. Self - Aligning barrel Roller Bearing	single	9.5			
	double	3.2 → 6.4			

Table 4.7 Selected example single row deep groove ball bearing ratings



d (mm)	D (mm)	B (mm)	Basic dynamic load rating C (N)	Basic static load rating C_o (N)	Speed limit for grease lubrication (rpm)	Speed limit for oil lubrication (rpm)	Code
15	24	5	1570	800	28 000	34 000	61802
	32	8	5600	2850	22 000	28 000	16002
	32	9	5600	2850	22 000	28 000	6002
	35	11	7850	3750	19 000	24 000	6202
	42	13	11 500	5400	17 000	20 000	6302
17	26	5	1690	930	24 000	30 000	61803
	35	8	6060	3250	19 000	24 000	16003
	35	10	6060	3250	19 000	24 000	6003
	40	12	9550	4750	17 000	20 000	6203
	47	14	13 600	6550	16 000	19 000	6303
	62	17	23 000	10 800	12 000	15 000	6403
20	32	7	2750	1500	19 000	24 000	61804
	42	8	6900	4050	17 000	20 000	16004
	42	12	9400	5000	17 000	20 000	6004
	47	14	12 800	6550	15 000	18 000	6204
	52	15	16 000	7800	13 000	16 000	6304
	72	19	30 800	15 000	10 000	13 000	6404
25	37	7	4400	2600	17 000	20 000	61805
	47	8	7600	4750	14 000	17 000	16005
	47	12	11 300	6550	15 000	18 000	6005
	52	15	14 050	7800	12 000	15 000	6205
	62	17	22 600	11 600	11 000	14 000	6305
	80	21	36 000	19 300	9000	11 000	6405
30	42	7	4500	2900	15 000	18 000	61806
	55	9	11 300	7350	12 000	15 000	16006
	55	13	13 400	8300	12 000	15 000	6006
	62	16	19 600	11 200	10 000	13 000	6206
	72	19	28 200	16 000	9000	11 000	6306
	90	23	43 700	23 600	8500	10 000	6406

Table 3-2-4- 1: Selection table for bearing

Bearing calculation:

There are two types of bearing in our project one for first stage and the other for first stage rejection part.

Shaft bearing:

$$Load = Pr = 96.26$$
$$Px = 0$$
$$x = 1.4$$
$$Peq = x * Pr = 96.26 * 1.4 = 134.764\ N$$
$$N = 31\ RPM$$
$$Lh = 11520\ hours$$
$$L = 21.43\ Million\ of\ Revolution$$
$$n = 3$$
$$C = 374.96\ N$$
$$Co = Peq = 135\ N$$
$$C(table) = 12.7\ kN$$
$$Co(table) = 6.7\ kN$$

$$\because C(table) > C \,\&\, Co(table) > Co$$
$$\therefore Bearing\ of\ Shaft\ is\ safe.$$

Dimensions				Basic load ratings		Limiting speed	Designations		
				dynamic	static		Bearing unit	Housing	Bearing
d [mm]	J [mm]	L [mm]	T [mm]	C [kN]	C_0 [kN]	[r/min]			
20	63.5	92	34.8	10.8	6.55	5 000	F4BC 20M-TPSS	F4BC 504	YAR 204-2LPW/SS
20	63.5	92	34.8	12.7	6.55	5 000	F4BC 20M-TPZM	F4BC 504	YAR 204-2LPW/ZM
20	63.5	92	35	10.8	6.55	700	F4BC 20M-CPSS-DFH	F4BC 504	YAS 204-2LP1W/SS
20	64	86	33.2	12.7	6.7	6 500	UCF 204	F 204/Y	UC 204

Table 3-2-4- 2: Shaft bearing selection

Rejection shaft bearing:

$$Load = Pr = 6.13764\, N$$
$$Px = 0$$
$$x = 1.4$$
$$Peq = x * Pr = 6.13764 * 1.4 = 8.96\, N$$
$$N = 5\, RPM$$
$$Lh = 11520\, hours$$
$$L = 4.356\, Million\ of\ Revolution$$
$$n = 3$$
$$C = 13.547\, N$$
$$Co = Peq = 8.96\, N$$
$$C(table) = 9.56\, kN$$
$$Co(table) = 4.75\, kN$$
$$\because C(table) > C \,\&\, Co(table) > Co$$
$$\therefore Bearing\ of\ Rejection\ is\ safe.$$

Dimensions						Basic load ratings		Limiting speed	Designations		
						dynamic	static		Bearing unit	Housing	Bearing
d [mm]	A [mm]	H [mm]	H_2 [mm]	J [mm]	L [mm]	C [kN]	C_0 [kN]	[r/min]			
12	26	22.1	43.5	68	85.5	9.56	4.75	9 500	P 12 TF	P 40	YAR 203/12-2F
12	32	25.3	50.5	76	98.5	9.56	4.75	9 500	P 47 R-12 TF	P 47	YAR 203/12-2F
12	32	30.2	57	97	127	9.56	4.75	9 500	SY 12 TF	SY 503 M	YAR 203/12-2F

Table 3-2-4- 3: Rejection shaft bearing selection

3-2-5: Shafts

General consideration in shaft design:

At first you must cheek the affected load on shaft whether it act as **pure shear stress** (Twisting Torque or Moment) or **pure normal stress** (Bending Moment or Normal Force) or combined **Max shear stress** and **principle normal stress** (Twisting Torque & Bending moment together).

1. **Shaft under pure shear stress:**

   General equation of Twisting Torque (Torsion):

$$\frac{T}{I_p} = \frac{\tau}{r} = \frac{\theta G}{L}$$

Where,
T: $Torque\ or\ Twisting\ Moment$
Ip : $polar\ moment\ of\ inertia\ of\ shaft$
τ : $Torsional\ shear\ stress$
r: $radius\ of\ shaft$
θ : $Angel\ of\ Twist$
G: $Modulus\ of\ rigidity$

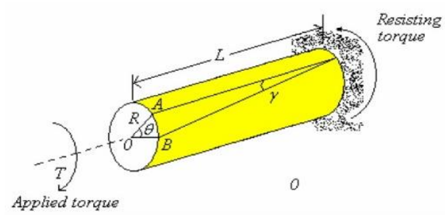


Figure 3-2-5- 1: Angel of Twist

- **Solid shaft under pure shear stress**

$I_p = I_{xx} + I_{yy} = \frac{\pi}{32}\ d^4$ by compensation in the general equation we get

$$d = \sqrt[3]{\frac{16\,T}{\pi\,\tau}} \qquad (3\text{-}2\text{-}5\text{-}1)$$

- **Hollow shaft under pure shear stress**

$I_p = \frac{\pi}{32}\ (d_o^4 - d_i^4)$ by compensation in the general equation we get

$$T = \frac{\pi\,\tau}{16\,d_o}(d_o^4 - d_i^4)$$

Take $K = \frac{d_i}{d_o}$ we get

$$d_o = \sqrt[3]{\frac{16\,T}{\pi\,\tau\,(1 - K^4)}} \qquad (3\text{-}2\text{-}5\text{-}2)$$

2. **Shaft under pure normal stress**

General Equation of Normal stress:

$$\sigma_b = \frac{M\,Y}{I}$$

Where,

σb normal stress due to bending moment

M Maximum Bending moment acting on critical section

I Second moment of inertia

Y Distance from neutral axis to the outer

- **Solid shaft under pure normal stress**

$I = \frac{\pi}{64} d^4$ & $y = \frac{d}{2}$ by compensation in the general equation

$$\boldsymbol{d = \sqrt[3]{\frac{32\,M}{\pi\,\sigma_b}}} \qquad (3\text{-}2\text{-}5\text{-}3)$$

- **Hollow shaft under pure normal stress**

$I = \frac{\pi}{64}(d_o^4 - d_i^4)$ & $Y = \frac{d_o}{2}$ by compensation in the general equation

$\sigma_b = \frac{M\,(d_o/2)}{\frac{\pi}{64}(d_o^4 - d_i^4)}$ By Take $K = \frac{d_i}{d_o}$ we get

$$d_o = \sqrt[3]{\frac{32\,M}{\pi\,\sigma_b\,(1-k^4)}} \qquad (3\text{-}2\text{-}5\text{-}4)$$

3. **Shaft under combined Normal stress and shear stress**

In this case we must calculate Maximum shear stress theory and maximum normal stress theory.

i. **Maximum shear stress theory (Guest's Theory)**

General Equation of maximum shear stress theory:

$$\tau_{max} = \frac{1}{2}\sqrt{\sigma_b^2 + 4\,\tau^2}$$

Where,

σ_b Normal stress due to Bending moment

τ Shear stress due to Twisting moment

- **Solid shaft in maximum shear stress theory**

$$\boldsymbol{\sigma_b = \frac{32M}{\pi d^3}} \ \ \& \ \ \boldsymbol{\tau = \frac{16T}{\pi d^3}} \ \text{by compensation in the general equation}$$

$$d = \sqrt[3]{\frac{16\sqrt{M^2+T^2}}{\pi \, \tau_{max}}} \qquad (3\text{-}2\text{-}5\text{-}5)$$

- **Hollow shaft in maximum shear stress theory**

$$d_o = \sqrt[3]{\frac{16\sqrt{M^2+T^2}}{\pi \, \tau_{max}(1-K^4)}} \qquad (3\text{-}2\text{-}5\text{-}6)$$

ii. **Maximum Normal stress theory**

General Equation of Maximum normal stress theory:

$$\sigma_y(max) = \frac{1}{2}[\sigma_b + \sqrt{\sigma_b^2 + 4\tau^2} \ ]$$

Where,

$\boldsymbol{\sigma_y}$ yield stress of shaft material

- **Solid shaft in Maximum normal stress theory**

$$\sigma_b = \frac{32M}{\pi d^3} \ \ \& \ \ \tau = \frac{16T}{\pi d^3} \ \text{by compensation in the general equation}$$

$$\frac{\pi}{32}\sigma_y d^3 = \left(M + \sqrt{M^2+T^2}\right)$$

$$d = \sqrt[3]{\frac{16 * (\frac{1}{2}[M + \sqrt{M^2+T^2}])}{\pi \sigma_y}} \qquad (3\text{-}2\text{-}5\text{-}7)$$

- **Hollow shaft in Maximum normal stress theory**

$$d_o = \sqrt[3]{\frac{16 * (\frac{1}{2}[M + \sqrt{M^2+T^2}])}{\pi \sigma_y \, (1-K^4)}} \qquad (3\text{-}2\text{-}5\text{-}8)$$

Shaft calculations:

There are four types of shafts in our project, Rejection shaft, driven shaft, drive shaft, and motor shaft.

1. **Rejection shaft Design**

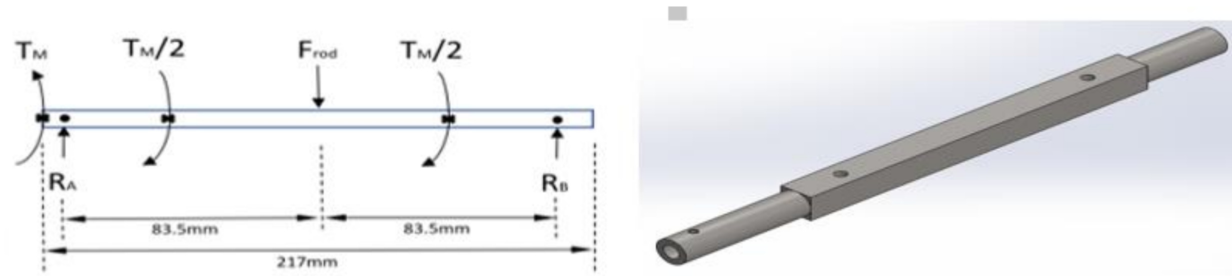


Figure 3-2-5- 2: Rejection shaft

Known that Motor torque $T\_m = 0.7357\ N.m$, maximum weight of orange is 0.5Kg, reject sheet metal weight $M_{SM} =$ 0.562 Kg and shaft weight is $0.226\ Kg$, note that A and B are two Bearing.

$$F_{rod} = F_{orange} + F_{shaft} + F_{SM} = 9.81(0.5 + 0.226 + 0.562) = 12.7\ N$$

Using moment summation to calculate Bearing Reaction.

$$\sum M_B = 0$$

$$R_A = \frac{12.7*0.0835}{0.167} = 6.35\ N \quad , \ R_B \text{ Equal to } R_A \text{ due to symmetric.}$$

From diagram we obtain that maximum moment is $M = 1.06\ N.m$**,**

as shown in Figure 3-2-5-3.

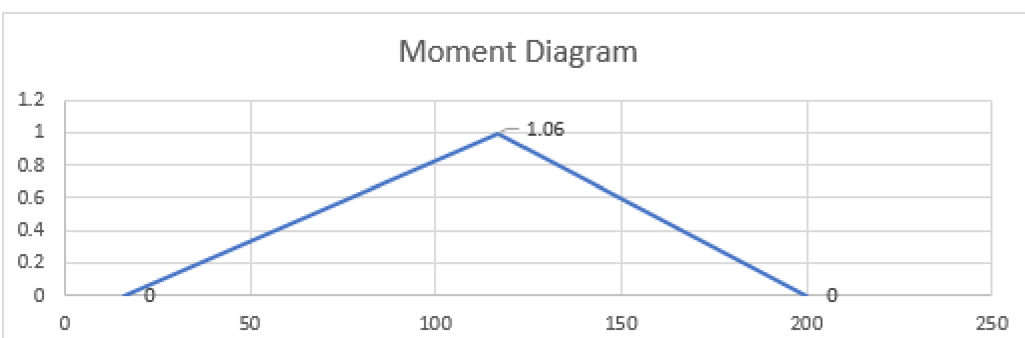


Figure 3-2-5- 3: moment diagram for rejection shaft

Final design consideration

$M = 1.06\ N.M, T_m = 0.7357\ N.M$, Maximum shear stress & maximum normal stress for 1020 steel $\tau = 470\ MPa, \sigma = 390 MPa$, combined shock & fatigue factor for Bending and Torsion $K_m = K_T = 2$.

- **Solid circular part of shaft under combined stress:**

Max shear stress Theory Eqn (3-2-5-5) we get:

$$d = \sqrt[3]{\frac{16\sqrt{(2 \times 1.06)^2 + (2 \times 0.73575)^2}}{\pi \times 470 \times 10^6}} = 2.7mm$$

Principle Normal stress Theory Eqn (3-2-5-7) we get:

$$d = \sqrt[3]{\frac{16 \times \frac{1}{2}\left[(2 \times 1.06) + \sqrt{(2 \times 1.06)^2 + (2 \times 0.73575)^2}\right]}{\pi \times 390 \times 10^6}} = 2.95mm$$

- **Hollow circular part of shaft under combined stress:**

Inner diameter for hollow shaft d_i =6.35mm

Max shear stress Theory Eqn (3-2-5-6) we get:

$$d_o = \sqrt[3]{\frac{16\sqrt{(2 \times 1.06)^2 + (2 \times 0.73575)^2}}{\pi \times 470 \times 10^6 \times (1 - (\frac{0.00635}{d_o})^4)}} = 6.52mm$$

Principle Normal stress Theory Eqn (3-2-5-8) we get:

$$d_o = \sqrt[3]{\frac{16 \times \frac{1}{2}\left[(2 \times 1.06) + \sqrt{(2 \times 1.06)^2 + (2 \times 0.73575)^2}\right]}{\pi \times 390 \times 10^6\ \times (1 - (\frac{0.00635}{d_o})^4}} = 6.54mm$$

- **Square part of shaft under combined stress:**

$$\sigma = \frac{My}{J} \quad \& \quad \tau = \frac{Tr}{J} \quad , \quad J = I_x + I_y, \ = \frac{b^4}{12} + \frac{b^4}{12} = \frac{b^4}{6}, y = r = \frac{b}{2}$$

By using previous equations, we obtain:

$$\sigma = \frac{3M}{b^3} \qquad \& \qquad \tau = \frac{3T}{b^3} \qquad (3\text{-}2\text{-}5\text{-}9)$$

Max shear stress Theory:

$\tau_{max} = \frac{1}{2}\sqrt{\sigma^2 + 4\tau^2}$ by compensate Eqn (3-2-5-9) we obtain

$$\tau_{max} = \frac{3}{2b^3}\sqrt{M^2 + 4{T_m}^2}$$

$$b = \sqrt[3]{\frac{3}{2\,\tau_{max}}\sqrt{M^2 + 4{T_m}^2}} = \sqrt[3]{\frac{3}{2 \times 470 \times 10^6}\sqrt{(2\times 1.06)^2 + 4(2\times .073575)^2}} = 2.26\text{mm}$$

Principle Normal stress Theory:

$$\sigma_{max} = \frac{1}{2}[\sigma + \sqrt{\sigma^2 + 4\tau^2}] \quad \text{by compensate Eqn (3-2-5-9) we obtain}$$

$$\sigma_{max} = \frac{3}{2b^3}[M + \sqrt{M^2 + 4T^2}]$$

$$b = \sqrt[3]{\frac{3}{2\sigma_{max}}[M + \sqrt{M^2 + 4T^2}]} =$$

$$\sqrt[3]{\frac{3}{2\times 390\times 10^6}[(2\times 1.06) + \sqrt{(2\times 1.06)^2 + 4(2\times 0.73575)^2}]}$$

$$= 2.81\text{mm}$$

After calculate diameter of each part for Rejection shaft, finally we had known that shaft diameter must be higher than 6.54mm so we select the shaft with diameter 12mm.

$$\boxed{d = 12mm}$$

Stress concentration on the shaft

- **Maximum stress for rotating shaft**

The endurance limit of rotating shaft specimen is

$$S_e^{\sim} = \frac{1}{2}S\_(y\,) = 0.5 \times 390 = 195MPa$$

$$S\_e = K\_a\ \ K\_b\ \ s_e^{\sim}$$

$$Surface\ factor\ K\_a = 4.515\ S_y^{-0.265} = \ 4.515 \times\ 390^{-0.265} = 0.929$$

$$Size\ factor\ K_b = \left(\frac{d}{7.62}\right)^{-0.107} = \left(\frac{12}{7.62}\right)^{-0.107} = 0.952$$

$$S_e = 0.929\ \times 0.952\ \times 195 = 172.4\ MPa$$

- **Bolt (M4) on Square part**

$$K_f = 1 + q(K_t - 1)$$

From figure 2.3 we get q=0.9

$K_t = 2$ from table A-15-2

$K_f = 1 + 0.9(2 - 1) = 1.9$

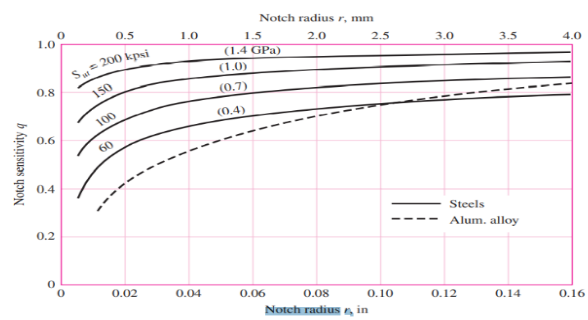


Figure 3-2-5- 4: Notch radius

$J = \frac{(w-d)h^3}{12}$

$$\sigma_o = \frac{MY}{J} K_f = \frac{1.06 \times 0.006}{\frac{(12-4)12^3}{12}} \times 1.9 = 10.5MPa$$

$$\tau = \frac{Tr}{J}\, K_f = \frac{0.73575 \times 0.006}{\frac{(12-4)12^3}{12}} \times 1.9 = 7.28MPa$$

$$\sigma_{Max} = \sqrt{\sigma_o^2 + 3\tau^2} = \sqrt{10.5^2 + 3 \times 7.28^2} = 16.41\ MPa$$

$$Factor\ of\ safty\ \ N = \frac{S_e}{\sigma_{Max}} = \frac{172.4}{16.41} = 10.4$$

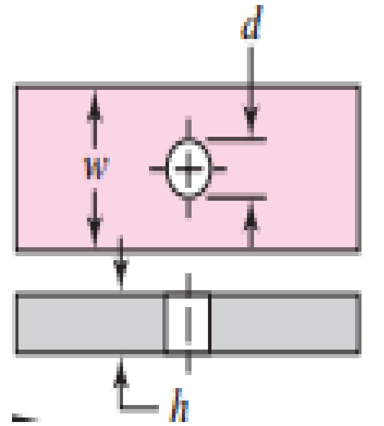


Figure 3-2-5- 5: Bolt stress concentration

- **Hollow circular shaft with Bolt (M3)**

From Table 16 for $\frac{a}{D} = 0.25$ and $\frac{d}{D} = 0.53$ we get

Bending moment calculation:

A=0.63 , $K_t = 2.16$

$$K_f = 1 + 0.9(2.16 - 1) = 2.044$$

$$Z_{net} = \frac{\pi A}{32D}(D^4 - d^4)$$

$$\sigma = \frac{M}{Z_{net}} K_f = \frac{1.06}{\frac{\pi \times 0.63}{32 \times 0.012}(0.012^4 - 0.00635^4)} 2.044 = 22MPa$$

Note that Z_{net} is reduced of the section modulas for Bolt.

Shear stress calculation:

A=0.8 , $K_{ts} = 1.7$

$K_{fs} = 1 + 0.9(1.7 - 1)$ =1.63

$$J_{net} = \frac{\pi A}{32}(D^4 - d^4)$$

$$\tau = \frac{T\ D}{2\,J_{net}} K_{fs} = \frac{0.73575 \ \times 0.012}{2 \times \frac{\pi \ \times 0.8}{32}(0.012^4 - 0.00635^4)}\ 1.63 = 4.8\ MPa$$

Note that J_{net} reduced value of second moment polar of area

$$\sigma_{Max} = \sqrt{\sigma_o^2 + 3\tau^2} = \sqrt{22^2 + 3 \times 4.8^2} = 23.5\ MPa$$

Factor of safty N=$\frac{S_e}{\sigma_{Max}} = \frac{172.4}{23.5} = 8$

Finally Over all factor of safty N=8

2. **Drive shaft Design**

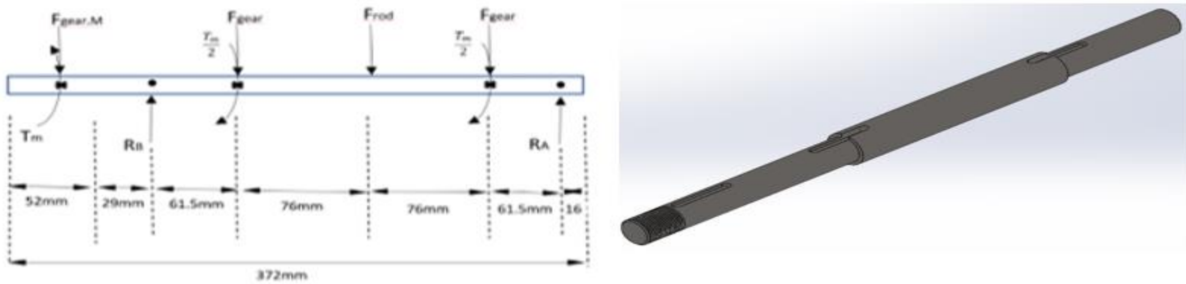


Figure 3-2-5- 6: Drive Shaft

Known that Motor Torque $T_m = 25.24\ N.M$, Gear weight M_{gear} = 5.51 Kg, Motor Gear $M_{gear.M}$ = 3.4 Kg, shaft weight $M_{rod} = 1.1\ Kg$ and A & B are two Bearing.

$$F_{gear} = 9.81 \times 5.51 = 54\ N$$

$$F_{gear.M} = 9.81 \times 3.4 = 33.35N$$

$$F_{rod} = 9.81 \times 1.1 = 10.8\ N$$

Using moment summation to calculate Bearing Reaction.

$$\sum M_B = 0$$

$$R_A = \frac{54 * 0.0615 + 10.8 * 0.1375 + 54 * 0.2135 - 33.35 * 0.029}{0.275} = 55.88\ N$$

$$\sum M_A = 0$$

$$R_B = \frac{54 * 0.0615 + 10.8 * 0.1375 + 54 * 0.2135 + 33.35 * 0.304}{0.275} = 96.26\ N$$

From diagram we obtain that maximum moment is $\boldsymbol{M = 16.335\ N.m}$,

as shown in Figure 3-2-5-7.

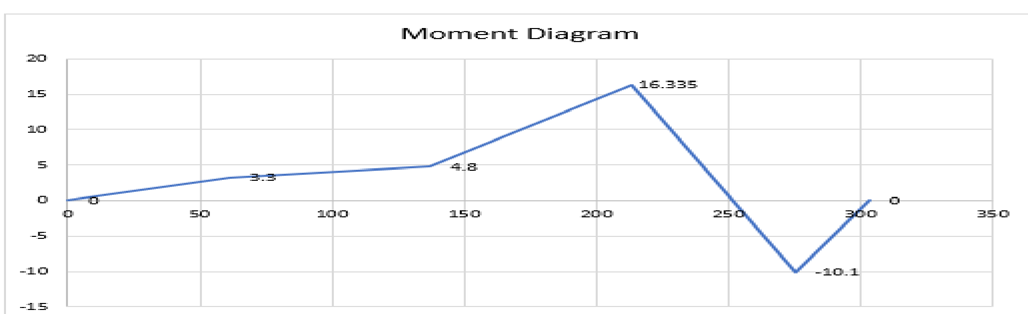


Figure 3-2-5- 7:Moment diagram for drive shaft

Final design consideration

M =16.335 N.M, T_m =25.24 N.M, Maximum shear stress & maximum normal stress for 1020 steel $\tau = 470\ MPa, \sigma = 390MPa$, combined shock & fatigue factor for Bending and Torsion $K_m = K_T = 2$.

Solid circular shaft under combined stress:

Max shear stress Theory Eqn (3-2-5-5) we get:

$$d = \sqrt[3]{\frac{16\sqrt{(2 \times 16.335)^2 + (2 \times 25.24)^2}}{\pi \times 470 \times 10^6}} = 8.66\ mm$$

Principle Normal stress Theory Eqn (3-2-5-7) we get:

$$d = \sqrt[3]{\frac{16 \times \frac{1}{2}\left[(2 \times 16.335) + \sqrt{(2 \times 16.335)^2 + (2 \times 25.24)^2}\right]}{\pi \times 390 \times 10^6}} = 8.46\ mm$$

After calculate Diameter for both Theory we had known that diameter must be higher than 8.66mm so we select diameter 20 mm.

$$\boxed{\boldsymbol{d = 20mm}}$$

Stress concentration on the shaft

- **Maximum stress for rotating shaft**

  The endurance limit of rotating shaft specimen is

$$S_e^{\sim} = \frac{1}{2} S_y = 0.5 \times 390 = 195MPa$$

$$S\_e = K\_a\ \ K\_b\ \ s_e^{\sim}$$

$$Surface\ factor\ K_a = 4.515\ S_y^{-0.265} = 4.515 \times 390^{-0.265} = 0.929$$

$$Size\ factor\ K_b = \left(\frac{d}{7.62}\right)^{-0.107} = \left(\frac{20}{7.62}\right)^{-0.107} = 0.91$$

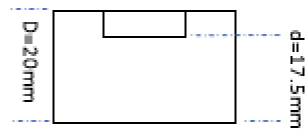
$$S_e = 0.929 \times 0.91 \times 195 = 165\ MPa$$

➢ Stress concentration on key

$$From\ Table\ 7-1\ with\ standard\ \frac{r}{d} = 0.02\ \ where\ r\ refers\ to\ endmill\ radius\ we\ get$$

$$K_t\ = 2.14\quad ,\qquad K_{ts}\ = 3$$

$$K_f\ = 1 + 0.9(2.14 - 1) =\ \ 2.02$$



$$K_{fs} = 1 +\ \ \ 0.9(3 - 1)\ \ \ \ =\ 2.8$$

$$D\ =\ 20\ mm, t\ =\ 2.5\ mm, d\ =\ 17.5\ mm$$

$$From\ Table\ A-15-16$$

$$\sigma_o = \frac{32M}{\pi d^3} K_f = \frac{32 \times 16.335}{\pi \times 0.0175^3}\ 2.02 = 62.5MPa$$

$$From\ Table\ A-15-17$$

$$\tau = \frac{16T}{\pi d^3}\ K_{fs} = \frac{16 \times 25.24}{\pi \times 0.0175^3}\ 2.8 = 24MPa$$

$$\sigma_{Max}\ = \sqrt{\sigma_o^2 + 3\tau^2} = \sqrt{62.5^2 + 3 \times 24^2} = 75\ MPa$$

$$Factor\ of\ safty\ \ N = \frac{S_e}{\sigma_{Max}}\ = \frac{165}{75} = 2.2$$

➢ Stress concentration on shaft step

$$From\ table\ A-15-8\ \&\ A-15-9$$

$$K_t\ = 1.6\quad ,\qquad K_{ts}\ =\ 1.35$$

$$K_f\ = 1 + 0.9(1.6 - 1) =\ \ 1.54$$

$$K_{fs} = 1 +\ \ \ 0.9(1.35 - 1)\ \ \ \ =\ 1.31$$

$$\sigma_o\ = \frac{32M}{\pi d^3} K_f\ = \frac{32 \times 16.335}{\pi \times 0.02^3}\ 1.54 = 32\ MPa$$

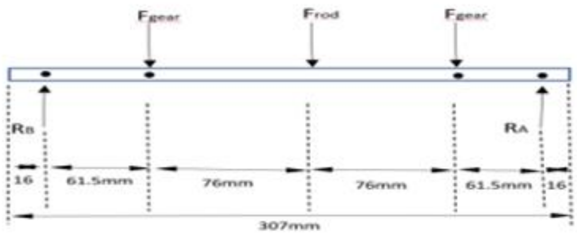
$$\tau = \frac{16T}{\pi d^3}\ K_{fs} = \frac{16 \times 25.24}{\pi \times 0.02^3}\ 1.31 = 21\ MPa$$

$$\sigma_{Max}\ = \sqrt{\sigma_o^2 + 3\tau^2} = \sqrt{32^2 + 3 \times 21^2} = 48.4\ \ MPa$$

$$Factor\ of\ safty\ \ N = \frac{S_e}{\sigma_{Max}}\ = \frac{165}{48.4} = 3.41$$

Finally, Over all factor of safety for drive shaft N= 2.2.

3. Driven shaft Design



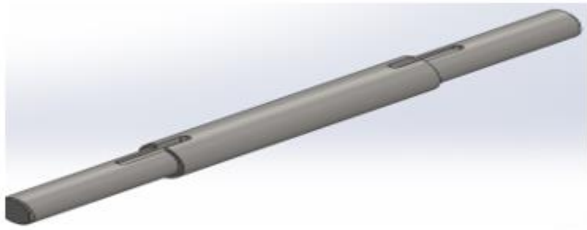


Figure 3-2-5- 8: Driven Shaft

Known that Gear weight M_{gear} = 5.51 Kg, shaft weight $M_{rod} = 0.95\ Kg$ and A & B are two Bearing.

$$F_{gear} = 9.81 \times 5.51 = 54\ N$$

$$F_{rod} = 9.81 \times 0.95 = 9.32\ N$$

$$Using\ moment\ summation\ to\ calculate\ Bearing\ Reaction.$$

$$\sum M_B = 0$$

$$R_A = \frac{54 * 0.0615 + 9.32 * 0.1375 + 54 * 0.2135}{0.275} = 58.66\ N$$

$$R\_B = R\_A = 58.66\ N\ due\ to\ symmetric$$

From diagram we obtain that maximum moment is $M = 16.13\ N.m$, as shown in Figure 3-2-5-8.

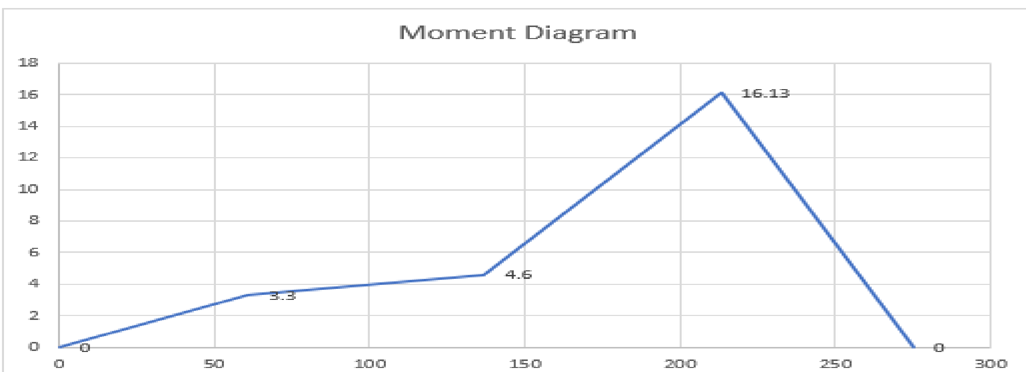


Figure 3-2-5- 9: Moment diagram for driven shaft

Final design consideration

M =16.13 N.M, maximum normal stress for 1020 steel $\sigma = 390MPa$, combined shock & fatigue factor for Bending $K_m = 2$.

Solid circular shaft under Pure Normal stress:

Pure Normal stress Theory Eqn (3-2-5-3) we get:

$$d = \sqrt[3]{\frac{32\ \mathrm{M}}{\pi\ \sigma_b}} = \sqrt[3]{\frac{32\ \times 16.13}{\pi\ \times 390 \times 10^6}} = 7.5mm$$

After calculate Diameter for both Theory we had known that diameter must be higher than 7.5 mm so we select diameter 20 mm.

$$\boxed{\boldsymbol{d = 20mm}}$$

Stress concentration on the shaft

- **Maximum stress for rotating shaft**

  The endurance limit of rotating shaft specimen is

$$S_e^{\sim} = \frac{1}{2} S_y = 0.5 \times 390 = 195MPa$$

$$S\_e = K\_a\ K\_b\ s_e^{\sim}$$

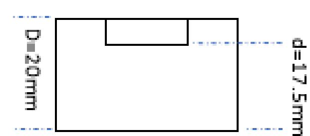
$$Surface\ factor\ K_a = 4.515\ S_y^{-0.265} = 4.515 \times\ 390^{-0.265} = 0.929$$

$$Size\ factor\ K_b = \left(\frac{d}{7.62}\right)^{-0.107} = \left(\frac{20}{7.62}\right)^{-0.107} = 0.91$$

$$S_e = 0.929\ \times 0.91\ \times 195 = 165\ MPa$$

- **Stress concentration on key**

  From Table 7-1 with standard $\frac{r}{d} = 0.02$ we get



$$K\_t\ = 2.14$$

$$K\_f = 1 + 0.9(2.14 - 1) = \ \ 2.02$$

$$D\ = \ 20\ mm, t\ = \ 2.5\ mm, d\ = \ 17.5\ mm$$

$$From\ Table\ A - 15$$

$$\sigma_o = \frac{32M}{\pi d^3} K_f = \frac{32 \times 16.13}{\pi \times 0.0175^3} 2.02 = 62.1MPa$$

$$Factor\ of\ safty\ \ N = \frac{S_e}{\sigma_o} = \frac{165}{62.1} = 2.65$$

- **Stress concentration on shaft step**

$$From\ table\ A-15-8$$

$$K_t\ = 1.6$$

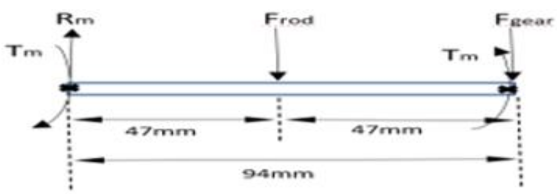
$$K_f = 1 + 0.9(1.6 - 1) =\ 1.54$$

$$\sigma_o = \frac{32M}{\pi d^3} K_f = \frac{32 \times 16.13}{\pi \times 0.02^3}\ 1.54 = 31.6\ MPa$$

$$Factor\ of\ safty\ \ N = \frac{S_e}{\sigma_o} = \frac{165}{31.6} = 5.2$$

Finally, Over all factor of safety for drive shaft N= 2.65.

4. DC motor shaft



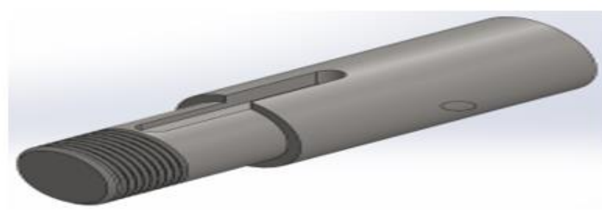


Figure 3-2-5- 10: DC motor shaft

Known that Motor Torque $T\_m = 7.64\ N.m$, Gear weight $M\_gear\ = 0.33\ Kg$, shaft weight $M_{rod} = 0.265\ Kg$ and Point M is the main shaft of DC Motor.

$$F\_gear = 9.81\ \times 0.33 = 3.237N$$

$$F\_rod =\ 9.81\ \ \times\ \ 0.265 = 2.6\ N$$

$$R\_M\ \ = F\_rod +\ \ F\_gear = 2.60 + 3.237 = 5.837\ N$$

$$M\_M =\ 2.6 * 0.047 + 3.237 * 0.094 =\ \ 0.43\ N.m$$

Stress Cheek for main shaft of Dc motor

$$\sigma_o = \frac{32M}{\pi\ d^3} = \frac{32\ \times 0.43}{\pi \times\ 0.015^3} = 1.3\ MPa$$

Very low stress on Main DC Motor shaft so it's safe.

Final design consideration

T_m =7.64 N.M, Maximum shear stress for 1020 steel $\tau = 470\ MPa$, combined shock & fatigue factor for Torsion $K_T = 2$.

Hollow circular shaft under Pure Shear stress:

Inner diameter $d_i = 15mm$

Pure Shear stress Theory from Eqn (3-2-5-2) we get

$$d_o = \sqrt[3]{\frac{16 \times 7.64}{\pi \times 470 \times 10^6\,(1-(\frac{0.015}{d_o})^4)}} = 15.2\ mm$$

Solid circular shaft under Pure Shear stress:

Pure Shear stress Theory from Eqn (3-2-5-1) we get

$$d = \sqrt[3]{\frac{16\,T}{\pi\,\tau}} = \sqrt[3]{\frac{16 \times 7.64}{\pi \times 470 \times 10^6}} = 4.35mm$$

After calculate Diameter for shear stress Theory we had known that diameter of solid part must be higher than 4.35mm and diameter of hollow part must be higher than 15.2mm so we select solid diameter 20 mm and outer diameter for hollow shaft d_o= 25mm.

$$\boxed{\boldsymbol{d = 20mm\ \&\ d_o = 25mm}}$$

Stress concentration on the shaft

- **Maximum stress for rotating shaft**

  The endurance limit of rotating shaft specimen is

$$S_e^{\sim} = \frac{1}{2} S_y = 0.5 \times 390 = 195MPa$$

$$S_e = K_a\, K_b\, s_e^{\sim}$$

$$Surface\ factor\ K_a = 4.515\, S_y^{-0.265} = 4.515 \times 390^{-0.265} = 0.929$$

$$Size\ factor\ K_b = (\frac{d}{7.62})^{-0.107} = (\frac{20}{7.62})^{-0.107} = 0.91 \qquad (\boldsymbol{D = 20mm})$$

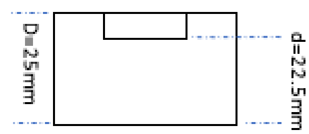
$$Size\ factor\ K_b = (\frac{d}{7.62})^{-0.107} = (\frac{25}{7.62})^{-0.107} = 0.88 \qquad (\boldsymbol{D = 25mm})$$

$$S_e = 0.929 \times 0.91 \times 195 = 165\ MPa$$

$$S_e = 0.929 \times 0.88 \times 195 = 159\ MPa \quad (\textbf{Select for design})$$

- **Stress concentration on key**

$$From\ Table\ 7-1\ with\ standard\ \frac{r}{d}=0.02\ \ we\ get\ \ K_{ts}\ =3$$



$$K_{fs}=1+0.9(3-1)=\ \ 2.8$$

$$D\ =\ 25\ mm, t\ =\ 2.5\ mm, d\ =\ 22.5\ mm$$

$$From\ Table\ A-16$$

$$\tau=\frac{16T}{\pi d^3}\ K_{fs}=\frac{16\times 7.64}{\pi\times 0.0225^3}\ 2.8=9.6\ MPa$$

$$Factor\ of\ safty\ \ N=\frac{S_e}{\tau}\ =\frac{159}{9.6}=16$$

- **Stress concentration on shaft step**

$$From\ table\ A-15-8$$

$$K_{ts}\ =1.8$$

$$K_f\ =1+0.9(1.8-1)=\ \ 1.72$$

$$\tau=\frac{16T}{\pi d^3}\ K_{fs}=\frac{16\times 7.64}{\pi\times 0.02^3}\ 1.72=8.4MPa$$

$$Factor\ of\ safty\ \ N=\frac{S_e}{\tau}=\frac{159}{8.4}=18.9$$

- **Stress Concentration on Bolt (M4)**

$$From\ \ Table\ 16\ \ for\ \ \frac{a}{D}=\frac{4}{25}=0.16\ \ and\ \ \frac{d}{D}=\frac{15}{25}=0.6\ \ we\ get$$

Shear stress calculation

$$A=0.87\qquad ,\quad K_{ts}=1.69$$
$$K_{fs}=1+0.9(1.69-1)=1.62$$
$$J_{net}=\frac{\pi A}{32}(D^4-d^4)$$
$$\tau=\frac{T\ D}{2\ J_{net}}\ K_{fs}=\frac{7.64\ \times 0.025}{2\ \times\frac{\pi\ \times 0.87}{32}(0.025^4-0.015^4)}\ \ 1.62=5.3\ MPa$$
$$Note\ that\ J_{net}\ reduced\ value\ of\ second\ moment\ polar\ of\ area$$

$$Factor\ of\ safty\ \ N=\frac{S_e}{\tau}\ =\frac{159}{5.3}\ =30$$

Finally Over all factor of safty for DC Motor shaft N= 16

Tables Used in Shaft Design:

Table 3-2-5- 1: tables used in design of shaft

3-2-6: Keys

Key is mechanical element to connect mor than one part to another and transmitting the power without no losses in power.

The connection between shaft and hub by key, the key in connected in parallel axis to shaft, the slot in shaft is called keyway.

There are 4 types of keys each one has its own use depend on circumstances of the mechanism used, the four types are:

1. Sunk key
2. Saddle key
3. Tangential key
4. Round key

1. Sunk key:

The idea of this key from its name sunk, the key half of it sunk in the shaft while the other half is sunk on the hub, by doing this the torque transfer from the shaft to hub through key, or from hub to shaft.

In Sunk key there are 5 types, parallel, taper, GIB-head, feather, woodruff.

- **Parallel and Taper:**

  The difference between the two, is the two sides either parallel or one is taper to the other as shown in FIG 3-2-6-1.

  Both of them can the shape either be flat(rectangular) or square, the advantage of taper over parallel is taper cannot be get out off easily, while parallel can be get off its own slot in high vibration, but parallel can be used if the hub is either gears or pully while taper is used in pully only, because in taper the height is different from side to another so in gears the center line may shift and it won't be fixed.

- **GIB-head key:**

  It can be square or flat and side is taper, the addition is the head for easier remove as shown in FIG 3-2-6-1.

- **Feather Key:**

  This type is fixed to shaft by screws instead of force like other types its advantage the ability of hub to move in axial motion along the shaft as shown in FIG 3-2-6-1.

- **Woodruff key:**

  It is a semi-circular disc and fits into a circular recess in the shaft as shown in FIG 3-2-6-1, since the force acts on it is small so it used in low power machine tool.

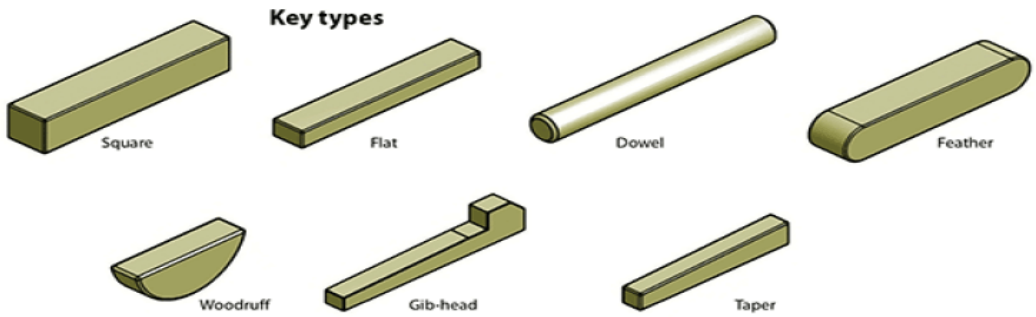


Figure 3-2-6- 1: Different types of sunk key

2. Saddle key

It's different from sunk as the key is on the surface of the shaft and sunk on the hub, power transmission is achieved through friction between the shaft and the key, there are two types either flat or hollow the different is the side that touch the shaft is flat while the other is curved as shown in FIG 3-2-6-2.

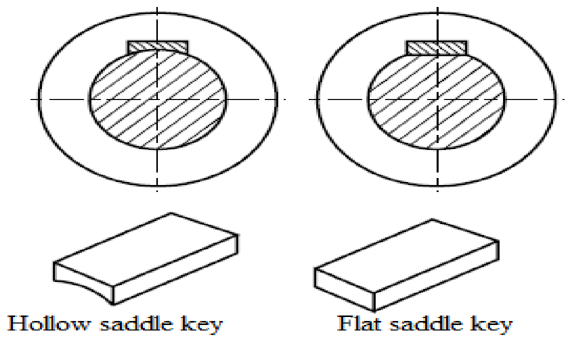


Figure 3-2-6- 2: two types of saddle key

3. Tangent key:

Its key consists of pair in the shape of right angle as shown in FIG 3-2-6-3, it uses in heavy load shaft.

Figure 3-2-6- 3: Tangent key

4. Round Key:

The round keys are circular in section and fit into holes drilled partly in the shaft and partly in the hub, the advantage is the easy manufacturing, usually considered to be most appropriate for low power drives.

KEY DESIGN AND CALCULATION:

For the suitable on are design we need one for high power since our project is production line, cost effective one without the need of complicated manufacture, so by see the for types we are gone use SUNK KEY, saddle working principle is friction so transmit high torque is difficult, round type is also for light load, as for tangential it's good for heavy load but the manufacture process is quite costly, so SUNK KEY is bitter.

For SUNK KEY types parallel type is suitable one as more fixation of hub and good power transmitting.

There are three parameters to calculate width(W), height(H), length(L)

For width,

$$w = \frac{d}{4} \qquad (3\text{-}2\text{-}6\text{-}1)$$

For height in rectangle,

$$H = \frac{2}{3}\omega = \frac{d}{6}$$

For height in square,

$$w = H$$

For length,

Length is depending on the type of stress act on the key, due to the torque act on the shaft so there is force act on key bottom in shaft and the reaction opposite to original force, the reaction came from hub, so crashing stress will act on it, also since the fore and reaction not in the same line so there are also shear stress act on key.

So, there are two types of stress crashing and sheer,

$$\tau = \frac{F}{A} = \frac{F}{L \cdot w}$$

$$T = F \cdot \frac{d}{2} = L * w * \tau * \frac{d}{2} \qquad (3\text{-}2\text{-}6\text{-}2)$$

$$\sigma = \frac{F}{A} = \frac{F}{L \cdot \frac{H}{2}}$$

$$T = L \cdot \frac{H}{2} \cdot \frac{d}{2} \cdot \sigma \qquad (3\text{-}2\text{-}6\text{-}3)$$

Where,

w: is the width of key

d: is the diameter of shaft

H: is the height of key

τ: is shear stress act on key

F: is the force act on key due to shaft torque

A : is the area in which stress act on it

σ: is the crashing stress act on key

T: is torque act on key

τ': is shear stress on shaft

e: shaft strength factor

We need to avoid one type stress occur before another so in design we can't design on crashing only or shear only, so to design on both, so both occur on the same time which means crashing stress equal to shear stress from equation 2 and 3 we get,

$$L * w * \tau * \frac{d}{2} = L * \frac{H}{2} * \sigma * \frac{d}{2} \qquad (3\text{-}2\text{-}6\text{-}4)$$

Since the material of key is steel 34,42, or even 50, which means the $\sigma = 2\,\tau$

By sub in equation 4 we get,

$$w = H$$

So, the shape of parallel sunk key is square.

The shear stress on shaft is,

$$T = \frac{\pi}{16} * \tau' * d^3 \qquad (3\text{-}2\text{-}6\text{-}5)$$

From equation 3-2-6-2 and 3-2-6-5 we get,

$$L = \frac{\frac{\pi}{8} * \tau' d^2}{w * \tau} \qquad (3\text{-}2\text{-}6\text{-}6)$$

By sub equation 3-2-6-1 in 3-2-6-6 we get,

$$L = 1.57 * d * \frac{\tau'}{\tau}$$

And in our design the material of shaft is the same as material of key so,

$$L = 1.57 * d \quad (3\text{-}2\text{-}6\text{-}7)$$

The effect of key way is the increase of stress concentration of shaft so it means the reduction of shaft strength, so for safety measure we need to get shaft strength factor.

Where shaft strength factor is the relation between shaft with keyway to shaft without keyway,

$$e = 1 - 0.2 * \frac{w}{d} - 1.1 * \frac{H}{d} < 1 \quad (3\text{-}2\text{-}6\text{-}8)$$

We can also get the width and height from the standard table as shown in TABLE 3-2-6-1

Shaft Diameter (mm) upto and Including	Key Cross-section		Shaft Diameter (mm) upto and Including	Key Cross-section	
	Width (mm)	Thickness (mm)		Width (mm)	Thickness (mm)
6	2	2	85	25	14
8	3	3	95	28	16
10	4	4	110	32	18
12	5	5	130	36	20
17	6	6	150	40	22
22	8	7	170	45	25
30	10	8	200	50	28
38	12	8	230	56	32
44	14	9	260	63	32
50	16	10	290	70	36
58	18	11	330	80	40
65	20	12	380	90	45
75	22	14	440	100	50

Table 3-2-6- 1: Keys width and height standard table

The given shaft diameter is 20 mm, so from equation 3-2-6-1 we

$$w = \frac{d}{4} = \frac{20}{4} = 5\ mm$$

$$since, key\ is\ square\ the\ H = W = 5\ mm$$

From equation 3-2-6-7 we get,

$$L = 1.57 * d = 1.57 * 20 = 31.4\ mm$$

From equation 3-2-6-8 we get,

$$e = 1 - 0.2 * \frac{5}{20} - 1.1 * \frac{5}{20} = 0.675 < 1\ , so\ its\ safe$$

The actual length if key will be higher than 31.4, because the key will purchase for the market so the stander is square with two semi-circle at the end of each edge so total length will be

$$L = 31.5 + 2.5 + 2.5 = 36.4\ mm$$

In the market the step of key is 5 mm so either 35 mm or 40 mm, so the actual length of key will be 40 mm.

3-2-7: Gears and Sprocket chain

A conveyor system is used in many industries as a standard piece of mechanical handling equipment to move goods, products, raw goods, and other materials from one location to another, usually in the same area or building. They are extremely handy for businesses that deal with heavy goods, sharp items, raw materials, and mass-produced products.

1. **Conveyor chain:**

   Conveyer Chains, like transmission chains, are a series of journal bearings secured together by constraining plates linking each journal bearing. Production facilities can only be efficient when they're running at peak productivity, something that's impossible if conveyor belts are slow or saggy. The heavy loads and high pressure to which your conveyor chain is subjected can be incredibly damaging, especially if you're using sub-standard chains.

   These chains are used for elevating and conveying the materials continuously, the conveyor chains are usually made of malleable cast iron. These chains do not have smooth running qualities. The conveyor chains run at slow speeds of about 0.8 to 3 m/s.

2. **Pitch type of conveyor:**

   There are two types of pitch, double and single pitch, where double pitch is similar to standard roller chain, except the pitch is twice that of standard roller chain. These chains weigh less and are lower in cost than standard roller chain of the same strength. They are ideal for slow and moderate speed applications, particularly when shaft centers are relatively long. There are two types of double-pitch chains. Transmission type has figure-eight shaped link plates. Conveyor type has straight edged link plates and are available with standard rollers or with over-sized carrier rollers.

3. **Sprockets**

   Sprockets for conveyors are usually the same size for the head shaft and tail shaft. Sprockets having the largest practical number of teeth are desirable to reduce chordal action, provide for smooth operation and obtain maximum chain wear life.

   It is recommended that sprockets have a minimum of 15 effective teeth. The number of effective teeth is the number of teeth engaged by the chain rollers in one revolution of the sprocket. If a single-pitch conveyor chain is used the effective teeth equals the number of sprocket teeth. When using double-pitch chain, use single-pitch sprockets only when more than 15 effective (30 actual) teeth are designed in. For drives with less than 30 actual (15 effective) teeth, use special cut double-pitch sprockets for maximum chain and sprocket life. Additionally, if a single-pitch sprocket is used on a double-pitch chain conveyor, an odd number of teeth in the sprocket is desirable. This allows for the chain to engage alternate teeth each revolution, thus distributing the tooth wear.

Calculations

- **Sprockets:**

$$PCD = p\ cosec\ (\frac{180°}{T})$$
$$P\ is\ pitch = 1.25\ inch = 31.75\ mm$$

$Since\ the\ two\ sprockets\ are\ the\ same\ diameter, so\ the\ speed\ ratio\ is\ 1\ and$ $T = 31\ (From\ table\ 21.5\ page\ 770\ machine - design - khurmi - gupta).$

$$PCD = 31.75 * cosec\ (\frac{180}{31}) = 313.833\ mm.$$

- **Velocity fluctuation:**

We know that the linear velocity of the sprocket is not uniform but varies from maximum to minimum during every cycle of tooth engagement.

This results in fluctuations in chain transmission and may be minimized by reducing the angle θ or by increasing the number of teeth on the sprocket.

It has been observed that for a sprocket having 11 teeth, the variation of speed is 4 percent and by increasing number of teeth velocity fluctuation decreases.

$$Vmax = \frac{\pi * d * N}{60} = \frac{\pi * 0.313833 * 30.5}{60} = 0.50118\ m/s.$$

$$Vmin = \frac{\pi * d * N * cos\ (\frac{\alpha}{2})}{60} = \frac{\pi * 0.313833 * 30.5 * cos\ (\frac{180}{2 * 31})}{60}$$
$$= 0.50054\ m/s.$$

$$Maximum\ fluctuation = Vmax - Vmin = 0.00064\ m/s \sim 0.13\ \%\ (very\ small\ value)$$

- **Length of chain and center distance:**

$Sprocket\ links\ must\ be\ equal\ to\ multiple\ of\ 12\ because\ rollers\ repeat\ itself\ after\ 12\ links.$

$$Sprocket\ links\ =\ 12*n$$

$$L\ =\ \frac{sprocket\ links\ -\ 2*T}{4}*P$$

$$L\ >\ length\ of\ feeding\ tank\ (725mm)\ +\ length\ of\ camera\ box\ (268\ mm)$$

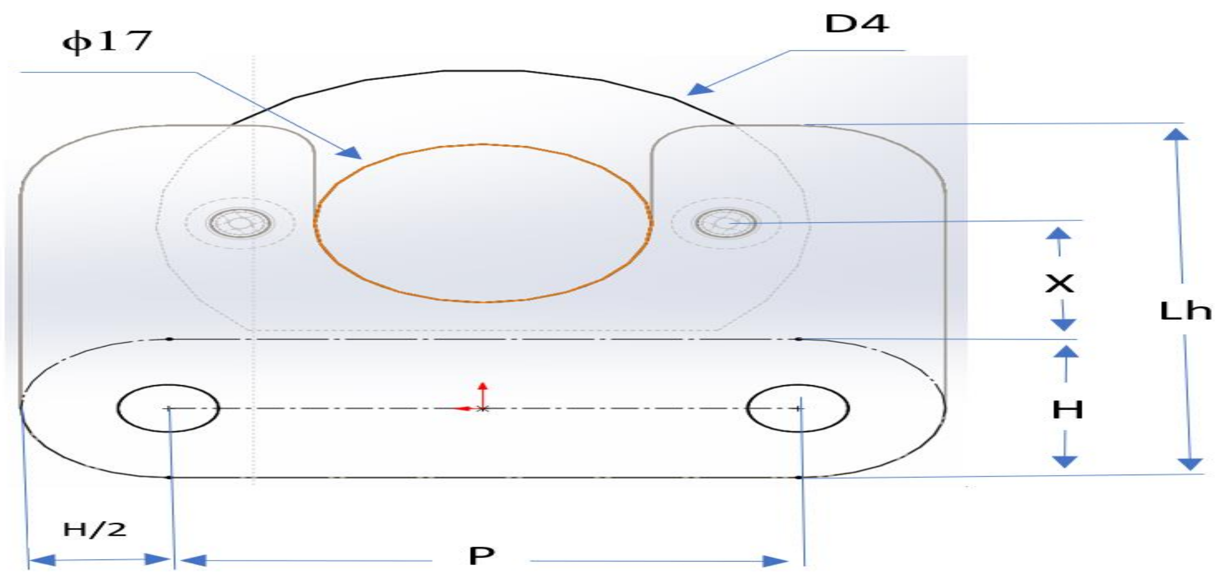
$$L\ >\ 1011, then\ \frac{12*n\ -\ 31\ *\ 2}{4}*\ 31.75\ >\ 1011$$

$$n\ >\ 7.9\ , so\ let\ n\ =\ 9$$

$$L\ =\ 1222.375\ mm\ and\ by\ adding\ 5\ mm\ to\ accommodate\ initial\ sag\ in\ the\ chain\ L = 1227\ mm$$

$$Total\ distance\ of\ the\ chain\ =\ 12*9*p\ =\ 12*9*31.75$$
$$=\ 3429\ mm$$

- **Attachment Chain part:**



$$X = \frac{d_4}{2} - 5 = \frac{33}{2} - 5 = 11.5\ mm$$

$$L_h > H + X + \frac{17}{2} > 14.859 + 11.5 + \frac{17}{2} > 34.859\ mm, \qquad L_h = 37.8\ mm$$

From solid works simulation analysis

- The attachment part made of steel AISI 1010, hot rolled, with the same thickness of original chain links 2 mm.
- The maximum stress is 21.14 MPa, and the part is subjected to sudden load 1.5 * 21.14 equal 42.28 MPa
- Yield stress of AISI 1010 is 180 MPa
- So, the factor of safety is 180/42.28 = 5.67, so the material is safe.
- The maximum displacement is 0.002, so acceptable.

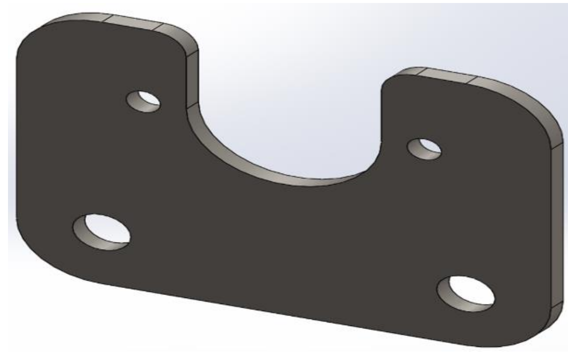


Figure 3-2-7- 1: Attachment chain part

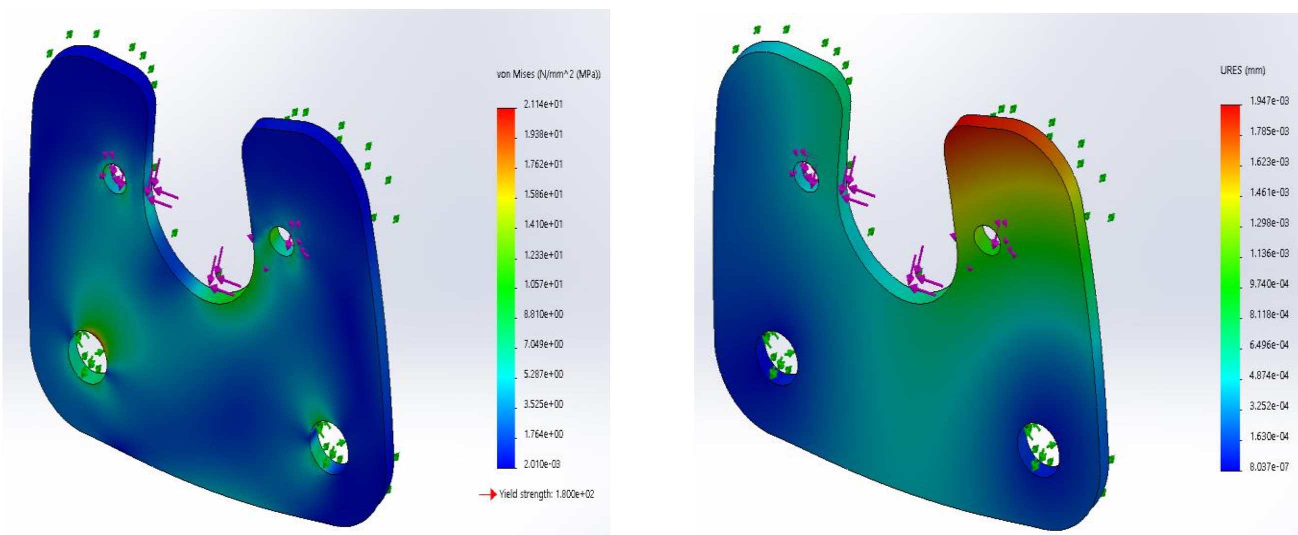


Figure 3-2-7- 2: Stress and Displacement analysis for attachment chain part

- **Chain selection calculations:**

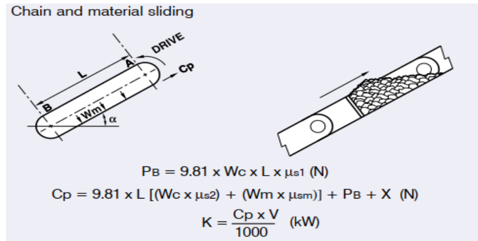


Figure 3-2-7- 3: Chain layout, E type

$$Mass\ of\ Load\ on\ Conveyor\ (Wm)\ =\ 8\ kg\ (orange)$$

$$Mass\ per\ meter\ of\ rollers\ with\ slats\ =\ 6\ rollers, 3\ inner\ slat,$$
$$6\ outer\ slat\ /m\ =\ (6 * 0.456) + (3 * 0.455) + (6 * 0.518)\ =\ 7.209\ kg/m$$

$$Estimated\ Mass\ of\ Chain\ =\ 0.8642\ kg/m$$
$$(from\ table\ 1\ Cross\ Morse\ BS\ precision\ ISO\ 606\ DIN\ 8187)$$

$$Estimated\ Mass\ of\ Chain\ \&\ rollers\ \&\ slats\ (Wc1)\ =\ 0.8642 + 7.209$$
$$=\ 8.0732\ kg/m$$

$$Preliminary\ Chain\ Pull\ (PB1)\ =\ 9.81 * Wc1 * L * \mu s1\ (N)\ \&\ Wc1$$
$$=\ 8.0732\ Kg/m, L\ =\ 1.227\ m$$
$$\mu s1\ =\ (\mu c\ cos(\alpha) - sin(\alpha))\ =\ (0.2\ cos(15) - sin(15))\ =\ -0.0656$$
$$\mu s2\ =\ (\mu c\ cos(\alpha) + sin(\alpha))\ =\ (0.2\ cos(15) + sin(15))\ =\ 0.452$$
$$(\alpha = 15°)\ \&\ (\mu c\ =\ 0.2\ \_\ from\ table\ 2\ P\ 72\ Renold)$$
$$PB1\ =\ 9.81 * 8.0732 * 1.227 * -0.0656\ =\ -6.3747\ N$$

$$Cp1\ (Chain\ pull)\ =\ 9.81 * L * [(Wc1 * \mu s2) + (Wm * \mu sm)] + PB1\ \ N$$
$$Wm\ =\ 8\ kg$$
$$\mu sm\ =\ (\mu m * cos(\alpha)) + sin\ (\alpha)\ =\ 0.4 * cos(15) + sin\ (15)\ =\ 0.6452$$
$$(\mu m\ =\ 0.4\ from\ table\ 8\ page\ 79\ Renold)$$

$$Cp1\ =\ 9.81 * 1.227 * [(8.0732 * 0.452) + (8 * 0.6452)] - 6.3747$$
$$=\ 99.68 \sim 100\quad N$$

$$Minimum\ breaking\ load\ =\ \frac{|PB1| * n}{number\ of\ chains}\ =\ \frac{6.3747\ \ * 10}{2}$$
$$=\ 31.8735 \sim 32\ N/chain$$
$$(Factor\ of\ safety\ (n)\ =\ 10\ \_\ from\ table\ 1\ page\ 72\ Renold)$$
$$Breaking\ load\ for\ 1.25\ inch\ pitch$$
$$=\ 64.5\ KN\ (From\ table\ 21.1\ page\ 765\ machine - design$$
$$- khurmi - gupta).$$

- **Final Calculations:**

$$Chain\ mass\ +\ K1\ integral\ attachment\ two\ side\ every\ pitch$$
$$=\ 0.8642\ +\ 12\ *\ (0.024)\ =\ 1.152\ kg/m$$

$$Mass\ of\ Both\ Chains\ =\ 1.152\ x\ 2\ =\ 2.3044\ kg/m$$

$$Mass\ of\ rollers\ and\ slats\ with\ bolts$$
$$=\ 0.456\ *\ 6\ +\ 0.455\ *\ 3\ +\ 0.518\ *\ 6\ +0.002*36$$
$$=\ 7.281\ kg/m$$

$$Mass\ of\ Chains\ +\ Rollers\ \&\ slats\ (Wc2)\ =\ 2.3044\ +\ 7.281\ =\ 9.5854\ kg/m$$

$$PB\ 2\ =\ 9.81\ *\ Wc2\ *\ L\ *\ \mu s1\ =\ 9.81\ *\ 9.5854\ *\ 1.227\ *\ -0.0656$$
$$=\ -7.5688\ N$$

$$Cp\ 2\ =\ 9.81\ *\ L\ *\ [\ (\ Wc2\ *\ \mu s2\ )\ +\ (\ Wm\ *\ \mu sm)\ ]\ +\ PB2\ \ N$$

$$Cp\ 2\ =\ 9.81\ *\ 1.227\ *\ [\ (9.5854\ *\ 0.452)\ +\ (8\ *\ 0.6452\ )\ ] - 7.5688$$
$$=\ 106.711 \sim 107\quad N$$

$$Factor\ of\ Safety\ =\ \frac{Breaking\ load\ x\ 2}{Total\ chain\ pull} = \frac{64500\ x\ 2}{106.711}$$
$$=\ 1208.87\ (very\ safe)$$

$$Power\ required\ to\ drive\ the\ conveyor\ would\ be:$$

$$K\ =\ Chain\ pull\ x\ Chain\ speed\ =\ Cp2\ x\ V\ =\ 106.711\ *\ 0.5$$
$$=\ 53.355 \sim 54\ watt.$$

$$Head\ shaft\ RPM\ required\ using\ 31\ tooth\ (313.833\ mm\ PCD)\ sprocket\ would\ be$$

$$RPM\ =\ \frac{V * 60}{PCD * \ \pi} = \frac{0.5\ * 60}{0.313833 * \pi}\ =\ 30.427\ rpm$$

$$Head\ shaft\ Torque\ =\ \frac{Cp2\ x\ PCD}{2} = \frac{106.711 *\ 0.313833}{2}\ =\ 16.74\ Nm$$

- **Used Excel console program results for sprockets:**

	Inputs		
P	Chain pitch in inch	1.25	inch
Vratio	Velocity ratio (1,2,3,4,5,6)	1	
V	Chain linear velocity in m/s	0.5	m/s
Wm	Total weight of orange	8	kg
chain_mass	Chain mass	0.8642	kg/m
attach_n	Total number of attachments	24	attachment
attach_m	Mass of each attachment	0.022	kg
bolt1_n	Total number of bolts for attachments/m	24	bolt
bolt1_m	Mass of each bolt for attachment	0.002	kg
roller_n	Number of rollers/m	6	roller
roller_m	Mass of each roller	0.456	kg
slatout_n	Number of outer slats/m	6	slat
slatout_m	Mass of each outer slat	0.518	kg
slatin_n	Number of inner slats/m	3	slat
slatin_m	Mass of each inner slat	0.455	kg
bolt2_n	Number of bolts on slats/m	36	bolt
bolt2_m	Mass of each bolt on slat	0.002	kg
L	Conveyor center distance in meter	1.227	m
Alpha	Angle of inclined Conveyor to the horizontal	15	degree

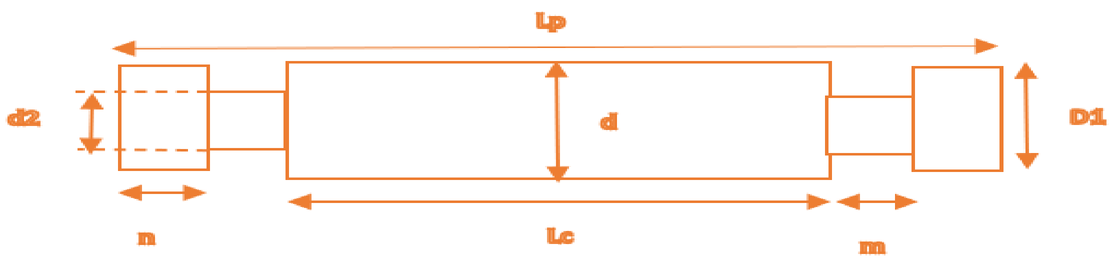
Figure 3-2-7- 4: Excel console program results for sprockets

- **Used Excel console program results for chains:**

Outputs		
Pitch	31.75	mm
PCD 1	313.8334	mm
PCD 2	313.8334	mm
no. of teeth 1	31	
no. of teeth 2	31	
Vmax	0.5	m/s
Vmin	0.499358	m/s
Vfluct	0.128349	%
Vmax.fluct	0.000642	m/s
N	30.44335	rpm
Overall weight/m	9.5854	kg/m
MS1	-0.0656	
MS2	0.452	
MSM	0.6452	
Chain pull	106.7116	N
Factor of safety	1208.865	
Head shaft Power	53.35582	Watt
Head shaft torque	16.74484	N.m

Figure 3-2-7- 5 :Excel console program results for chains

- **Chain pin calculations and E-clips selection:**



$$L_c \geq 18 \rightarrow 18 \cdot 5$$

From table with d1 equal to 5 mm, the E-clips selected with 4 mm inner diameter.

Then d2 = 4 mm, m = 0.74mm, n > 1.2, n = 1.26.

$$L_p = \ L_c + 2 * m + 2 * n = 18.5 + (2 * 0.74) + (2 * 1.26) = 22.5\ mm$$

The material selected for pin is the same material of original conveyor chain stainless steel with 5 mm diameter.

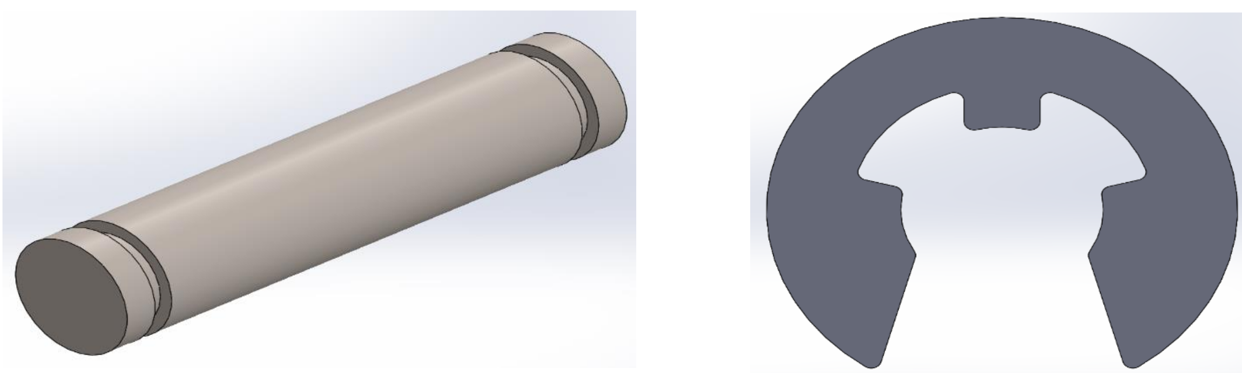


Figure 3-2-7- 7: Sprocket Pin and E-clips

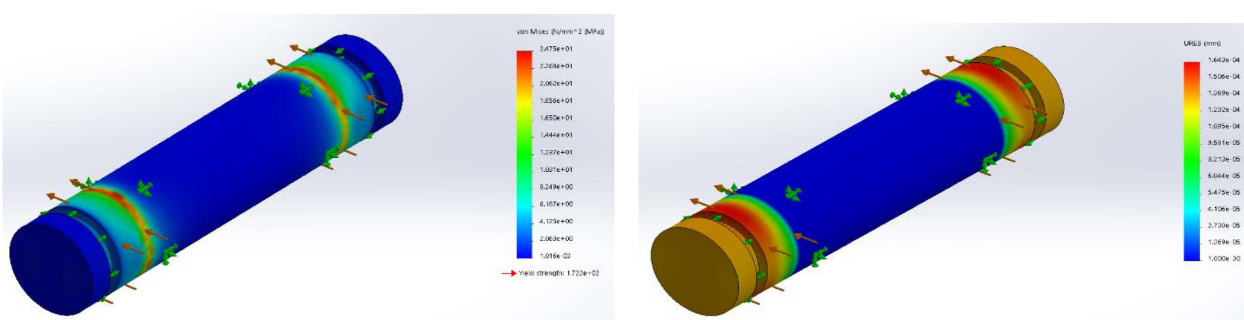


Figure 3-2-7- 6: Stress and Displacement analysis for sprocket pin

D2	D1		S		A		WEIGHT KG/1000PCS	D2		M		N	D3	FN		FS	G	F[illegible]
nominal size	Min.	Max.		tolerance		tolerance			tolerance		tolerance	Min.	Max.	kN	for d1	kN		
0,8	1	1,4	0,2		0,58		0,003	0,8	0	0,24	+0,04	0,4	2,25	0,03	1,2	0,08	0,3	0,
									-0,04		0							
									(h11)									
1,2	1,4	2	0,3		1,01	±0,04	0,009	1,2	0	0,34		0,6	3,25	0,04	1,5	0,12	0,4	0,
1,5	2	2,5	0,4		1,28		0,021	1,5	-0,06	0,44		0,8	4,25	0,07	2	0,22	0,6	0,
1,9	2,5	3	0,5	±0,02	1,61		0,04	1,9	(h11)	0,54	+0,05	1	4,8	0,1	2,5	0,35	0,7	0,
2,3	3	4	0,6		1,94		0,069	2,3		0,64	0	1	6,3	0,15	3	0,5	0,9	0,
3,2	4	5	0,6		2,7		0,088	3,2	0	0,64		1	7,3	0,22	4	0,65	0,9	0,
4	5	7	0,7		3,34		0,158	4	-0,075	0,74		1,2	9,3	0,25	5	0,95	1	0,
5	6	8	0,7		4,11	±0,048	0,236	5	(h11)	0,74		1,2	11,3	0,9	7	1,15	1	0
6	7	9	0,7		5,26		0,255	6		0,74		1,2	12,3	1,1	8	1,35	1,1	0
7	8	11	0,9		5,84		0,474	7	0	0,94		1,5	14,3	1,25	9	1,8	1,3	
8	9	12	1		6,52		0,66	8	-0,09	1,05	+0,08	1,8	16,3	1,42	10	2,5	1,5	1,
9	10	14	1,1		7,63	±0,058	1,09	9	(h11)	1,15	0	2	18,8	1,6	11	3	1,6	1
10	11	15	1,2		8,32		1,25	10		1,25		2	20,4	1,7	12	3,5	1,8	1,
12	13	18	1,3		10,45		1,63	12	0	1,35		2,5	23,4	3,1	15	4,7	1,9	2
15	16	24	1,5	±0,03	12,61	±0,07	3,37	15	-0,11	1,55		3	29,4	7	20	7,8	2,2	3
19	20	31	1,75		15,92		6,42	19	(h11)	1,8		3,5	37,6	10	25	11	2,5	3
24	25	38	2		21,88		8,55	24	0	2,05		4	44,6	13	30	15	3	[illegible]
						±0,084			-0,13									
30	32	42	2,5		25,8		13,5	30	(h11)	2,55		4,5	52,6	16,5	36	23	3,5	5

Table 3-2-7- 1: E-Clips selection table

To transmit the power from motor shaft to the conveyor driving shaft we decided to use power transmitting chain drive, while these chains are used for transmission of power, when the distance between the centers of shafts is short.

- **Bush roller chain type:**

  It is extremely strong and simple in construction. It gives good service under severe conditions. There is a little noise with this chain which is due to impact of the rollers on the sprocket wheel teeth. This chain may be used where there is a little lubrication. When one of these chains elongates slightly due to wear and stretching of the parts, then the extended chain is of greater pitch than the pitch of the sprocket wheel teeth. The rollers then fit unequally into the cavities of the wheel. The result is that the total load falls on one tooth or on a few teeth. The stretching of the parts increases wear of the surfaces of the roller and of the sprocket wheel teeth.

  The roller chains are standardized and manufactured on the basis of pitch. These chains are available in single-row or multi-row roller chains such as simple, duplex or triplex strands.

- **Power Transmitting Chain calculations:**

$$Rated\ power\ =\ 80\ W, N1\ =\ 100\ rpm, N2\ =\ 30.5\ rpm.$$

$$We\ know\ that\ the\ velocity\ ratio\ of\ chain\ drive,$$

$$V.R. = \frac{N1}{N2} = \frac{100}{30.5}\ =\ 3.286 \sim 4$$

From Table 21.5, we find that for the roller chain, the number of teeth on the smaller sprocket or pinion,

$$T1\ for\ a\ velocity\ ratio\ of\ 4\ are\ 23.$$

$$\therefore\ Number\ of\ teeth\ on\ the\ larger\ sprocket\ or\ gear,$$

$$T2\ =\ T1\ *\ \frac{N1}{N2} =\ 23\ \times\ \frac{100}{30.5}\ =\ 75.5 \sim 76$$

We know that the design power = Rated power × Service factor (KS)

The service factor (KS) is the product of various factors K1, K2 and K3. The values of these factors are used as follows:

$$Load\ factor\ (K1)\ for\ variable\ load\ with\ mild\ shock\ =\ 1.25$$

$$Lubrication\ factor\ (K2)\ for\ periodic\ lubrication\ =\ 1.5$$

$$Rating\ factor\ (K3)\ for\ 16\ hours\ per\ day\ =\ 1.25$$

$$\therefore\ Service\ factor, KS\ =\ K1.K2.K3\ =\ 1.25\ \times\ 1.5\ \times\ 1.25\ =\ 2.344$$

$$Design\,power\ =\ 80\ \times\ 2.344\ =\ 187.5W$$

From Table 21.4, we find that corresponding to a pinion speed of 100 rpm.
The power transmitted for chain No. 8 is 0.64 kW per strand. Therefore, a chain No.8 with one strand can be used to transmit the required power.
From Table 21.1, we find that

$$Pitch\,p\ =\ 12.7\,mm\ =\ 0.5\,inch$$

$$Roller\ diameter\ d\ =\ 8.51\,mm$$

$$Minimum\,width\ of\ roller\,w\ =\ 7.7\,mm$$

$$Breaking\ load\,WB\ =\ 17.8\,KN$$

We know that pitch circle diameter of the smaller sprocket or pinion.

$$PCD1\ =\ p\ cosec\ (\frac{180}{T1})\ =\ 12.7\ cosec\ (\frac{180}{23})\ =\ 93.268\,mm$$

$$Pitch\ circle\ diameter\ of\ the\ larger\ sprocket\ or\ gear$$

$$PCD2\ =\ p\ cosec\ (\frac{180}{T2})\ =\ 12.7\ cosec\ (\frac{180}{76})\ =\ 307.32\,mm$$

$$Pitch\ line\ velocity\ of\ the\ smaller\ sprocket$$

$$V1\ =\ \frac{\pi\ *\ D1\ *\ N1}{60}\ =\ \frac{\pi\ *\ 93.268\ *\ 10^{-3}\ *\ 100}{60}\ =\ 0.48835\,m/s$$

$$\therefore\ Load\ on\ the\ chain\,W\ =\ \frac{Rated\ power}{Pitch\ line\ velocity}\ =\ \frac{80}{0.48835}\ =\ 163.82\ N$$

$$Factor\ of\ safety\ =\ \frac{WB}{W}\ =\ \frac{8.9}{0.16382}\ =\ 54.33$$

This value is more than the value given in Table 21.2, which is equal to 8.

The minimum center distance between the smaller and larger sprockets should be 30 to 50 times the pitch, let us take it as 30 times the pitch.

$$\therefore\ Centre\ distance\ between\ the\ sprockets\ (X)\ =\ 30\,p\ =\ 30\ \times\ 12.7\ =\ 381\,mm$$

In order to accommodate initial sag in the chain, the value of center distance is reduced by 2 to 5 mm.

$$\therefore\ Correct\ center\ distance\ X\ =\ 381-3\ =\ 378\,mm$$

$$We\ know\ that\ the\ number\ of\ chain\ links$$

$$K\ =\ \frac{T1+T2}{2}\ +\ \frac{2X}{p}+\ (\frac{T2-T1}{2\pi})^2\ *\ \frac{p}{x}\ =\ 112\ links$$

$$\therefore\ Shortest\ total\ length\ of\ the\ chain\ L\ =\ K\ *\ p\ =\ 112\ \times\ 12.7\ =\ 1422.4\,mm$$
$$=\ 1.422\ m\ Ans.$$

$$-The\ decided\ used\ length\ of\ chain\ due\ to\ design\ reasons$$
$$L\ =\ 1.8288m$$
$$with\ number\ of\ links\ =\ 144\ links$$

- **Velocity fluctuation:**

$$Vmax\ =\ \frac{\pi\ *\ d\ *\ N}{60}\ =\ \frac{\pi\ *\ 0.093268\ *\ 100}{60}\ =\ 0.4883\ m/s.$$

$$Vmin\ =\ \frac{\pi\ *\ d\ *\ N\ *\ cos\ (\frac{\alpha}{2})}{60}\ =\ \frac{\pi\ *\ 0.093268\ \ *\ 100\ *\ cos\ (\frac{180}{2\ *\ 23})}{60}$$
$$=\ 0.4872\ m/s.$$

$$Maximum\ fluctuation\ =\ Vmax - Vmin\ =\ 0.0011\ m/s \sim 0.225\ \%\ (very\ small\ value)$$

- **Drawing of sprockets using SolidWorks program:**

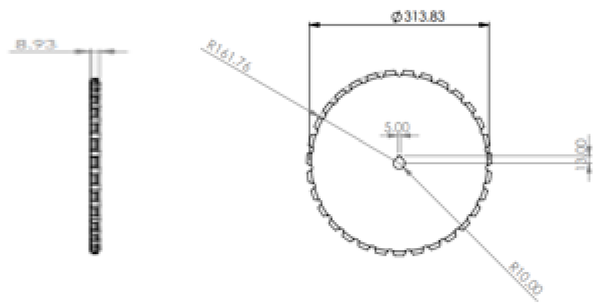


Figure 3-2-7- 8: T31 Sprocket_P1.25

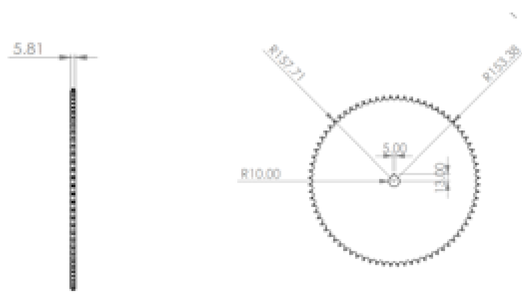


Figure 3-2-7- 9: T76 Sprocket_P0.5

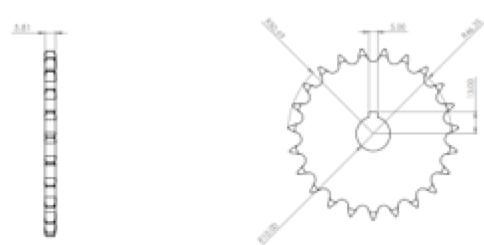


Figure 3-2-7- 10: T23 Sprocket_P0.5

- **Conclusion:**

  The selection for Conveyor system would be 2 single strands of 1.25 inch = 31.75 mm pitch, with total length = 3.429 * 2 = 6.885 m, equivalent to 108 links for every strand while the number of chains is C2050 which equivalent to C210 and using of 4 sprockets with 31 teeth number.

  The selection for power transmission method would be single strands of 0.5 inch = 12.7 mm pitch, with total length 1.8288 m, equivalent to 144 links while the number of chains is 085 and using of 2 sprockets of 76 and 31 teeth.

Where,

$\mu s1 = (\mu c \; x \; cos \; \alpha) - sin \; \alpha$

$\mu s2 = (\mu c \; x \; cos \; \alpha) + sin \; \alpha$

$\mu sm = (\mu m \; x \; cos \; \alpha) + sin \; \alpha$

$d4$: diameter equal 33 mm

T: number of teeth = 31

d1: pin diameter = 5mm

3-2-8: Bolts

There is more than one way to fix the parts together, such as welding and bolts. Fixing parts with nails so that I can re-disassemble these parts.

There are 2 types of Threaded Fasteners:

- Bolt: Threaded fastener designed to pass through holes in mating members and to be secured by tightening a nut from the end opposite the head of the bolt.
- Screw: Threaded fastener designed to be inserted through a hole in one member and into a threaded hole in a mating member

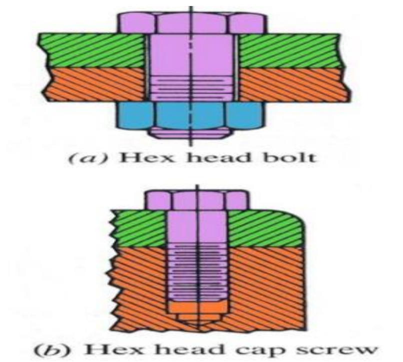


Figure 3-2-8- 1: Bolts and Screws

There are 2 types of connections on bolt:

- Tension Connection
- Shear Connection

In case of tension connection:

$$l = lt + ld \qquad (3\text{-}2\text{-}8\text{-}1)$$

$$L > l + H \qquad (3\text{-}2\text{-}8\text{-}2)$$

$$L = ld + Lt \qquad (3\text{-}2\text{-}8\text{-}3)$$

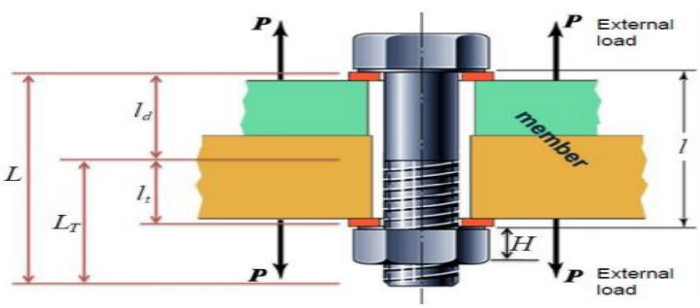


Figure 3-2-8- 2: Tension Connection

Bolt stiffness (kb) in the grip (clamped zone):

Two tension springs in series:

$$k = \frac{AE}{l} \qquad (3\text{-}2\text{-}8\text{-}4)$$

$$k_d = \frac{A_d E_b}{L_d}, k_t = \frac{A_t E_b}{L_t} \qquad (3\text{-}2\text{-}8\text{-}5)$$

$$Kb = \frac{k_d k_t}{k_d + k_t} = \frac{A_d A_t E_b}{A_d L_t + A_t L_d} \qquad (3\text{-}2\text{-}8\text{-}6)$$

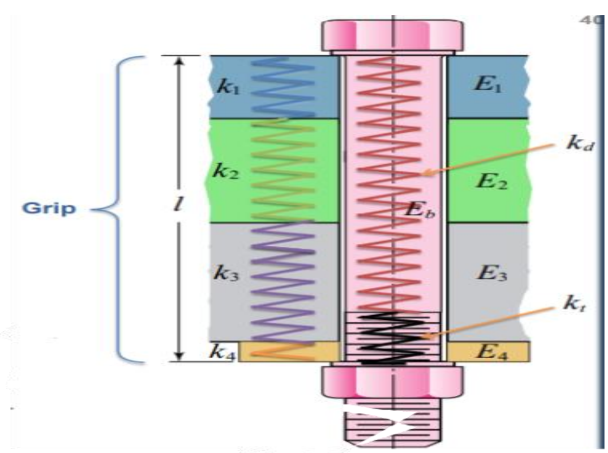
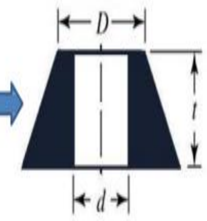


Figure 3-2-8- 3: Stiffness in the grip

A set of compression springs in series.

In general, if we have n-springs in series, then

$$k = \frac{P}{\delta} = \frac{0.5774\pi E d}{\ln \frac{(1.115t + D - d)(D + d)}{(1.115t + D + d)(D - d)}}$$



$$\frac{1}{Km} = \frac{1}{K1} + \frac{1}{K2} + \frac{1}{K3} + \cdots + \frac{1}{Kn}$$

Where,

At: from tables(8-1,8-1)

Eb: represents the modulus of elasticity of the bolt material

Kb: equivalent stiffness of the bolt in the grip zone

Kd: stiffness of unthreaded portion

Kt = stiffness of threaded portion

Bolt Strength:

In the specification standards for bolts, the strength is specified by stating ASTM minimum quantities, the minimum proof strength, or minimum proof load (Fp) and the minimum tensile strength.

The proof load (Fp): is the maximum force that a bolt can withstand without acquiring a permanent set.

The proof strength (Sp): is the quotient of the proof load and the tensile-stress area.

$$Sp = \frac{proofload}{At} (measured\ on\ actualbolt) \qquad (3\text{-}2\text{-}8\text{-}7)$$

Where,

Sut: minimum tensile strength of bolt material

Sy: minimum yield strength of bolt material

Ssy = 0.577Sy, Shear strength of bolt material

From tables (8-9,8-10,8-11) from Shrigley-machine-design

Bolt tightening torque (T):

Calculating the torque needed to tightening the bolt.

Recommended preloading: tensile load that a bolt is subjected to as it is stretched by tightening of the nut.

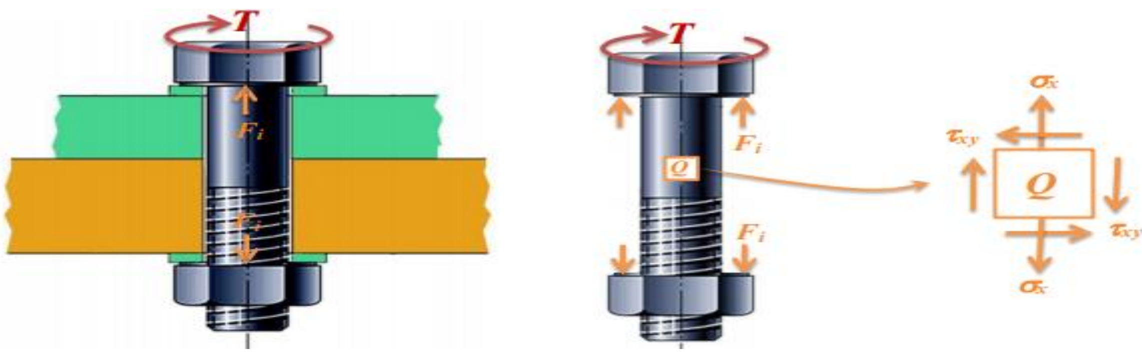


Figure 3-2-8- 4: Torque on bolt

$T = k * F_i * d$

$F_i = 0.9 * F_p \; (for\ permanant\ connections)$

$F_i = 0.75 * F_p \; (for\ nonpermanent\ connections, reused\ fasteners)$

$F_p = A_t S_p$

Bolt Condition	K
Nonplated, black finish	0.30
Zinc-plated	0.20
Lubricated	0.18
Cadmium-plated	0.16
With Bowman Anti-Seize	0.12
With Bowman-Grip nuts	0.09

Table 3-2-8- 1: Stiffness of bolt

Bolt Tension with External Joint-Separating Force P:

(3-2-8-10)

$c = \frac{k_b}{k_b k_m}$

$F_m = F_i - ((1 - c) * p)$

$F_P = F_i + c * p$

Where

P: load applied on connected parts

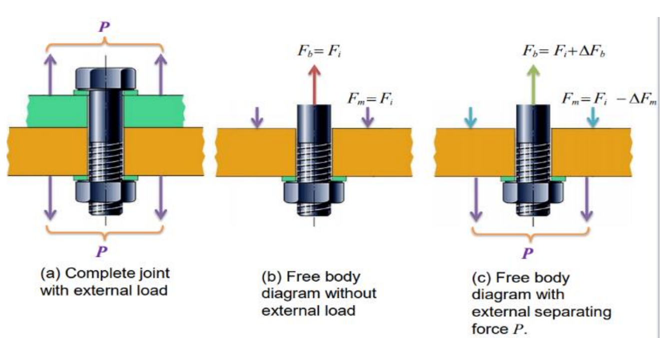


Figure 3-2-8- 5: Bolt Tension with External Joint Force

Bolt selection for steady loading (i.e., P is static):

To ensure safe joint, the following conditions must be satisfied:

1. Factor of safety guarding against bolt yielding must be greater than one; $n_p > 1$
2. Factor of safety guarding against bolt Loading must be greater than one; $n_L > 1$
3. Factor of safety guarding against joint separation must be greater than one; $n_o > 1$

Now, the overall factor of safety is n = min (n_p, n_o) It must be greater than one.

$$n_p = \frac{s_P A_t}{Cp + F_i} \qquad (3\text{-}2\text{-}8\text{-}11)$$

$$n_L = \frac{s_P A_t - F_i}{Cp} \qquad (3\text{-}2\text{-}8\text{-}12)$$

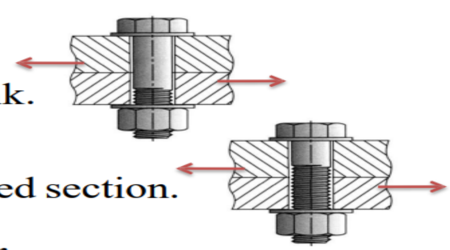
$$n_o = \frac{F_i}{p * (1 - c)} \qquad (3\text{-}2\text{-}8\text{-}13)$$

It is necessary to ensure that $n = \min(np, n0) > 1$ when designing a tension connection. Usually, separation occurs first.

Shear stress on bolt:

$$\boxed{\tau_i = \frac{F_i}{A_i}}$$

where $\begin{cases} A_i = \dfrac{\pi d^2}{4}, & \text{for shear on shank.} \\ A_i = A_t, & \text{for shear on threaded section.} \end{cases}$



Factor of safety guarding against shear yielding in bolt i is:

$$\boxed{n_i = \frac{S_{sy}}{\tau_i} = \frac{0.577 S_p}{\tau_i}} \quad \text{must be greater than one.}$$

To compute the factor of safety guarding against shear yielding for the entire joint, n, we select the critical bolt which subjected to maximum load, i.e., maximum F_i.

Calculation of bolts:

1. Rejection Gate plate:

From table 8-11 class 5.8,

$$A_t = 8.78\,mm^2$$

, for medium carbon

$$s_y = 420\,MPa\,,\quad E = 205\,GPa$$

$$W = 0.5 * 9.81 = 4.905\,N$$

$$F = W * \cos(10)$$

$$= 4.905 * \cos(10)$$

$$= 4.8304\,N$$

$$F_i = \frac{F}{2} = 2.4152\,N$$

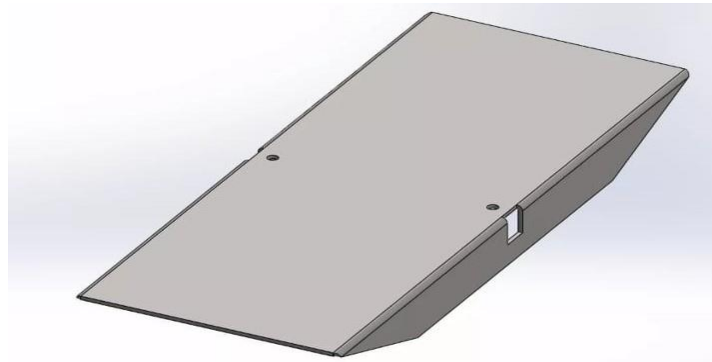
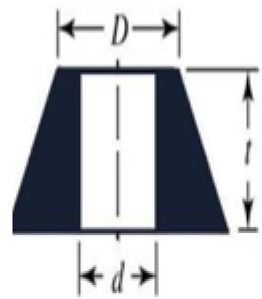


Figure 3-2-8- 6: Rejection plate

The bolt is between two material one is the rejection plate itself and the other is rejection shaft so we need to get the member stiffness in the clamped zone.

Equation for tension connection,



$$K = \frac{0.5774 * \pi * E * d}{\ln\left(\frac{(1.115 * t + D - d)(D + d)}{(1.115 * t + D \mp d)(D - d)}\right)}$$

For rejection plate:

$$D = 1.5 * d,\;\; d = 4\,mm,\;\; D = 6\,mm\;\;, t_1 = 2\,mm\,, E = 205GPA$$

$$K_1 = \frac{1487443591}{\ln\left(\frac{4.23 * 10^{-5}}{2.446 * 10^{-5}}\right)} = 2.715562 * 10^9\,\frac{N}{m}$$

For rejection shaft:

$$D = 1.5 * d,\;\; d = 4\,mm,\;\; D = 6\,mm\;\;, t_2 = 5\,mm\,, E = 205GPA$$

$$D_1 = 11.7735\,mm\,, D_2 = 19.8564\,mm$$

$$K_2 = \frac{1487443591}{\ln\left(\frac{2.1053 * 10^{-4}}{1.65952 * 10^{-4}}\right)} = 6.249 * 10^9\,\frac{N}{m}$$

$$D = 1.5 * d,\;\; d = 4\,mm,\;\; D = 6\,mm\;\;, t_3 = 7\,mm\,, E = 205GPA$$

$$K_3 = \frac{1487443591}{\ln\left(\frac{9.805 * 10^{-5}}{3.561 * 10^{-5}}\right)} = 1.46857 * 10^9\,\frac{N}{m}$$

To get K_m,

$$\frac{1}{K_m} = \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3} = 826.9875 * 10^6 \frac{N}{m}$$

To get bolt stiffness:

$$K_b = K_t = \frac{A_t * E_b}{2 * d + 6} = \frac{8.78 * 10^{-6} * 205 * 10^9}{14 * 10^{-3}} = 128.564 * 10^6 \frac{N}{m}$$

$$C = \frac{K_b}{K_b + K_m} = \frac{128.564 * 10^6}{128.564 * 10^6 + 826.9875 * 10^6} = 0.134826$$

$$F_b = F_i + C * P = 0.75 * F_p + C * P = 0.75 * (S_p * A_t) + C * P$$

$$F_b = 0.75 * (225 * 10^6 * 8.678 * 10^{-6}) + (0.134826 * 2.4152) = 1481.954\ N$$

$$\delta_n = \frac{F_b}{A_t} = 168.751\ MPa$$

Factor of safety guarding against bolt yielding:

$$n_p = \frac{s_P A_t}{Cp + F_i} = \frac{225 * 10^6 * 8.72 * 10^{-6}}{0.134826 * 2.4152 + \left(0.75 * (225 * 10^6 * 8.72 * 10^{-6})\right)} = 1.333$$

$$n_p > 1$$

Factor of safety guarding against bolt Loading:

$$n_L = \frac{s_P A_t - F_i}{Cp} = \frac{225 * 10^6 * 8.72 * 10^{-6} - \left(0.75 * (225 * 10^6 * 8.72 * 10^{-6})\right)}{0.134826 * 2.4152}$$
$$= 1410.4928$$

$$n_L > 1$$

Factor of safety guarding against joint separation:

$$n_o = \frac{F_i}{p * (1 - c)} = \frac{\left(0.75 * (225 * 10^6 * 8.72 * 10^{-6})\right)}{2.1452 * (1 - 0.134826)} = 798.30169$$

$$n_o > 1$$

$$n = \min(n_o, n_p) = 1.333\ , \qquad so\ safe$$

The length of bolt:

$$L = thickness\ of\ material + nut + washers$$

$$L = t_1 + t_2 + 0.8 * D = 2 + 12 + (0.8 * 4) = 17.2\ mm$$

$$L > 17.2\ mm$$

2. Stepper Motor fixation:

The load in shear stress:

$$T_{Shaft} = 0.5 * 9.81 * \cos(10) * 0.15$$
$$= 0.72457\ N.m$$

In stepper motor fixation there are two types of bolts, one for motor with fixation and the other for fixation with mechanism part.

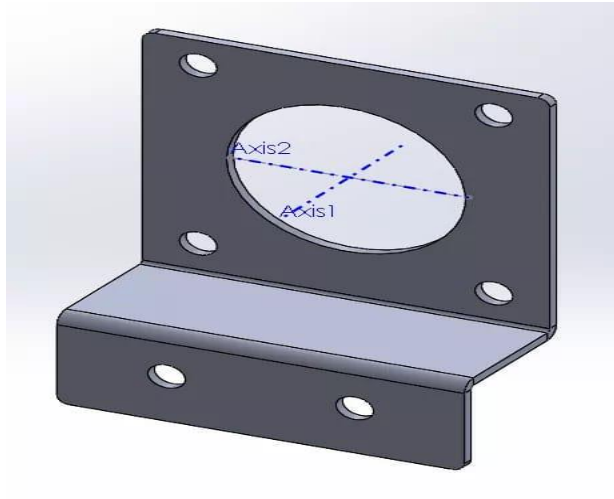


Figure 3-2-8- 7: stepper motor fixation

Motor with fixation:

$$F = \frac{T}{d} = \frac{0.72457}{\frac{66.69 * 10^{-3}}{2}} = 21.739\ N$$

$$F_i = \frac{F}{4} * \cos(45) + \frac{9.81}{4}$$
$$= \frac{21.739}{4} * \cos(45) + \frac{9.81}{4}$$
$$= 6.294\ N$$

$$\tau_i = \frac{F_i}{A_t}\ , A_t = 14.2\ mm^2\ for\ M5\ from\ table\ 8-11\ class\ 5.8, \qquad S_y = 420\ MPa$$

$$\tau_i = \frac{6.294}{4.2 * 10^{-6}} = 443.239 * 10^3\ Pa$$

$$n_i = \frac{s_{sy}}{\tau_i} = \frac{0.577 s_y}{\tau_i} = \frac{0.577 * 420 * 10^6}{443.339 * 10^3} = 546.624592\ , \qquad safe$$

Length of bolt:

$$L = t_1 + t_2 + 0.8 * D + 2 * 0.15 * D = 5 + 2 + (0.8 * 5) + (2 * 0.15 * 5) = 12.5\ mm$$
$$L > 12.5\ mm$$

Fixation with mechanism:

$$F = \frac{0.72457}{45.26 * 10^{-3}} = 16N$$

$$F_i = \frac{16}{2} * \cos(70.46) + \frac{9.81}{2} = 7.58071\ N$$

$$\tau_i = \frac{F_i}{A_t} = \frac{7.58071}{14.2 * 10^{-2}} = 533.8528169 * 10^3\ Pa$$

$$n_i = \frac{s_{sy}}{\tau_i} = \frac{0.577 s_y}{\tau_i} = \frac{0.577 * 420 * 10^6}{533.8528 * 10^3} = 453.9453572, \qquad safe$$

Length of bolt:

$$L = t_1 + t_2 + 0.8 * D + 2 * 0.15 * D = 2 + 25 + (0.8 * 5) + (2 * 0.15 * 5)$$
$$= 32.5\ mm$$
$$L > 32.5\ mm$$

3. Feeding tank: (M6)

$$F = 8 * 9.81 * \cos(75) = 20.3121\ N$$

$$A_t = 20.1 * 10^{-6}\ m^2, \quad S_y = \ 420\ Mpa\ , number\ of\ bolts\ is\ 6$$

$$F_i = \frac{F}{6} = \frac{20.3121}{6} = 3.3853\ N$$

$$\tau_i = \frac{F_i}{A_t} = \frac{3.3853}{20.1 * 10^{-6}} = 168.4228856 * 10^3$$

$$n_i = \frac{s_{sy}}{\tau_i} = \frac{0.577 s_y}{\tau_i} = \frac{0.577 * 420 * 10^6}{168.422885 * 10^3} = 1438.878095, \qquad safe$$

Length of bolt:

$$L = \ t_1 + t_2 + 0.8 * D + 2 * 0.15 * D = 2 + 25 + (0.8 * 6) + (2 * 0.15 * 6)$$
$$= 33.6\ mm$$

$$L > 33.6\ mm$$

4. Fixed plate fixation:(M6)

$$F_i = \frac{F}{4} = \frac{7 * 9.81}{4} = 17.1675\ N$$

$$\tau_i = \frac{F_i}{A_t} = \frac{17.1675}{20.1 * 10^{-6}} = 854.1044 * 10^3 Pa$$

$$n_i = \frac{s_{sy}}{\tau_i} = \frac{0.577 s_y}{\tau_i} = \frac{0.577 * 420 * 10^6}{854.1044 * 10^3} = 283.7358056, \ \ Safe$$

Length of bolt:

$$L = \ t_1 + t_2 + 0.8 * D + 2 * 0.15 * D = 25 + 25 + (0.8 * 6) + (2 * 0.15 * 6)$$
$$= 56.6\ mm$$

$$L > 56.6\ mm$$

5. Roller Fixation with chain link:

$$F_i = \frac{F}{4} = \frac{0.5 * 9.81}{4} = 1.22625\ N$$

$$\tau_i = \frac{F_i}{A_t} = \frac{1.22625}{5.03 * 10^{-6}} = 243.787 * 10^3 Pa$$

$$n_i = \frac{s_{sy}}{\tau_i} = \frac{0.577 s_y}{\tau_i} = \frac{0.577 * 420 * 10^6}{243.787 * 10^3} = 994.0644907, \;\; Safe$$

Length of bolt:

$$L = t_1 + t_2 + 0.8 * D + 2 * 0.15 * D = 2 + 14 + (0.8 * 3) + (2 * 0.15 * 3)$$
$$= 20.4\, mm$$
$$L > 20.4\, mm$$

6. Axe fixation: (M10&M6)

There are two types of bolts on axe fixation one for bearing with fixation bar (M10) and the other is fixation bar with the mechanism (M6) and each one will be different on driven and drive part.

$$m_{Chain} = 27\, kg$$
$$m_{bearing} = 0.56\, kg$$
$$m_{axe} = 1.5\, kg$$
$$m_{gear} = 5.5\, kg$$
$$m_{Sg} = 0.6\, kg$$
$$m_{bar} = 0.742\, kg$$
$$m_{small\ Chain} = 1.5\, kg$$

Bearing with fixation bar on driven side:

$$F_{i1} = \left(\frac{0..56 * 2}{8} + \frac{5.5 * 2}{8} + \frac{1.5}{8} + \frac{27}{16}\right) * 9.81 = 33.2559\, N$$
$$\tau_i = \frac{F_{i1}}{A_t} = \frac{33.2559}{58 * 10^{-6}} = 573.377 * 10^3 Pa$$
$$n_i = \frac{s_{sy}}{\tau_i} = \frac{0.577 s_y}{\tau_i} = \frac{0.577 * 420 * 10^6}{573.377 * 10^3} = 422.653856, \;\; Safe$$

Length of bolt:

$$L = t_1 + t_2 + 0.8 * D + 2 * 0.15 * D = 25 + 10 + (0.8 * 10) + (2 * 0.15 * 10)$$
$$= 46\, mm$$

$$L > 46\, mm$$

Fixation bar with the mechanism on driven side:

$$F_{i2} = F_{i1} + \frac{F}{2} = 33.2559 + \frac{0..742 * 9.81}{2} = 36.52\, N$$

$$\tau_i = \frac{F_{i1}}{A_t} = \frac{36.52}{20.1 * 10^{-6}} = 1.835323 * 10^6 Pa$$

$$n_i = \frac{s_{sy}}{\tau_i} = \frac{0.577 s_y}{\tau_i} = \frac{0.577 * 420 * 10^6}{1.835323 * 10^6} = 132.0421528, \;\; Safe$$

Length of bolt:

$$L = t_1 + t_2 + 0.8 * D + 2 * 0.15 * D = 25 + 25 + (0.8 * 6) + (2 * 0.15 * 6) = 56.6\,mm$$

$$L > 56.6\,mm$$

Bearing with fixation bar on drive side:

$$F_{i1} = \left(\frac{0..56 * 2}{8} + \frac{5.5 * 3}{8} + \frac{1.5 + 1.5 + 0.6}{8} + \frac{27}{16}\right) * 9.81 = 42.57\,N$$

$$\tau_i = \frac{F_{i1}}{A_t} = \frac{42.57}{58 * 10^{-6}} = 734.0586 * 10^3 Pa$$

$$n_i = \frac{s_{sy}}{\tau_i} = \frac{0.577 s_y}{\tau_i} = \frac{0.577 * 420 * 10^6}{734.0586 * 10^3} = 330.1371307, \;\; Safe$$

Length of bolt:

$$L = t_1 + t_2 + 0.8 * D + 2 * 0.15 * D = 25 + 10 + (0.8 * 10) + (2 * 0.15 * 10) = 46\,mm$$

$$L > 46\,mm$$

Fixation bar with the mechanism on drive side:

$$F_{i2} = F_{i1} + \frac{F}{2} = 42.57 + \frac{0..742 * 9.81}{2} = 46.21551\,N$$

$$\tau_i = \frac{F_{i1}}{A_t} = \frac{46.21551}{20.1 * 10^{-6}} = 2.299 * 10^6 Pa$$

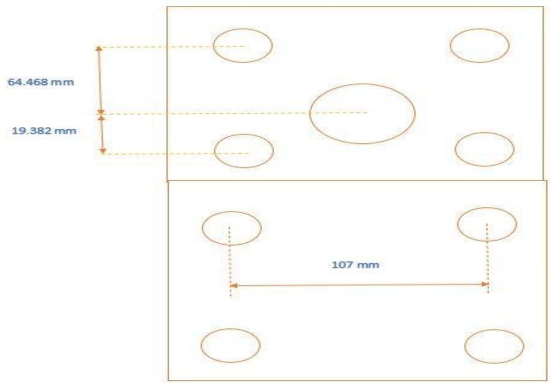
$$n_i = \frac{s_{sy}}{\tau_i} = \frac{0.577 s_y}{\tau_i} = \frac{0.577 * 420 * 10^6}{2.29927 * 10^6} = 105.39867, \;\; Safe$$

Length of bolt:

$$L = t_1 + t_2 + 0.8 * D + 2 * 0.15 * D = 25 + 25 + (0.8 * 6) + (2 * 0.15 * 6) = 56.6\,mm$$

$$L > 56.6\,mm$$

7. DC motor fixation: (M6)



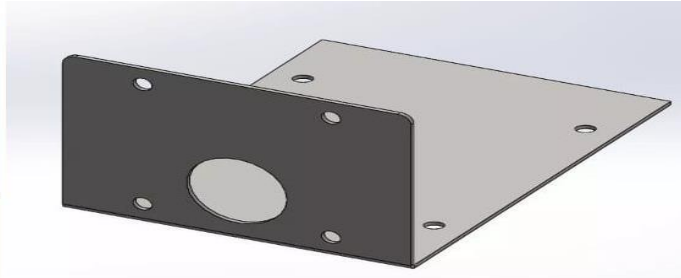


Figure 3-2-8- 8: DC fixation

$$t = 0.15 * D = 0.15 * 6 = 0.9\ mm$$
$$T = 7.64\ N.m$$
$$T = 4 * F_i * \frac{100.1}{3 * 1000}$$
$$F_i = 38.1618\ N$$
$$F_{axial} = \frac{7.64}{\frac{107}{1000}} = 71.40186\ N$$

There are two type of stress act on the bolt one is shear and the other is bending.

For sheer condition:

$$F_i = 38.1618, \qquad A_t = 20.1\ mm^2 from\ table\ 8-11\ class\ 5.8, \qquad S_y = 420\ MPa$$

$$n_i = \frac{0.577 * S_y}{\tau_i}, \tau_i = \frac{F_i}{A_t} = \frac{38.1618}{20.1 * 10^{-6}} = 1.89858\ MPa$$

$$n_i = \frac{0.577 * 420 * 10^6}{1.89858 * 10^6} = 127.6427646, \qquad safe$$

Length of bolt:

$$L = t_1 + t_2 + 0.8 * D + 2 * 0.15 * D = 2 + (0.8 * 6) + (2 * 0.15 * 6) = 8.6\ mm$$

$$L > 8.6\ mm$$

For bending condition:

$$F_{axial} = 71.40186\ N$$

To get maximum stiffness:

- $d = 6\ mm\ , D = 1.5 * 6 = 9\ mm, t_1 = 0.9\ mm, E = 205GPa$

$$D_1 = D + (2 * t * tan \propto) = 9 + (2 * 0.9 * \tan(30)) = 10.03923\ mm$$

$$K_1 = \frac{0.5774 * \ \pi * 205 * 10^9 * 6 * 10^{-3}}{\ln\left(\frac{6.1725 * 10^{-5}}{4.8345 * 10^{-5}}\right)} = \frac{2.231165 * 10^9}{0.244336}$$

$$= 9.131918 * 10^9 \frac{N}{m}$$

- $d = 6\ mm, D = \ D_1 = 10.03922\ mm, t = 2\ mm, E = 205GPa$

$$D_2 = 10.03922 + (2 * 2 * \tan(30)) = 12.3486\ mm$$

$$K_2 = \frac{0.5774 * \ \pi * 205 * 10^9 * 6 * 10^{-3}}{\ln\left(\frac{1.0055 * 10^{-4}}{7.37936 * 10^{-5}}\right)} = \frac{2.231165 * 10^9}{0.308934} = 7.222 * 10^4 \frac{N}{m}$$

- $d = 6\ mm, D = \ D_2 = 12.3486\ mm, t = 11.5\ mm, E = 205GPa$

$$D_3 = 12.3486 + (2 * 11.5 * \tan(30)) = 25.62765\ mm$$

$$K_3 = \frac{0.5774 * \ \pi * 205 * 10^9 * 6 * 10^{-3}}{\ln\left(\frac{3.517628 * 10^{-4}}{1.978928 * 10^{-4}}\right)} = 3.8787245 * 10^9 \frac{N}{m}$$

- $d = 6\ mm, D = \ D_1 = 10.03922\ mm, t = 13.5\ mm, E = 205GPa$

$$K_4 = \frac{0.5774 * \ \pi * 205 * 10^9 * 6 * 10^{-3}}{\ln\left(\frac{3.062166 * 10^{-4}}{1.25586 * 10^{-4}}\right)} = 2.5032 * 10^9 \frac{N}{m}$$

- $d = 6\ mm, D = \ 9\ mm, t = 0.9\ mm, E = 205GPa$

$$K_5 = \ K_1 = 9.131918 * 10^9 * 10^9 \frac{N}{m}$$

$$\frac{1}{K_m} = \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3} + \frac{1}{K_4} + \frac{1}{K_5} = 985.43215 * 10^6 \frac{N}{m}$$

To get bolt stiffness:

$$K_b = \ K_t = \frac{A_t * \ E_b}{l_t} = \frac{20.1 * 10^{-6} * 309 * 10^9}{28.5 * 10^{-3}} = 143.0729 * 10^6 \frac{N}{m}$$

$$C = \frac{K_b}{K_m + K_b} = 0.1267809$$

Factor of safety guarding against bolt yielding:

$$n_p = \frac{s_P A_t}{Cp + F_i} = \frac{225 * 10^6 * 20.1 * 10^{-6}}{0.1267809 * 71.40186 + \left(0.75 * (225 * 10^6 * 20.1 * 10^{-6})\right)} = 1.32978$$

$$n_p > 1$$

Factor of safety guarding against bolt Loading:

$$n_L = \frac{s_P A_t - F_i}{Cp} = \frac{225 * 10^6 * 20.1 * 10^{-6} - \left(0.75 * (225 * 10^6 * 20.1 * 10^{-6})\right)}{0.1267809 * 71.40186}$$
$$= 124.8979$$

$$n_L > 1$$

Factor of safety guarding against joint separation:

$$n_o = \frac{F_i}{p * (1 - c)} = \frac{\left(0.75 * (225 * 10^6 * 20.1 * 10^{-6})\right)}{71.40186 * (1 - 0.1267809)} = 54.4$$

$$n_o > 1$$

$$n = \min(n_o, n_p) = 1.32978\,, \qquad so\ safe$$

The length of bolt:

$$L = thickness\ of\ material + nut + washers$$

$$L = t_1 + t_2 + 0.8 * D = 2 + 25 + (0.8 * 6) + (2 * 0.15 * 6) = 33.6\ mm$$

$$L > 33.6\ mm$$

8. Roller fixation of second stage: (M5)

Given:

$$F_{Bending} = 21.88\ N$$

$$F_{Shear} = 3.88\ N$$

$$t_1 = 30\ mm$$

$$t_2 = 20\ mm$$

$$t_3 = 0.15 * 5 = 0.75\ mm$$

Check bending safety:

To get maximum stiffness:

- $d = 5\ mm\ , D = 7.5\ mm, t_1 = 25.375\ mm, E = 205GPa$

$$D_1 = 36.8034\ mm$$

$$K_1 = \frac{0.5774 * \ \pi * 205 * 10^9 * 5 * 10^{-3}}{\ln\left(\frac{3.84914 * 10^{-4}}{1.019828 * 10^{-4}}\right)} = 139.886176 * 10^6 \frac{N}{m}$$

- $d = 5\ mm, D = \ D_1 = 32.8034\ mm, t = 4.625\ mm, E = 205GPa$

$$D_2 = 31.46\ mm$$

$$K_2 = 4.115094 * 10^{10} \frac{N}{m}$$

- $d = 5\ mm, D = 8.366\ mm, t = 20\ mm, E = 205GPa$

$$K_3 = \frac{0.5774 * \ \pi * 205 * 10^9 * 5 * 10^{-3}}{\ln\left(\frac{3.43051 * 10^{-4}}{1.20051 * 10^{-4}}\right)} = 1.770829 * 10^9 \frac{N}{m}$$

- $d = 5\ mm, D = 7.5\ mm, t = 0.75\ mm, E = 205GPa$

$$K_4 = \frac{1859304488}{\ln\left(\frac{4.1703 * 10^{-5}}{3.334 * 10^{-5}}\right)} = 8.3073 * 10^9 \frac{N}{m}$$

$$\frac{1}{K_m} = \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3} + \frac{1}{K_4} = 127.259 * 10^6 \frac{N}{m}$$

To get bolt stiffness:

$$K_b = \ K_t = \frac{A_t * \ E_b}{l_t} = \frac{14.2 * 10^{-6} * 205 * 10^9}{50.75 * 10^{-3}} = 57.3596 * 10^6 \frac{N}{m}$$

$$C = \frac{K_b}{K_m + K_b} = 0.3106924$$

Factor of safety guarding against bolt yielding:

$$n_p = \frac{s_P A_t}{Cp + F_i} = \frac{225 * 10^6 * 14.2 * 10^{-6}}{0.3106924 * 21.88 + \left(0.75 * (225 * 10^6 * 14.2 * 10^{-6})\right)} = 1.329561$$

$$n_p > 1$$

Factor of safety guarding against bolt Loading:

$$n_L = \ \frac{s_P A_t - F_i}{Cp} = \frac{225 * 10^6 * 14.2 * 10^{-6} - \ \left(0.75 * (225 * 10^6 * 14.2 * 10^{-6})\right)}{0.3106924 * 21.88}$$
$$= 117.4986$$

$$n_L > 1$$

Factor of safety guarding against joint separation:

$$n_o = \frac{F_i}{p*(1-c)} = \frac{\left(0.75*(225*10^6*14.2*10^{-6})\right)}{21.88*(1-0.3106924)} = 159.46396$$

$$n_o > 1$$

$$n = \min\left(n_o, n_p\right) = 1.329\,, \qquad so\ safe$$

The length of bolt:

$$L = 30 + 20 + 0.75 + (0.8*5) = 54.75\ mm$$

$$L > 54.75\ mm$$

For sheer condition:

$$F_{shear} = 3.88\ N$$

$$F_i = \frac{3.88}{2} = 1.94\ N, \qquad A_t = 14.2\ mm^2\ from\ table\ 8-11\ class\ 5.8, \qquad S_y = 420\ MPa$$

$$n_i = \frac{0.577*\ S_y}{\tau_i}, \tau_i = \frac{F_i}{A_t} = \frac{1.94}{14.2*10^{-6}} = 136.6197\ KPa$$

$$n_i = \frac{0.577*420*10^6}{136.6197*10^3} = 1773.829104, \qquad safe$$

9. Sheet metal of second stage: (M4)

There are two shear forces on it so, I will check for the worst case.

$$F_1 = 27.94\ N\ \ , F_2 = 4.92\ N$$

$$F_i = \frac{4.92}{5} = 0.984\ N, \qquad A_t = 8.78\ mm^2\ from\ table\ 8-11\ class\ 5.8, \qquad S_y = 420\ MPa$$

$$n_i = \frac{0.577*\ S_y}{\tau_i}, \tau_i = \frac{F_i}{A_t} = \frac{0.984}{8.78*10^{-6}} = 112.0728\ KPa$$

$$n_i = 2162.344476, \qquad safe$$

The length of bolt:

$$L = 20 + 1 + 1 + (0.15*2*4) + (0.8*4) = 26.4\ mm$$

$$L > 26.4\ mm$$

3-2-9: Wielding

Welding, technique used for joining metallic parts usually through the application of heat.

Type of Welding:

- Arc welding.
- Laser Welding.
- Resistance Welding.
- Friction Welding.

We used the Arc Welding in our project for many reasons:

- Cheap.
- Available in all workshops
- Welded parts are not loaded with heavy loads.
- Does the purpose.

Type of joint:

- Butt Weld.
- Fillet Weld.
- Edge weld.

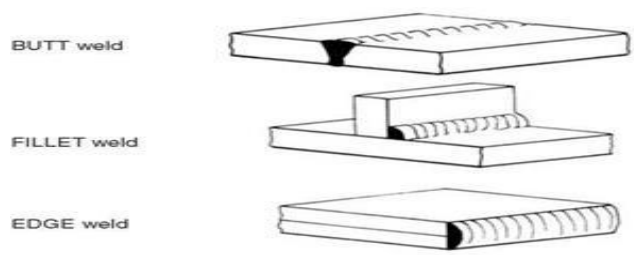


Figure 3-2-9- 1: Types of joints

The following notes are general guidance notes showing methods of calculation of the strength and size of welds. Welded joints are often crucially important affecting the safety of the design systems. It is important that the notes and data below are only used for preliminary design evaluations. Final detail design should be completed in a formal way using appropriate codes and standards and quality reference documents.

Variables related to welded joints:

1. Strength of deposited weld material
2. Type of joint and weld.
3. Size of weld.
4. Location of weld in relation to parts joined.
5. Types of stress to which the weld is subjected.
6. Conditions under which weld is carried out.
7. Type of equipment used for welding.
8. Skill of welder.

Table of Weld Capacities:

The following table is in accord with data in BS 5950 part 1. Based on design strengths as shown in Table 3-2-9-1

$$PL = a.pw$$
$$PT = a.K.pw$$

$$a = weld\ throat\ size.$$

$$K = 1{,}25 \sqrt{} (1{,}5 / (1 + Cos\ 2\ \theta)$$

$$PT\ based\ on\ elements\ transmitting\ forces\ at\ 90o\ i.e.,\ \theta = 45o\ and\ K = 1{,}25$$

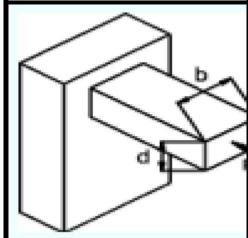
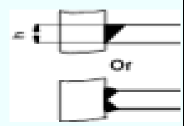
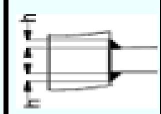
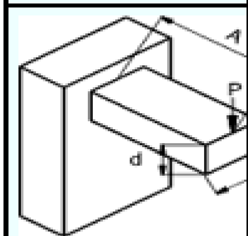
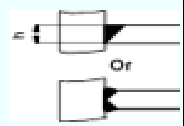
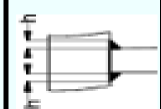
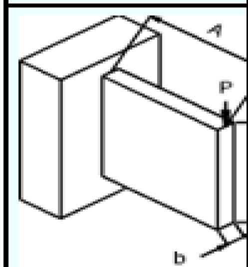
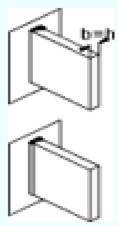
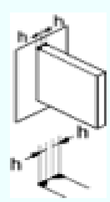
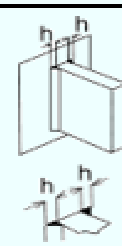
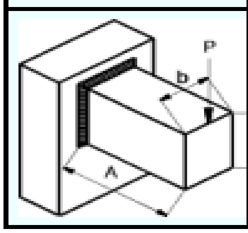
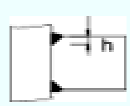
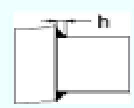
Method of Loading	Weldment	Stress in Weld σ b τ s Weld size (h)	Weldment	Stress in Weld σ b τ s Weld size (h)	Weldment	Stress in Weld τ b τ s Weld size (h)
		$\sigma_t = \frac{P}{b.h}$ $h = \frac{P}{b\ \sigma_t}$		$\sigma_t = \frac{0,5.P}{b.h}$ $h = \frac{0,5.P}{b.\sigma_t}$		$\tau_s = \frac{0,71.P}{b.h}$ $h = \frac{0,71.P}{b.\tau_s}$
		$\sigma_b = \frac{6.P.A}{b.h^2}$ $\tau_d = \frac{P}{b.h}$ $h = \sqrt{\frac{6.P.}{b.\sigma}}$		$x = d^3-(d-2h)^3$ $\sigma_b = \frac{6.P.A.d}{b.x}$ $\tau_s = \frac{P}{2.b.h}$		$x = (d+2h)^3 - d$ $\tau_b = \frac{8,5.P.A.(d+2}{b.x}$ $\tau_s = \frac{0,71.P}{b.h}$
		$\sigma_b = \frac{6.P.A}{h.d^2}$ $\tau_s = \frac{P}{d.h}$ $h = \frac{6.P}{\sigma_b d^2}$		$\sigma_b = \frac{3.P.A}{h.d^2}$ $\tau_s = \frac{P}{2.d.h}$ $h = \frac{3.P.A}{\sigma_b d^2}$		$\tau_b = \frac{4,24.P.A}{hd^2}$ $\tau_s = \frac{0,71.P}{hd}$ $h = \frac{2,121.P.A}{\tau_b d^2}$
				$x = (b-2h).(d-2h$ $y = (b-2h).(d-2$ $\sigma_b = \frac{6.P.A.d}{bd^3 - x}$ $\tau_s = \frac{P}{(bd-y)}$		$x=(b+2h).(d+2h$ $y=(b+2h).(d+2h$ $\tau_b = \frac{8,49.P.A.d}{x-b.d^3}$ $\tau_s = \frac{1,41.P}{(y-bd)}$

Table 3-2-9- 1: Design Strength of Pt and Pl

Design Strength p $_w$ of fillet welds:

Steel Grade	Electrode classification		
	35	43	50
	N/mm^2	N/mm^2	N/mm^2
S275	220	220	220
S355	220	250	250
S460	220	250	280

Table 3-2-9- 2: Design Strength of Pw

Weld Strength Calculations:

First stage:

- **Bar (1):**

$$Load = 650 * Sin(15) = 168.23\,N$$

$$Au = 2(25 + 25) = 100\,mm$$

$$Tb = 0$$

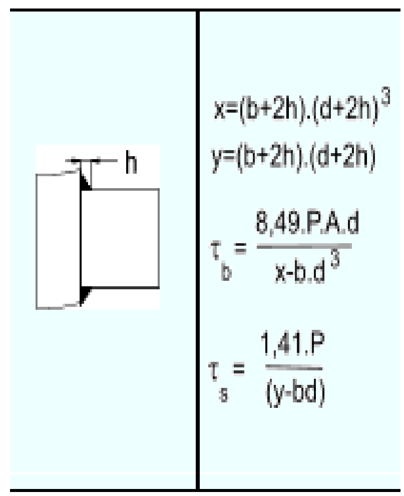
$$Ts = 168.23/100 = 1.68\,MPa$$

$$Tr = Ts$$

$$Pw = 220\,MPa\ from\ table\ of\ \text{“}electrode\ E35\ steel\text{”}$$

$$Factor\ of\ Safy\ \text{“}\eta\text{”} = Pw/Tr = 220/1.68 = 130.95$$

- **Bar (2):**



$$Load = 600 * Cos(15) = 579.55\,N$$

$$A = 300\,mm$$

$$h = 3\,mm$$

$$b = d = 25\,mm$$

$$x = 923521$$

$$y = 961$$

$$Tb = 69.25\,MPa$$

$$Ts = 2.43\,MPa$$

$$Tr = 69.29\,MPa$$

$$Factor\ of\ Safety\ \text{“}\eta\text{”} = Pw/Tr = 220/69.29 = 3.17$$

DC fixation:

$$Load\ =\ m*g=6*10\ =\ 60\ N$$

$$d=b\ =\ 25\ m$$

$$Au=2*(25+25)=100\ mm^2$$

$$Pw=220\ MPa$$

$$Tb\ =\ 0$$

$$Ts\ =\frac{60}{100}=0.6\ MPa$$

$$Tr\ =\ Ts=0.6\ MPa$$

$$Factor\ of\ Safety\ \text{“η”}\ =\ Pw/Tr\ =\ 220/0.6\ =\ 366.66$$

Stepper fixation:

$$Load\ =\ 15\ N$$

$$d=b\ =\ 25\ m$$

$$Au=2*(25+25)=100\ mm^2$$

$$Pw=220\ MPa$$

$$Tb\ =\ 0$$

$$Ts\ =\frac{15}{100}=0.15\ MPa$$

$$Tr\ =\ Ts=0.15\ MPa$$

$$Factor\ of\ Safety\ \text{“η”}\ =\ Pw/Tr\ =\ 220/0.15\ =\ 1466$$

Second stage:

- **Bar (1):**

$$Load = 230 * Cos(80) = 39.94\ N$$

$$Au = 2(20 + 20) = 80\ mm$$

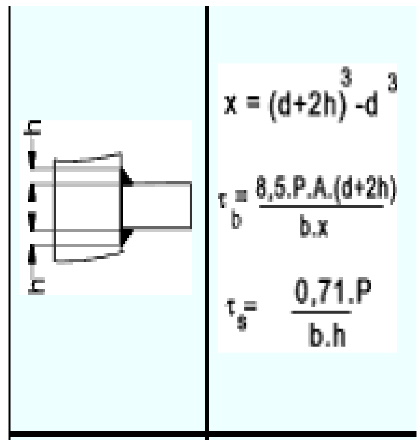
$$Tb = 0$$

$$Ts = 39.94/80 = 0.499 = 0.5\ MPa$$

$$Tr = Ts = 0.5\ MPa$$

$$Factor\ of\ Safety\ \text{“η”} = Pw/Tr = 220/0.5 = 440$$

- **Bar (2):**



$$Load = 11\ N$$

$$A = 30\ mm$$

$$h = 3\ mm$$

$$d = b = 20\ mm$$

$$X = 511600$$

$$Tb = 0.00712\ MPa$$

$$Ts = 0.13\ MPa$$

$$Tr = 0.13\ MPa$$

$$Factor\ of\ Safety\ \text{“η”} = Pw/Tr = 220/0.13 = 1687$$

3-2-10: Motors

Motor is the basic component for any machine or mechanism to move. It common in any embedded system as motor is type of actuator to convert electric signal from controller to mechanical motion, but there are different types of motor so it's important for the system to behave smoothly and without type of failure and that is the important of motor selection.

So, to select suitable motor for our machine we need to keep in mind some points that important for choosing out motor as environment, motor Specs, and motor parameter.

- **ENVIRMONIENT:**
  1. **Ingress Protection (IP):** a two-digit number established by the International Electro Technical Commission, it's a number to protect from dust and water that affect the motor temporarily or permanently as shown in TABLE 3-2-10-1.
  2. **Temperature:** the temperature of surroundings can affect the motor performance and failure in long time run as normal motors work on temperature from 20 to 40 degree, and for more temperature we choose suitable class, the table for class as shown in TABLE 3-2-10-2.
- **SPECS:**
  1. **Life of motor:** some component in motor affects its life span as bearing, brushes, and commutator, so depend on motor if it works for long time and for less maintenance, we can choose motor without either brushes and commutator.
  2. **Size and Weight:** in the design the size and weight will result different type of housing of motor, if the system in portable then we need the motor to be smaller in size and less in wight for example.
  3. **Noise:** there are different types of noise either mechanical or electrical as shown in TABLE 3-2-10-3, and since the noise is different frequency then the unit of electrical frequency is in decibel (dB).
- **PARAMETERS:**
  1. **Speed:** how many revelations does the motor rotate in minuet, for example we have camera that take different shots of product and the product in belt so we need to determine the speed needed for the camera to take 360 view of product.
  2. **Torque:** the main idea of motor is to move a specific mechanism so how mush load is the mechanism that will affect the shaft of motor.
  3. **Starting and stall torque:** the stall is when applying a huge load on motor shaft and the motor doesn't rotate even with its maximum current taken, and starting torque is when at the begging the speed is zero but some application needs high starting torque.
  4. **Duty Cycle:** we need to understand the operation of motor if it will work continuously, work for period of time then off, or work and off periodically, so operation will affect the internal temperature of motor.

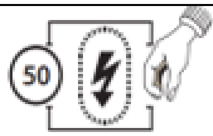
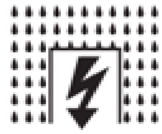
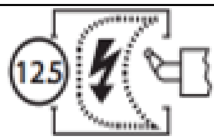
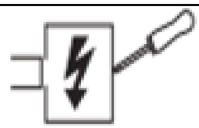
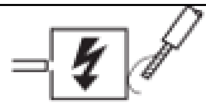
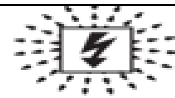
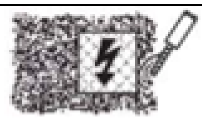
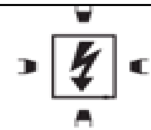
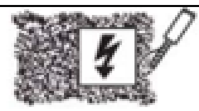
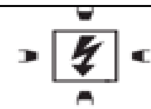
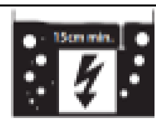
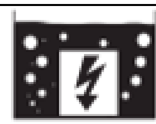
IP Requirements	Example	First digit: Ingress of solid objects	Example	Second digit: Ingress of liquids
0	-	No protection	-	No protection
1		Protected against solid objects over 50mm e.g., hands, large tools.		Protected against vertically falling drops of water or condensation.
2		Protected against solid objects over 12.5mm e.g., hands, large tools.		Protected against falling drops of water, if the case is disposed up to 15 from vertical.
3		Protected against solid objects over 2.5mm e.g., wire, small tools.		Protected against sprays of water from any direction, even if the case is disposed up to 60from vertical.
4		Protected against solid objects over 1.0mm e.g., wires.		Protected against splash water from any direction.
5		Limited protection against dust ingress. (no harmful deposit)		Protected against low pressure water jets from any direction. Limited ingress permitted.
6		Totally protected against dust ingress.		Protected against high pressure water jets from any direction. Limited ingress permitted.
7	-	-		Protected against short periods of immersion in water.
8	-	-		Protected against long, durable periods of immersion in water.

Table 3-2-10- 1: Ingress Protection for motor

CLASS	Maximum winding Temperature	Average working Temperature
A	105 C	55 C
B	150 C	80 C
F	180 C	115 C
H	200 C	130 C
N	220 C	150 C
R	220 C	170 C

Table 3-2-10- 2: Temperature classes for motor

Electrical Noise	Mechanical Noise
The system keeps the motor running, occasional spark occurs between brushes and commutator at the timing of the commutation	Frictional sound caused by brushes and commutator.
when the motor starts from its stalled position, comparably higher current, or a stall current, flows into the windings. Higher current usually causes higher noise	Frictional sound caused by shaft and bearings.
Noise that travels through power cables and connection cables.	Wind that occurs in a motor especially with a built-in cooling fan.

Table 3-2-10- 3: Types of noises for motor

There are different types of motor we can choose depend on multi factor as maintenance, noise, control requirement, and cost as shown in TABLE 3-2-10-4.

And for gear if we are using gear motor or will build on there are two types of gearmotor parallel and right side and the difference between them as shown in TABLE 3-2-10-5.

Comparison of BLDC motor with other motors

Feature	Brushless DC motor	Brushed DC motor	Induction Motor
Mechanical Structure	Field magnets on the stator and rotor are made of permanent magnets	Field magnets on the rotor and stator are made of permanent magnets or electromagnets	Both the rotor and stator have windings but the AC lines are connected to the stator
Maintenance	Low or no maintenance	Periodic maintenance because of brushes	Low maintenance
Speed-Torque characteristics	Flat – Operation at all speeds with rated load	Moderate – Loss in torque at higher speeds because of losses in brushes	Non-linear
Efficiency	High – No losses in the brushes; Stator is on the outer periphery and is thus able to dissipate more heat and produce more torque	Moderate – Losses in the brushes; Rotor is on the inner periphery	Low – Heat and current losses in both rotor and stator; High efficiency Induction motors are also available (higher cost)
Commutation method	Using solid state switches	Mechanical contacts between brushes and commutator	Special starting circuit is required
Speed range	High – No losses in brushes	Moderate – Loses in brushes	Low – Determined by the AC line frequency; Increases in load further reduces speed
Electrical noise	LOW	High – Because of brushes	LOW
Detecting method of rotor's position	Hall sensors, optical encoders, etc.	Automatically detected by brushes and commutator	NA
Direction reversal	Reversing the switching sequence	Reversing the terminal voltage	By changing the two phases of the motor input
Control requirements	A controller is always required to control the commutation sequence	No controller is required for a fixed speed; controller required for variable speed	No controller is required for a fixed speed; controller required for variable speed
System cost	High – Because of external controller requirement	Low	Low

Table 3-2-10- 4: Different type of motor

There is also universal motor but it works with both DC or AC but it purposes for high speed and short in life span, and also high current ripple.

Right side gearmotor	Parallel gearmotor
	
Low efficiency due to bevel gear	High efficiency
Self-backing means no reverse move	No self-backing
Normally smaller in size since shaft is in side	Larger in size

Table 3-2-10- 5: Different type of gearmotor

- **Speed calculation:**

$$N_L = \frac{D}{T} \qquad (3\text{-}2\text{-}10\text{-}1)$$

$$N_m = \frac{N_L * 60}{2\pi R} \qquad (3\text{-}2\text{-}10\text{-}2)$$

- **Acceleration rate:**

Since the motor work for period of time then we chose trapezoidal velocity profile as shown in FIG 3-2-10-1.

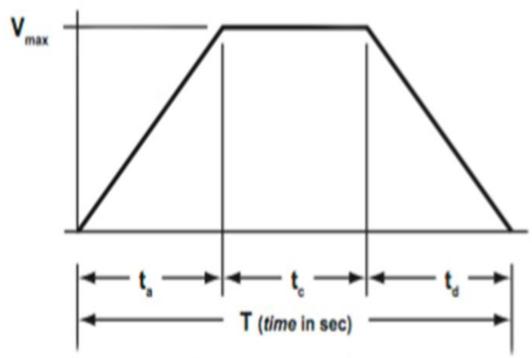


Figure 3-2-10- 1: Acceleration Rate

$$N = N_L * 1 \cdot 5 \qquad (3\text{-}2\text{-}10\text{-}3)$$

$$A = \frac{N}{t_a} \qquad (3\text{-}2\text{-}10\text{-}4)$$

$$t_a = \frac{1}{3} * T \qquad (3\text{-}2\text{-}10\text{-}5)$$

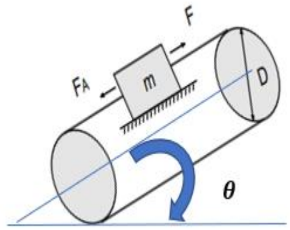
By sub,3-2-10-1,3,5 in 3-2-10-4 we get,

$$A = \frac{4 \cdot 5 * D}{T^2} \qquad (3\text{-}2\text{-}10\text{-}6)$$

- **Torque calculation:**

$$\boldsymbol{T_L = \frac{F}{2*\pi*\eta}*\pi*D = \frac{F*D}{2*\eta*i}} \qquad (3\text{-}2\text{-}10\text{-}7)$$

$$\boldsymbol{F = F_A + mg\cdot(sin\theta + \mu*cos\theta)} \qquad (3\text{-}2\text{-}10\text{-}8)$$



$$\boldsymbol{T_a = J*A} \qquad (3\text{-}2\text{-}10\text{-}9)$$

$$\boldsymbol{T = (T_L + T_a)} \qquad (3\text{-}2\text{-}10\text{-}10)$$

From Eqn, 3-2-10-7 we get,

$$T_L = \frac{106.711 * \ 0.313833}{2*1*1} = 16.744\ N.m$$

From Eqn, 3-2-10-9 we get,

$$T_a = 0.13782617553 * \frac{4.5*1655*10^{-3}}{(8*3600)^2} = 1.237534291*10^{-9}\ N.m$$

From Eqn, 3-2-10-10 we get,

$$T = (16.744 + 1.237534291*10^{-9}) = 16.744\ N.m$$

From Eqn, 3-2-10-2 we get the required speed,

$$N_m = \frac{0.5*60}{\pi*0.313833} = 30.42795559\ RPM$$

So power of motor needed is,

$$P = T*\frac{2*\pi*\ N_m}{60} = 16.744*\frac{2*\pi*\ 30.42795559}{60} = 53.35\ watt$$

The motor selected is PMDC with power of 80 watt and 100 RPM, and torque is 8.78 N.m.

So, the factor of safety of motor is $= \frac{80}{53.35} = 1.499 \approx 1.5$ **, so the motor is safe.**

The speed needed in our project is less than 30.427 RPM, so, by making gear ration 1:4 the motor speed will reduced to 25 RPM, and torque wil be 35.12 N.m.

Figure 3-2-10- 2: Selected PMDC motor

For rejection process we don't need any continuous movement, and high speed for specific angle so we are gone use either servo or steeper motor, from the comparison as shown in TABLE 3-2-10-6.

Servo	Stepper
Operate in a closed loop: have an internal feedback[7].	Operate in an open loop: no feedback and thus are more error-prone
RC Servo motors are limited to 0-180 degrees of movement and require physical and electrical modification in order to be able to move in 360 degrees.	Stepper motors do not have this limit.
Costly	Cheaper
Maintain the torque in high rotational speeds	lose torque in high rotational speeds

Table 3-2-10- 6: Servo vs Stepper

For calculation torque load is the same rule since it doesn't depend on motor but the accelerating torque and speed are different.

For Speed:

$$N_L = \frac{D}{T - t} \qquad (3\text{-}2\text{-}10\text{-}11)$$

For accelerating torque:

$$T_a = \frac{J_0 * i^2 + J_L}{9 \cdot 55} * \frac{Nm}{t} \qquad (3\text{-}2\text{-}10\text{-}12)$$

For rejection motor:

To get the needed torque,

$$T_L = m * g * \frac{L}{2} = 0.51 * 9.81 * 0.15 * \cos(10) = 0.7245\ N.m$$

From Eqn, 3-2-10-9 we get,

$$T_a = 0.00625110149 * \frac{4.5 * 1655 * 10^{-3}}{(8 * 3600)^2} = 5.612832555 * 10^{-11}\ N.m$$

From Eqn, 3-2-10-10 we get,

$$T = (0.7245 + 5.612832555 * 10^{-11}) = 0.7245\ N.m$$

The speed will not be measured since it doesn't matter, the motor is used to rotate 90 degrees counter clock wise to ensure the rotten orange in the waste box, and since only 90 degrees is need so, the selected stepper motor will be full step two phase.

Figure 3-2-10- 3: Selected Stepper Motor

Where,

$\boldsymbol{F}$**:** is the force of moving object in “Newton”

$\boldsymbol{\eta}$**:** is efficiency of motor

$\boldsymbol{F_A}$**:** is the external force act on object in “Newton”

$\boldsymbol{\theta}$**:** is the angle of inclination of mechanism in “degree”

$\boldsymbol{\mu}$**:** is the friction of coefficient of sliding surface

$\boldsymbol{J}$**:** is the total inertia of system in “$Kg.m^2$”

$\boldsymbol{T_L}$**:** is the load torque act on system in “$N.m$”

$\boldsymbol{T_a}$**:** is the accelerating torque act in acceleration of motor in “$N.m$”

$\boldsymbol{T}$**:** is the total torque multiply by factor of safety in “$N.m$”

N: is maximum speed

t_a: is the distance of accelerating speed

A: is the accelerating rate

N_L : is the required speed of load in “$\frac{m}{s}$”

D : distance in “meter”

T : time taken for object from start to reach end in “second”

N_m : is the speed of motor in “rpm”

R : is the radius of roller used in belt in “meter”

t: is the time taken in accelerating rate in “s”.

J_0: is the moment of inertia of rotor in “$kg.m^2$“.

J_L: is the moment of inertia of load in “$kg.m^2$”.

L: length of rejection gate plate equal to 30 cm

m : maximum mass of orange equal to 0.5 kg

g : gravity acceleration equal to 9.81 $\frac{m}{s^2}$

3-2-11: First stage Calculation

DC Motor Fixation:

The fixation of DC motor consists of three parts, welded with each other, [bending sheet metal, and two rips] as shown in Figure 3-2-11-1.

The bending sheet metal connected with DC motor with 4*M6 bolts and connected with base with 4*M6 bolts.

The material selected for DC motor fixation is steel 1010, hot rolled, sheet metal with thickness of 2mm.

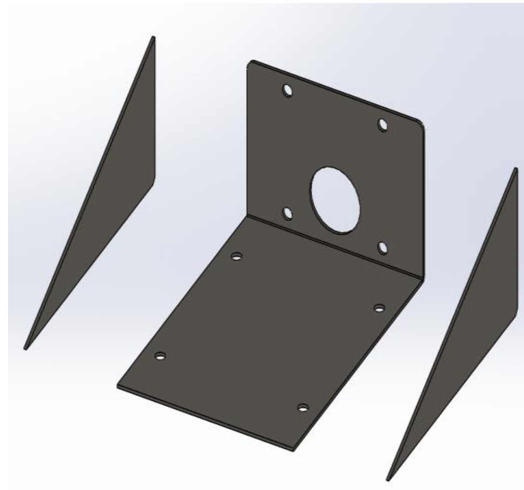


Figure 3-2-11- 1: DC motor fixation

Using solid works simulation analysis:

The maximum stress on DC motor fixation is $s_{max} = 102\ MPa$

The yield strength of material is $s_y = 180\ MPa$

The factor of safety for DC motor fixation is $n = \frac{s_{max}}{s_y} = 1.76,\ safe$

The material displacement for DC motor fixation is $0.0142\ mm$, this displacement is acceptable.

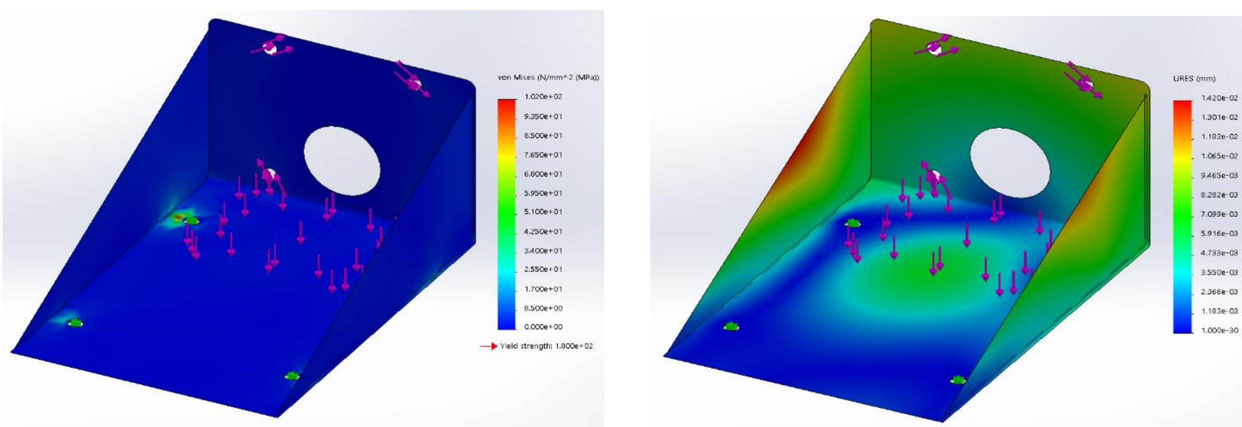


Figure 3-2-11- 2: Stress and Displacement analysis for Dc Motor Fixation

Rejection Motor Fixation:

The fixation of Stepper motor consist of sheet metal has two bending edges.

The stepper motor fixation connected to stepper motor with 4*M5 bolts and connected to base with 2*M5 bolts.

The material selected for stepper motor fixation is steel AISI 1010, hot rolled, sheet metal with thickness of 2 mm.

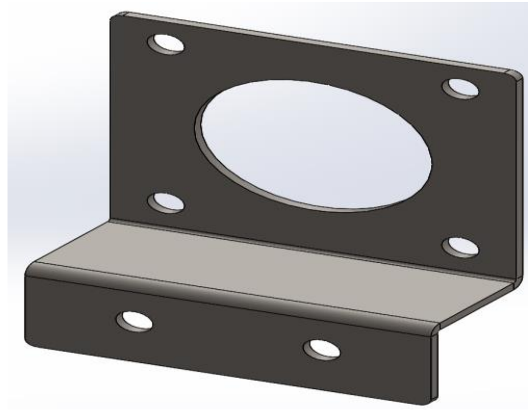


Figure 3-2-11- 3: Rejection Motor Fixation

Using solid works simulation analysis:

The maximum stress on DC motor fixation is $s_{max} = 23.17\ MPa$

The yield strength of material is $s_y = 180\ MPa$

The factor of safety for DC motor fixation is $n = \frac{s_{max}}{s_y} = 7.77,\ safe$

The material displacement for DC motor fixation is $0.01457\ mm$, this displacement is acceptable.

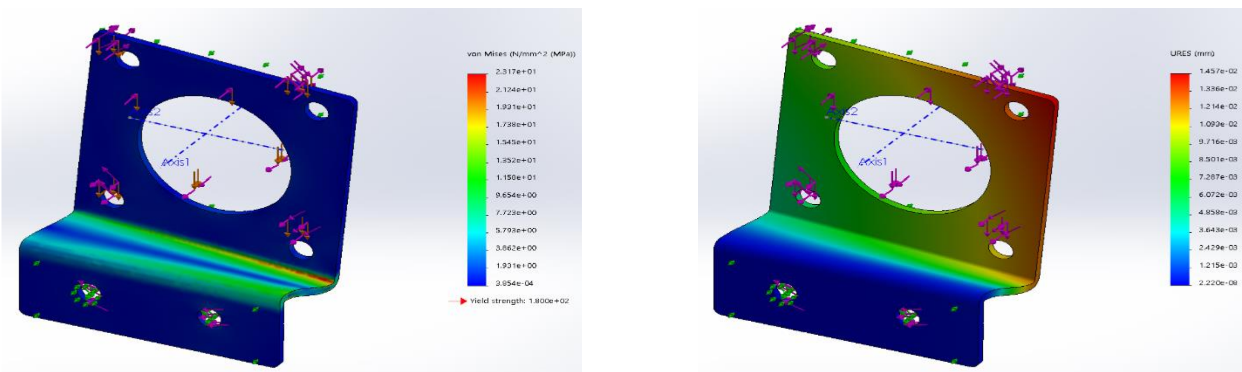


Figure 3-2-11- 4: Stress and Displacement analysis for Rejection Motor Fixation

Rejection Side Part:

It consists of Sheet metal welded with the base of first stage First part.

The material selected for this part is steel ASIS 1010, hot rolled, sheet metal with thickness of 1mm.

It doesn’t need any type of stress analysis since the part doesn’t applied to load.

Figure 3-2-11- 5: Rejection Side Part

Rejection Gate Plate:

The rejection gate plate consists of sheet metal with two bending edges to strength the plate.

The rejection gate plate connected to rejection shaft with 2*M4 bolts.

The material selected to rejection gate plate is steel AISI 1010, hot rolled, sheet metal with thickness of 2mm.

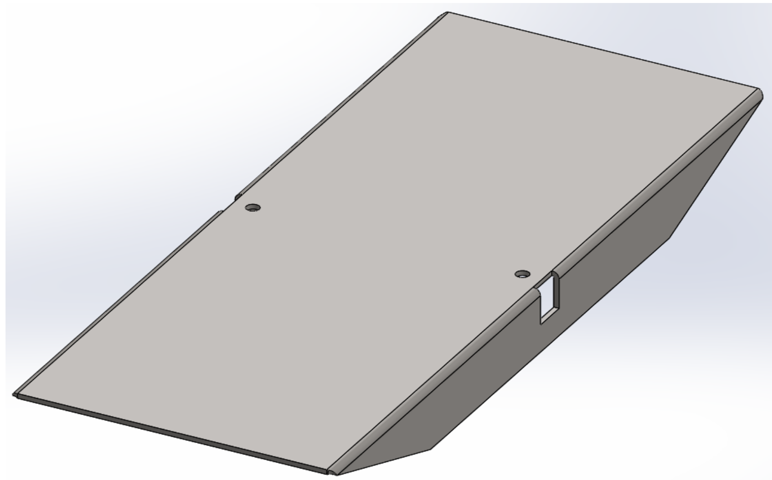


Figure 3-2-11- 6: Rejection Gate Plate

Using solid works simulation analysis:

The maximum stress on DC motor fixation is $s_{max} = 8.122\ MPa$

Because the part subjected to sudden load, $s_{max} = 1.5 * 8.122 = 12.183\ MPa$

The yield strength of material is $s_y = 180\ MPa$

The factor of safety for DC motor fixation is $n = \frac{s_{max}}{s_y} = 14.77,\ safe$

The material is safer for this part, and the thickness of material can be reduced but this thickness to reduce the cost of sheet metal because most of the design parts are 2 mm.

The material displacement for DC motor fixation is $0.02587\ mm$, this displacement is acceptable.

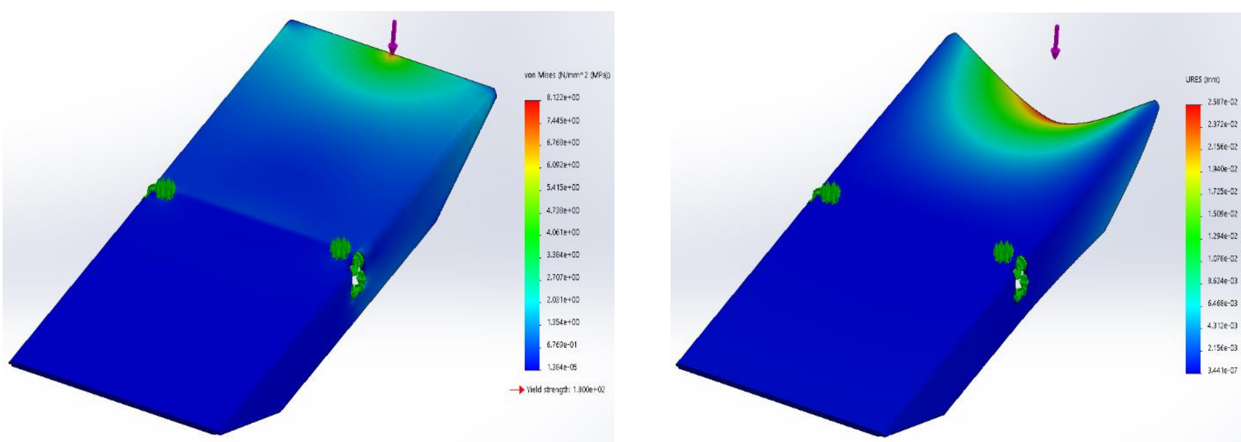


Figure 3-2-11- 7: Stress and Displacement analysis for Rejection Gate Plate

Rejection Dropped Plate:

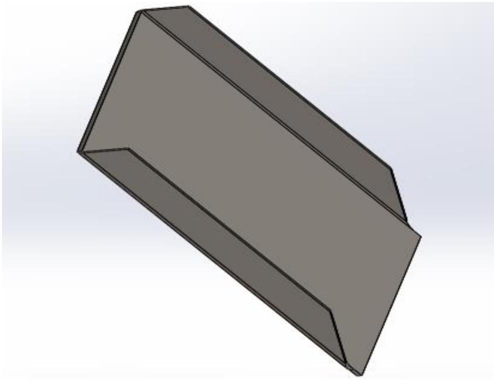


Figure 3-2-11- 8: Rejection Dropped Plate

It consists of sheet metal with two bending edges and welded with the base.

The material selected for this part is AISI 1010, hot rolled, sheet metal with thickness of 2 mm.

Using solid works simulation analysis:

The maximum stress on DC motor fixation is $s_{max} = 0.3729\ MPa$

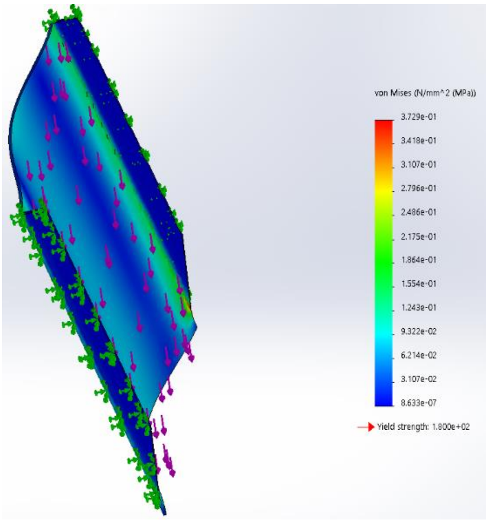
Because the part subjected to sudden load, $s_{max} = 1.5 * 0.3729 = 0.7458\ MPa$

The yield strength of material is $s_y = 180\ MPa$

The factor of safety for DC motor fixation is $n = \frac{s_{max}}{s_y} = 241,\ safe$

The material is safer for this part, and the thickness of material can be reduced but this thickness to reduce the cost of sheet metal because most of the design parts are 2 mm.

The material displacement for DC motor fixation is $9.1 * 10^{-4}\ mm$, this displacement is acceptable



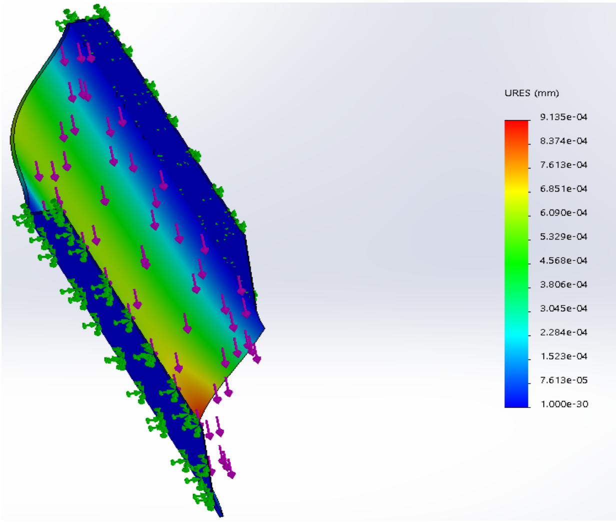


Figure 3-2-11- 9: Stress and Displacement analysis for Rejection Dropped Plate

Design of the Camera box with Sensor Fixation:

For the Design of camera box, we get the length of box from the distance between the center of two orange $25.8\ cm$, to ensure that only one orange will be in the camera room.

As for the height we get it from the suitable height the range of camera will be suitable, so the height will be $h =\ 21.04\ cm$, with thickness of $6\ mm$, is more suitable for box strength and availability in markets.

The design of box was selected to be suitable for 2D laser cutting so it will be easier in assembly and disassembly.

The 3 circles were made for sensor proximity sensor dimension.

Sensor Dimensions: (16mm x 8mm).

And due to the inclination of our project and the curvature of the chain, by making an easy way to manipulate the sensor position by the bolts and washer.

By making a vertical slot that can manipulate the high and a horizontal slot that can manipulate the position of the sensor.

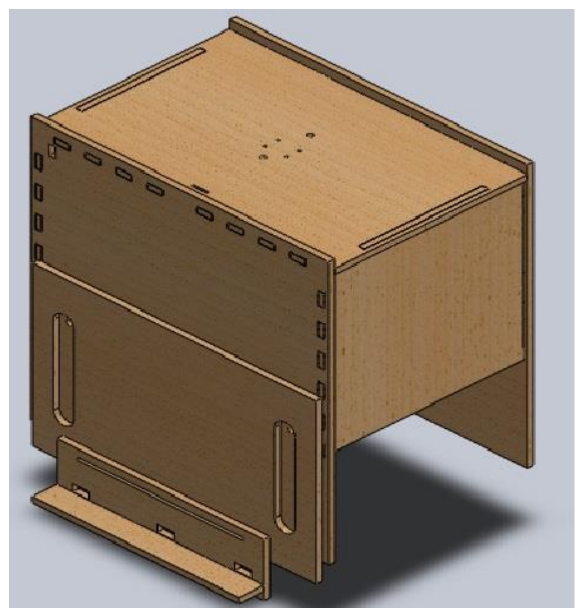


Figure 3-2-11- 10: Design of camera box and Sensor fixation

Parts of chain between two group of sorting rollers:

$d_{o.o}$ must be greater than 0.5 perimeter of largest orange plus diameter of largest orange to ensure the orange rotation, and $d_{c.c}$ must be multiple of 2 pitches.

$$perimter\ of\ largest\ orange = \pi\, d_2$$

$$d_{o.o} > 0.5 * \pi\, d_2 + d_2$$

$$d_{c.c} = n_2 * 2 * p$$

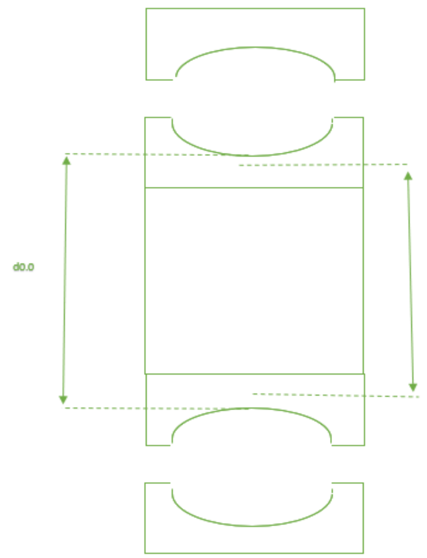
$$d_{o.o} = d_{c.c} + c\left(\frac{c - l_3}{2}\right)$$

$$n_2 * 2 * p + c - l_3 > 0.5 * \pi\, d_2 + d_2$$

$$n_2 * 2 * 31.75 + 127 - 103 > 0.5 * \pi\, 100 + 100$$

$$n_2 > 3.67, \quad n_2 = 4$$

$$d_{c.c} = 254\ mm$$



The distance between two group of rollers filled with three group of sheet metal represents the chain outer links.

Every group consists of three sheets metal parts has bending edges.

The three parts are group connected with each other with 4-M3 bolts and connected with chain with 4 pins and 8 E-clips.

The material selected for this part is steel AISI 1010, hot rolled, sheet metal with thickness of original outer links which is 2 mm.

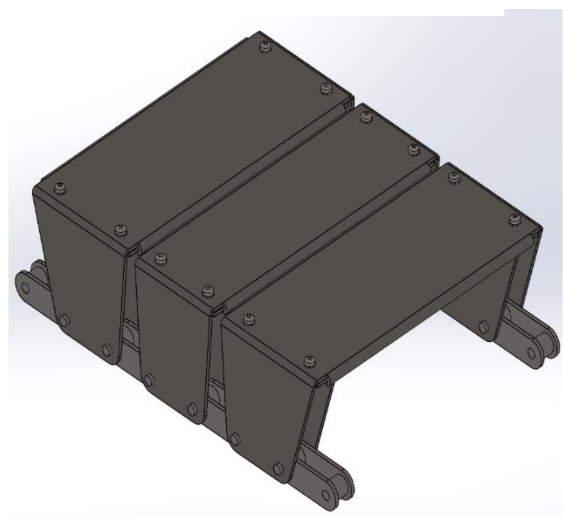


Figure 3-2-11- 11: Parts of chain between two group of sorting rollers

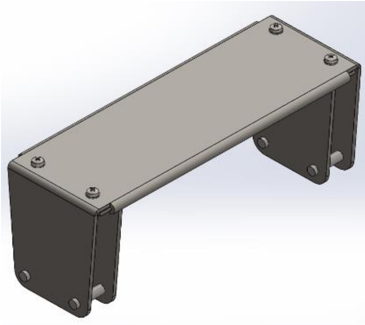


Figure 3-2-11- 12: First Group

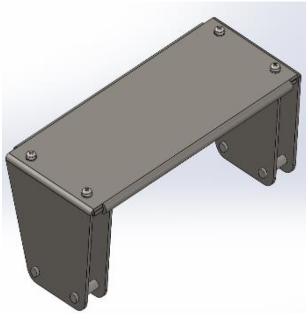


Figure 3-2-11- 13: Second Group

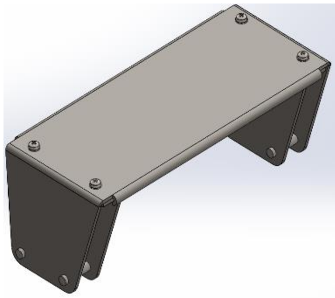


Figure 3-2-11- 14: Third Group

Using solid works simulation analysis:

The maximum stress on it is $s_{max} = 73.27\ MPa$

Because the part subjected to sudden load, $s_{max} = 1.5 * 73.27 = 109.905\ MPa$

The yield strength of material is $s_y = 180\ MPa$

The factor of safety for this part is $n = \frac{s_{max}}{s_y} = 1.64,\ safe$

The material displacement for this part is $0.2453\ mm$, this displacement is acceptable.

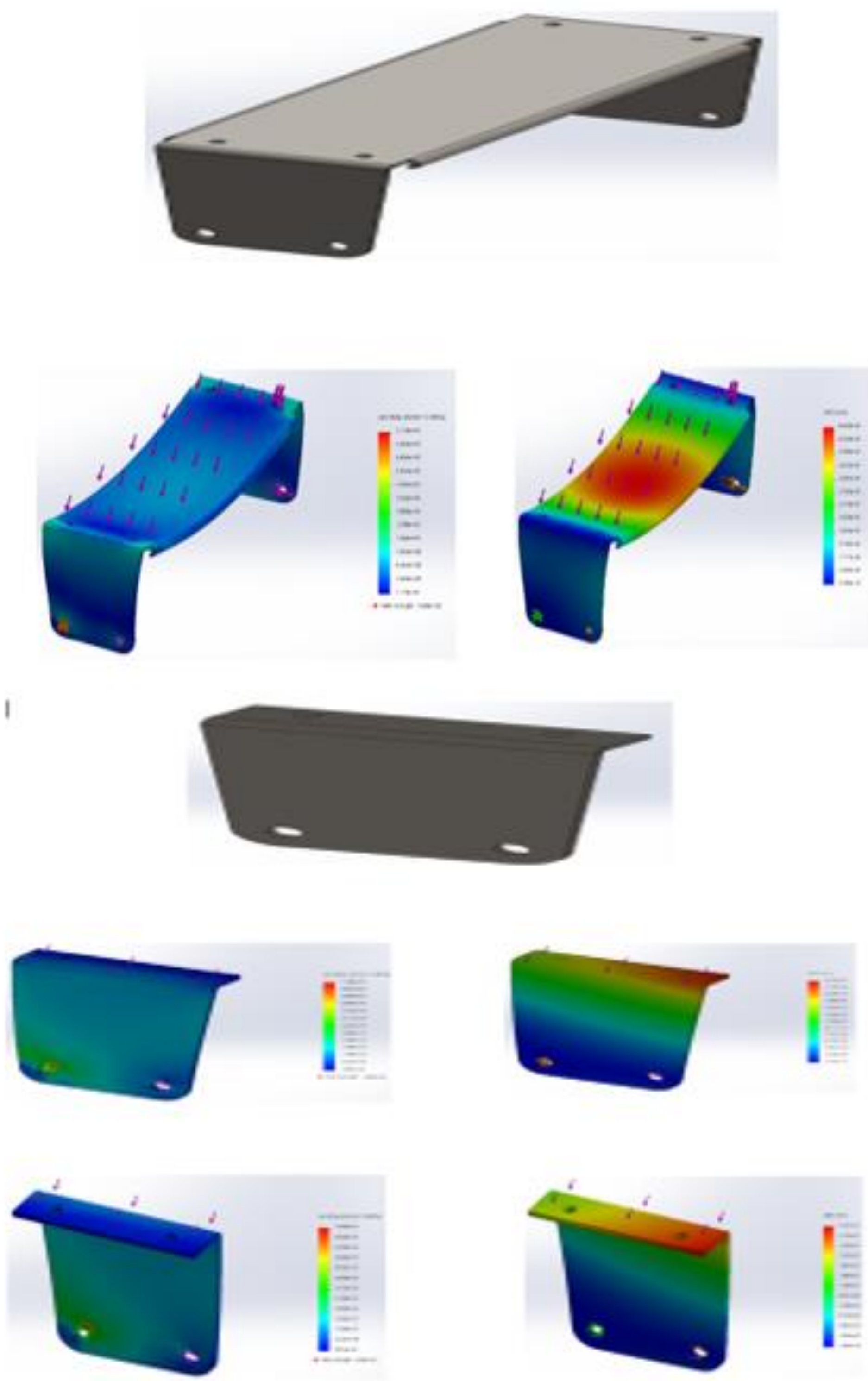


Figure 3-2-11- 15: Stress and Displacement analysis for First Part

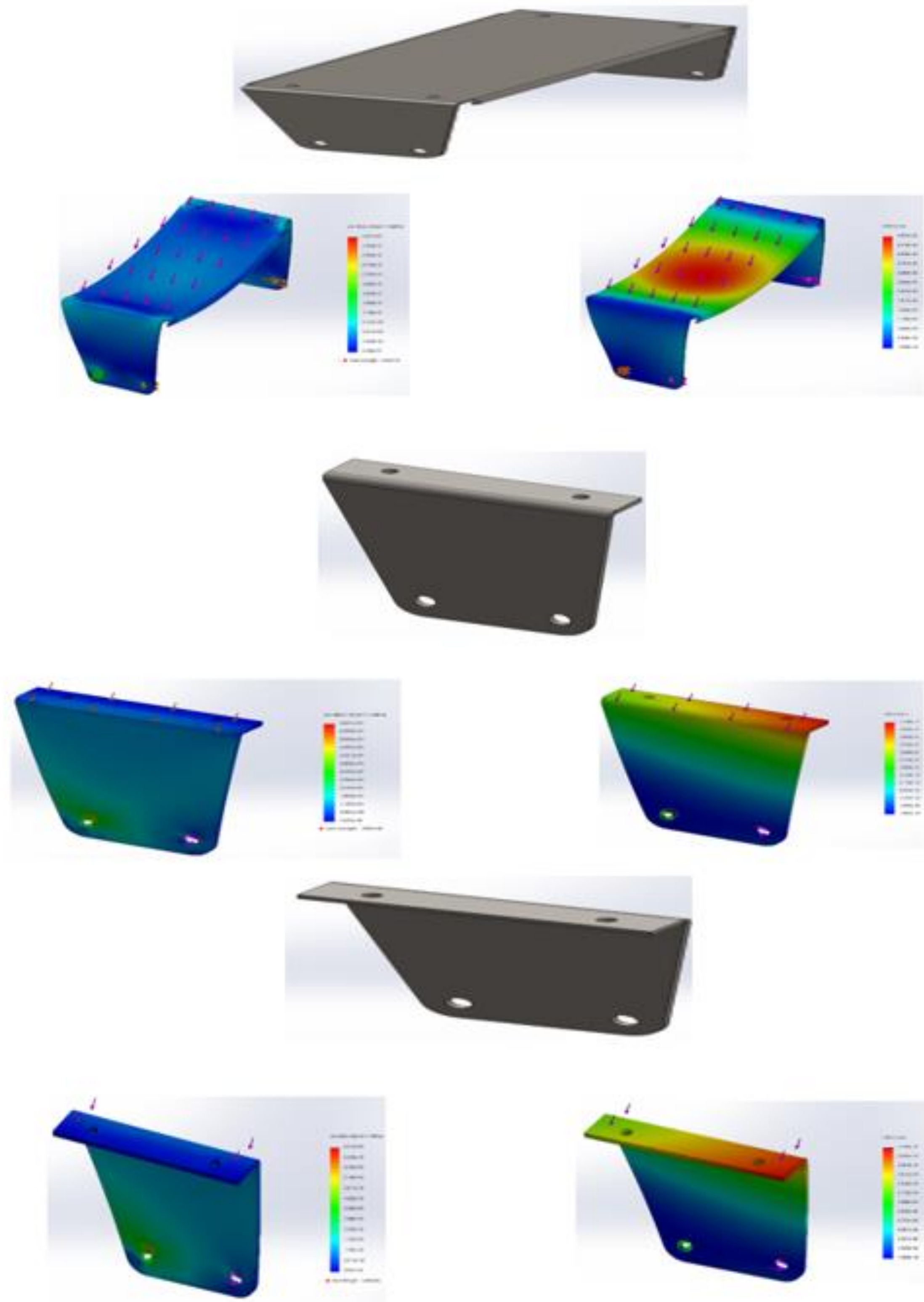


Figure 3-2-11- 16: Stress and Displacement analysis for Second Part

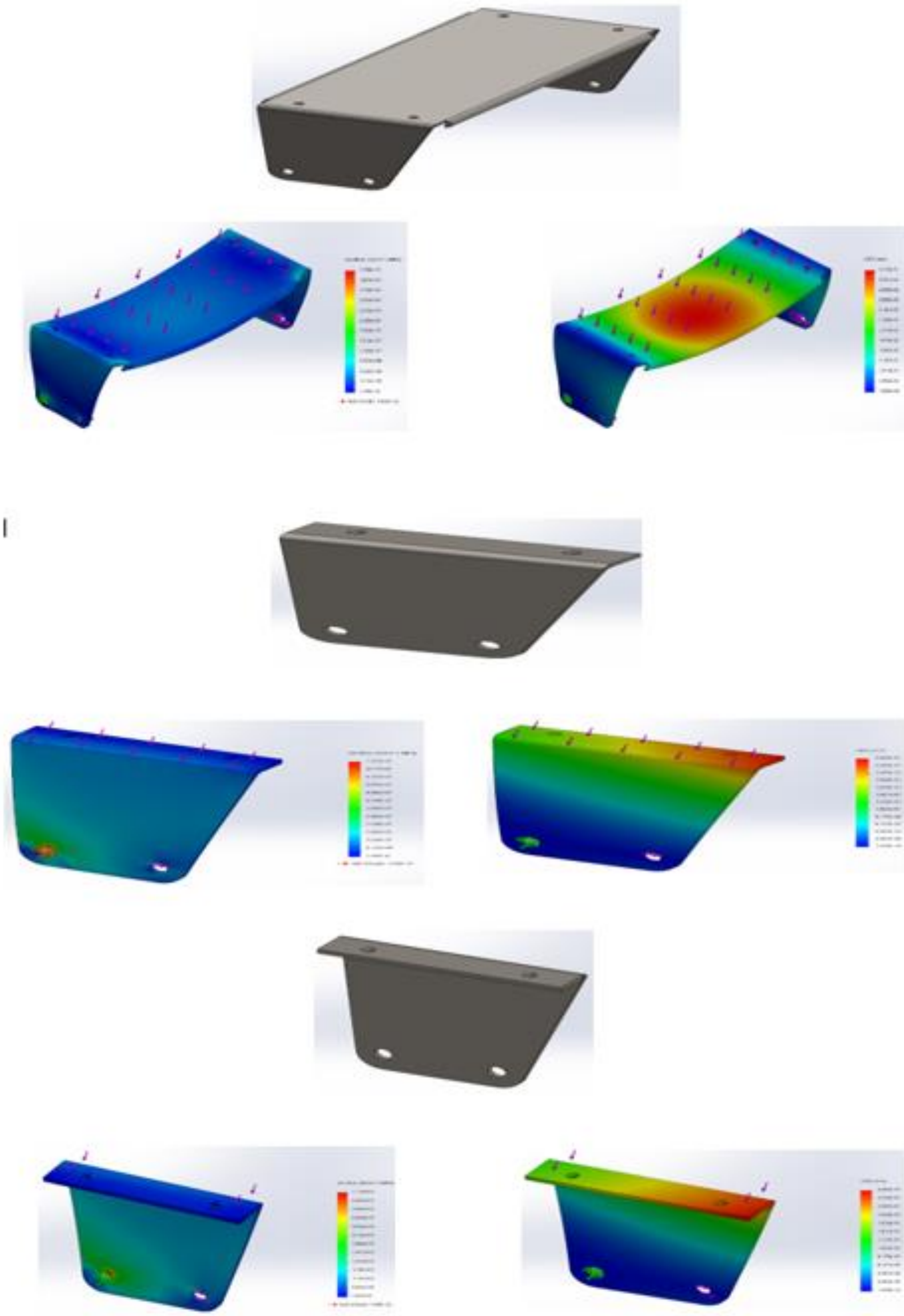


Figure 3-2-11- 17: Stress and Displacement analysis for Third Part

First stage base and Bearing Fixation:

The material selected for this part is AISI 1020, cold rolled, square bare $2.5 * 2.5\ cm^2$.

The base parts connected with each other with welding and the bearing fixation connected with base through 4*M6 bolts.

The maximum bolt used in it is M10, so the cross section is

$$Section\ width\ of\ bar\ must \geq 2.5 * 10 = 25\ mm$$

$$so\ the\ bar\ dimensions\ slected\ is\ 25mm * 25mm * 2mm$$

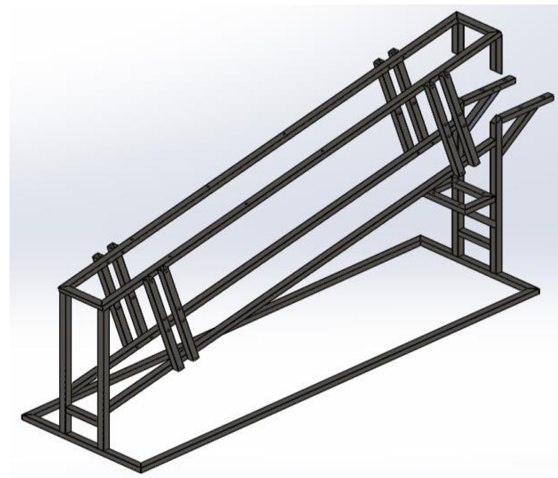


Figure 3-2-11- 18: First stage base and Bearing Fixation

Using solid works simulation analysis:

The maximum stress on it is $s_{max} = 150.6\ \ MPa$

Because the part subjected to sudden load, $s_{max} = 1.5 * 150.6 = 225.6\ MPa$

The yield strength of material is $s_y = 350\ MPa$

The factor of safety for this part is $n = \frac{s_{max}}{s_y} = 1.55,\ \ safe$

The material displacement for this part is $1.926\ mm$, this displacement is acceptable

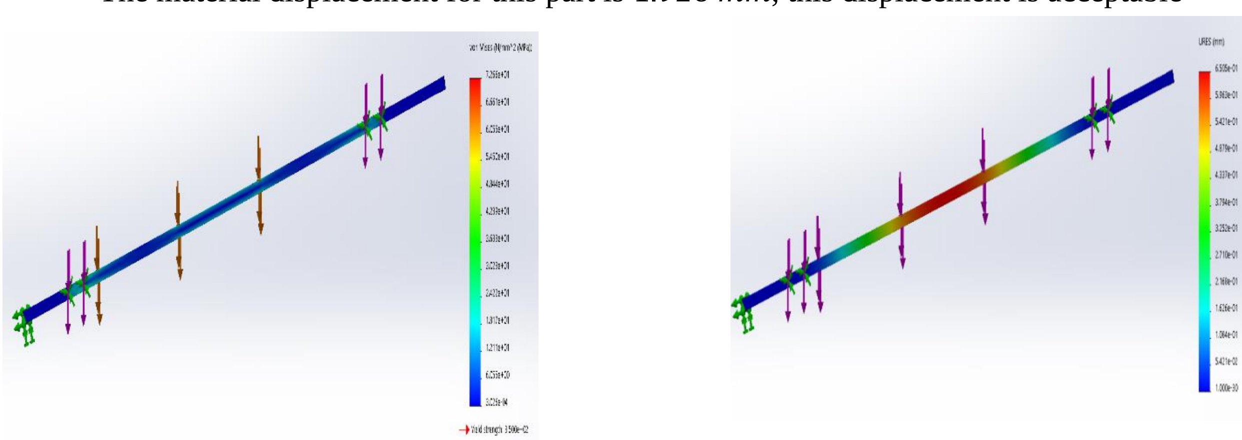


Figure 3-2-11- 19: Stress and Displacement analysis for top part in base

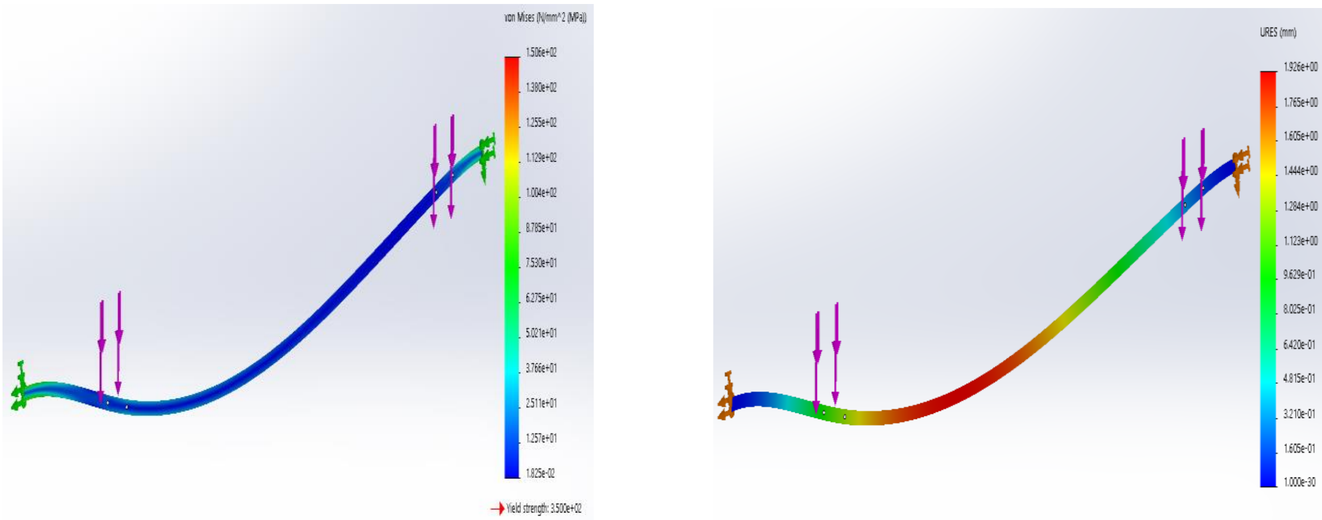


Figure 3-2-11- 20: Stress and Displacement analysis for medium part in base

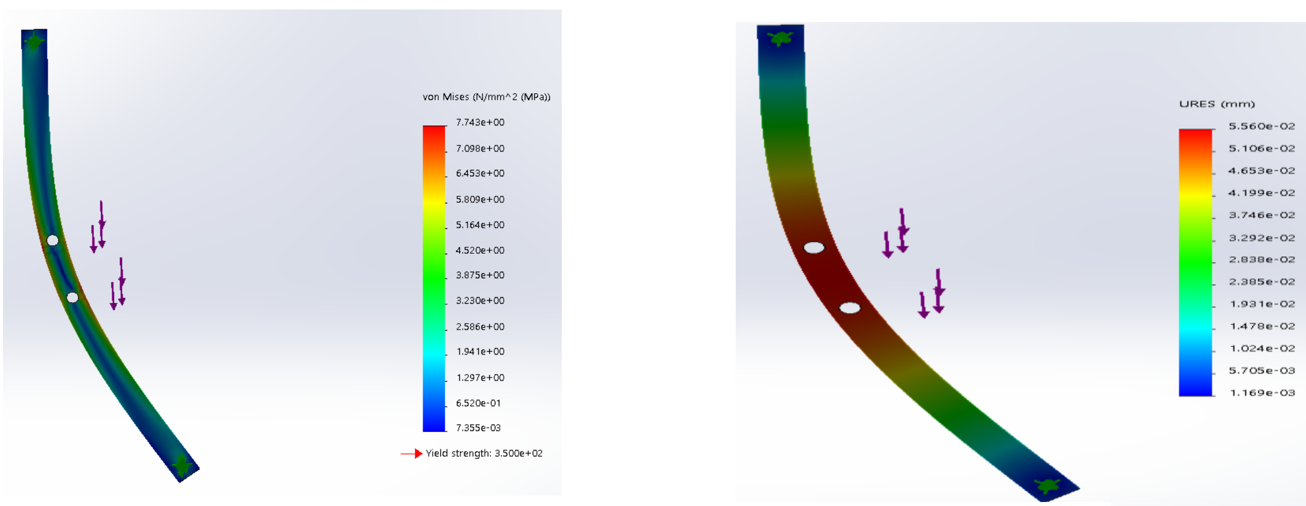


Figure 3-2-11- 22: Stress and Displacement analysis for Bearing Fixation in base

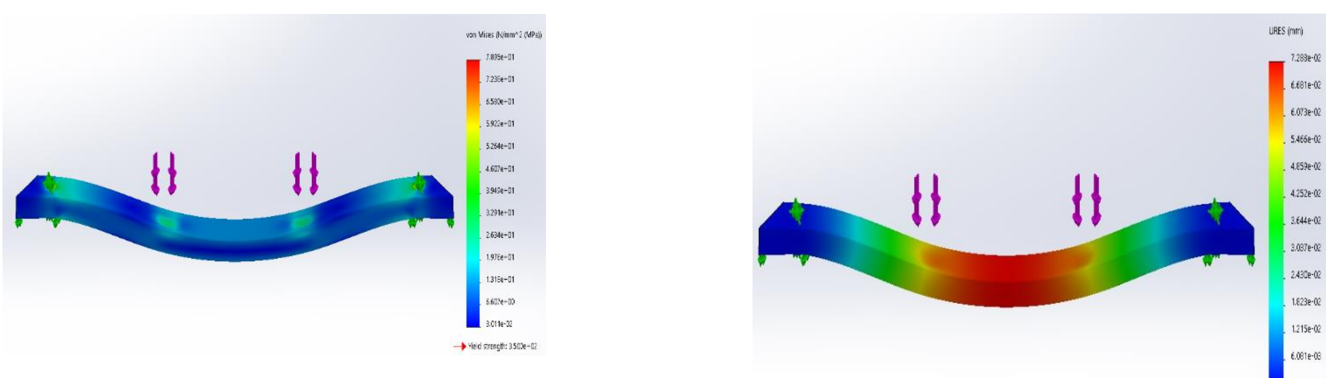


Figure 3-2-11- 21: Stress and Displacement analysis for base width

Control Panel:

It's a metallic box contains everything needed to control our project.

The components that the control panel will hold are,

1. PLC XBC- DN20SU
2. Coolant Fan (12cm x 12cm)
3. Power supply 12v
4. Circuit breaker
5. DC Motor Driver Single Channel with Double BTS7960 43A H-bridge High-power Module
6. Stepper Motor Driver tb6600
7. PCP (5cm x 5cm) & (8cm x 9cm) & (4cm x 4cm)
8. Conta Clip
9. LM2596 DC to DC Buck Converter 3 A
10. HMI eXP 40 TTA
11. Emergency Switch
12. Indicator lamp (availability of electricity).

The layout of Control Panel.

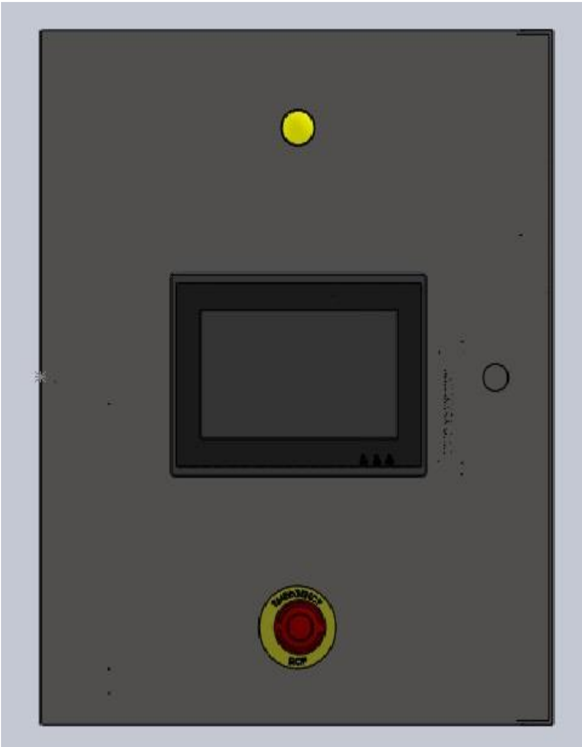


Figure 3-2-11- 23: Layout of control panel door

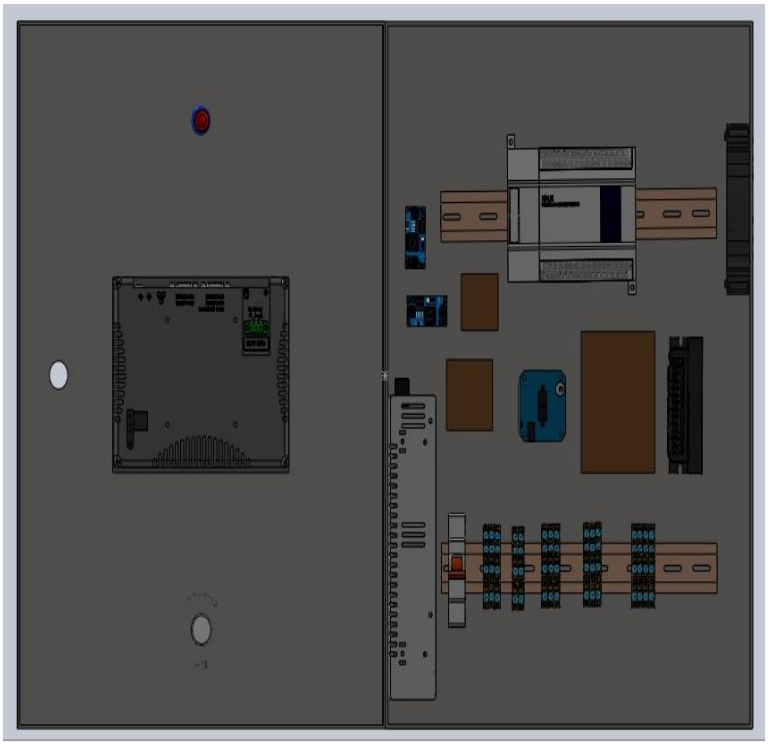


Figure 3-2-11- 24: Layout of control panel

The Fixation of the control panel:

The control panel must be visualized by the eye sight, So it's attached to the body of the 1st stage by bolts and the high of the fixation must be large.

So, the dimensions of the fixation: (150cm x 35cm x 15cm). {High, Length, thickness}.

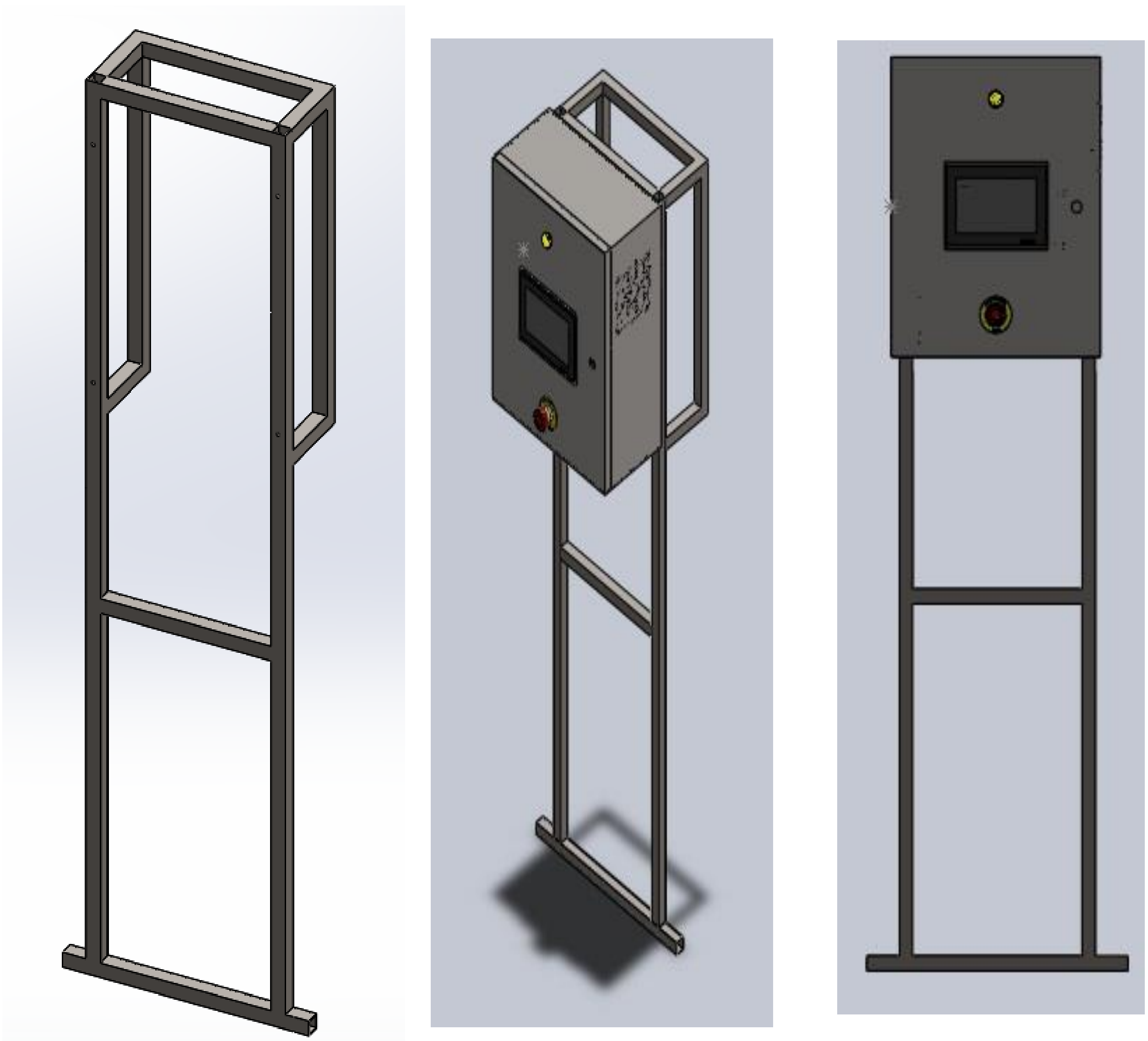


Figure 3-2-11- 25: Control Panel Fixation

3-2-12: Second stage calculation

The dimensions of the orange's box is 48*32*20 cm (W*L*H) and the second stage consist of 5 stages so we have 5 boxes, so the length is 5*320=1600 mm. For the fixation of rolls the length increase 40*4+40=200mm so the total length is 1800 mm so length of slope line is 1800/cos(x) mm now the target is calculating the angle of slope. From dynamic system of orange as shown in figure 3-2-11-1 conclude that:

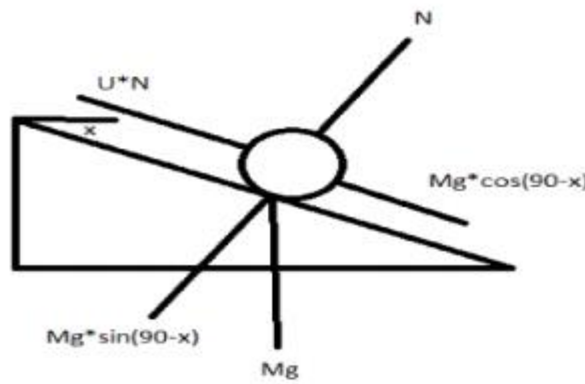


Figure 3-2-12- 1: Analysis of orange slop

From Newton's second law we get,

$$\Sigma F = Ma$$

$$Mg * cos(90 - x) - U * N = M * a \quad (3\text{-}2\text{-}11\text{-}1)$$

$$N = Mg * sin(90 - x) \quad (3\text{-}2\text{-}11\text{-}2)$$

By substituted equation 3-2-11-2 in 3-2-11-1 we get,

$$\cancel{M}g * cos(90 - x) - U * \cancel{M}g * sin(90 - x) = \cancel{M} * a \quad (3\text{-}2\text{-}11\text{-}3)$$

- Assuming the time will take the orange to reach to the last stage (stage number five) is 4 seconds.
- The total distance of sloping line is 1800/cos(x) mm.
- The initial velocity of orange Vx = 0.358.

From the newton's law,

$$s = Vx * t + 0.5 * a * t^2 \quad (3\text{-}2\text{-}11\text{-}4)$$

$$\frac{1.8}{cos(x)} = (0.358 * 3) + (0.5 * a * (3)^2)\ so \ldots$$

$$a = \frac{\left(\frac{1.8}{cos(10)} - 1.074\right)}{4.5} \frac{m}{s^2} \quad (3\text{-}2\text{-}11\text{-}5)$$

By substituted equation 3-2-11-3 in 3-2-11-5 we get,

$$g * cos(90 - x) \; - \; U * g * sin(90 - x) \; = \frac{\left(\frac{1.8}{cos(10)} - 1.074\right)}{4.5}$$

$$9.8 * cos(90 - x) - \; 0.15 * 9.8 * sin(90 - x) \;\; = \left(\frac{1.8}{8} * cos(x)\right) \qquad (3\text{-}2\text{-}11\text{-}6)$$

By solving the equation (3-2-11-6) the angle $x \; = \; 9.49 \; degree \; = \sim 10 \; degree$

So, the acceleration = a= $\frac{\left(\frac{1.8}{cos(10)} - 1.074\right)}{4.5} \; = \; 0.167 \; \frac{m}{s^2}$

And the final velocity = $V \; = \; Vx + a * t \; = \; 0.358 + (0.167 * 3\,) \; = \; 0.86 \;\; \frac{m}{s}$

Finally, the sloping angle of stage is 10 degree that can reach the orange to the final stage in 4 seconds.

…………………………………………………

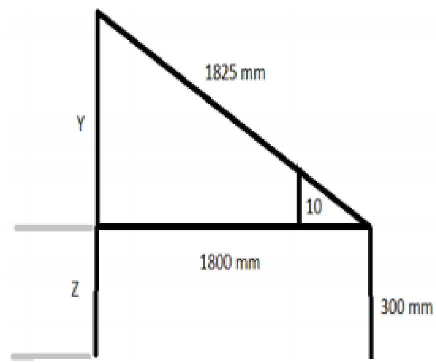


Figure 3-2-12- 2: The length of stage legs

Bars length:

$The\ long\ leg\ distance\ of\ stage \;\; = \; Y + Z$

$Y \; = 1800 * tan(10) = 317.39mm\ The\ height\ of\ box\ is\ 200\ mm\ so\ ..$

$Z \; = 300m\ with\ tolerance\ 10\ cm$

$So\ the\ total\ length\ of\ leg \;\; = \; 317.39 + 300 \; = \; 617.39mm$
$= \sim 617mm$

Roller length:

The length of the roll $= \frac{320}{cos(10)} = 325mm$ and the length is increase due to the fixation of it by $40 \; mm$ to became the total length of roll $365 \; mm$.

Roller Diameter:

The diameter of the roller was chosen because of the diameter of the screw (M5) and I needed the head of the nail to be submersible so as not to scratch the oranges it would move, and it have diameter 10 mm and therefore the diameter of the roller chose to be 30 mm.

Where,

M: mass of orange.

g: gravity acceleration

N: normal force on orange

U: friction coefficient of steel

X: the slope angle of the stage

S: the total distance of slope

a: acceleration of orange

v: velocity of orange

v_x: initial velocity of orange

T: total time has taken by orange to reach to last stage

Stress Analysis of parts:

The one roll is exposed to half weight of orange (2.41 N) that can stress on the roll.

And according to stress analysis the part is safe.

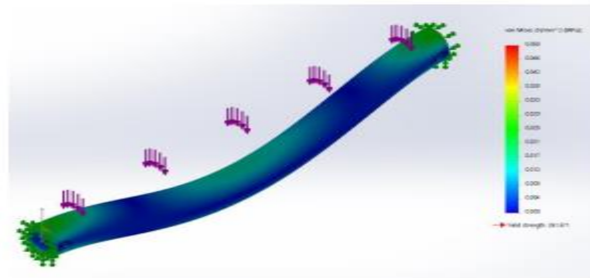


Figure 3-2-12- 3: Stress Analysis on Roll

The legs of base of stage are exposed to total weight of stage (rolls and roll bases and frame and sheet metal).

The small leg is weakest part and exposed to all weight divided by 4 (66 N).

According to stress analysis the small leg is safe and through that all the legs are safe.

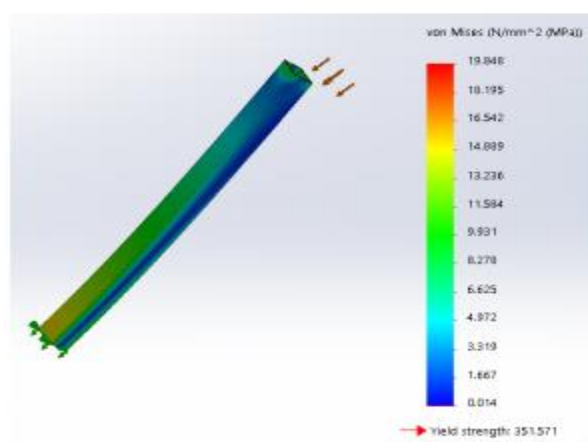


Figure 3-2-12- 4: Stress Analysis on Small Leg of Stage

The bases of rolls are exposed to the half weight of roll and quarter weight of orange.

The one part is exposed to the half weight of roll and the orange (11 N).

According to stress analysis on the small base of roll the part is safe and consequently the all bases of roll are safe.

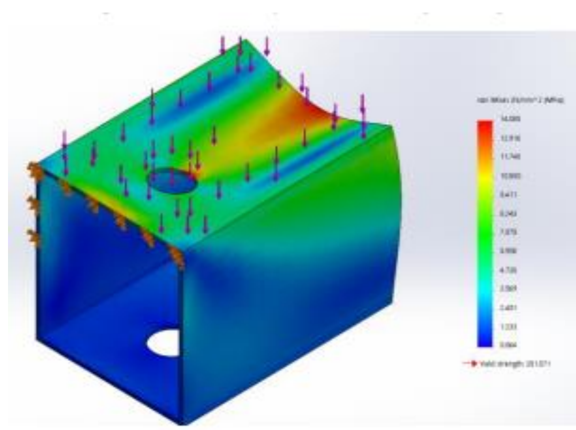


Figure 3-2-12- 5: Stress Analysis on The Base of Roll

The base of the basket exposed to the half weight of 5 box (367.5 N).

According to stress analysis the part is safe.

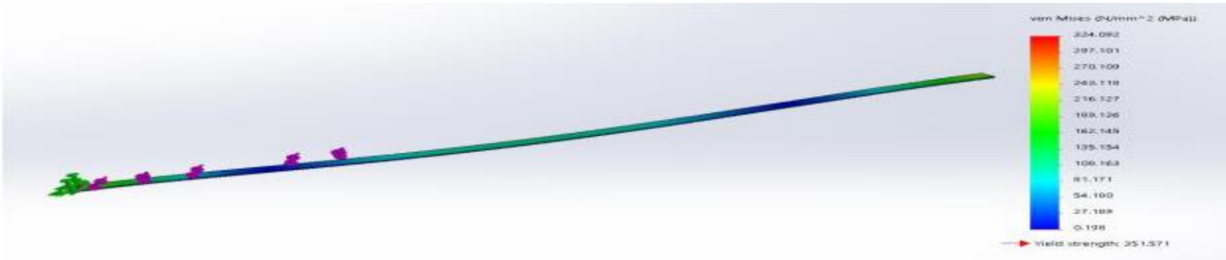


Figure 3-2-12- 6: Stress Analysis on The Base of Basket

The frame of base is exposed to all weight of rolls (78 N) and also exposed to small torque $(2.3\ N.m)$. According to stress analysis the part is safe.

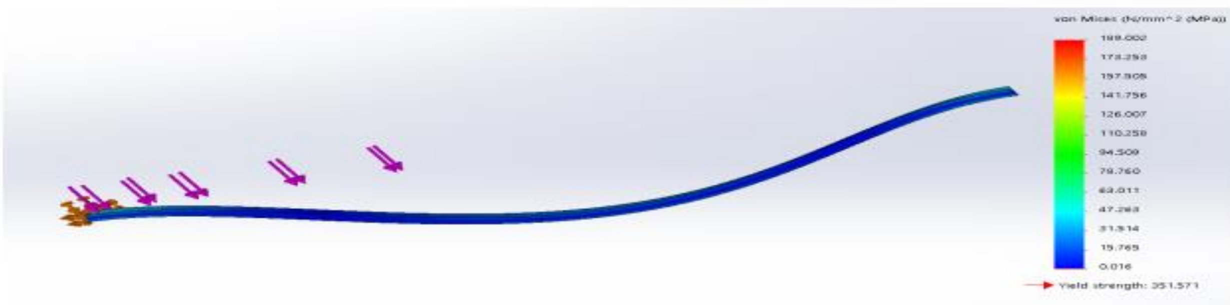


Figure 3-2-12- 7: Stress Analysis on The Frame of Rolls

The width of base exposed to total weight of stage divided by 2 (67 N for every leg).

According to stress analysis the part is safe.

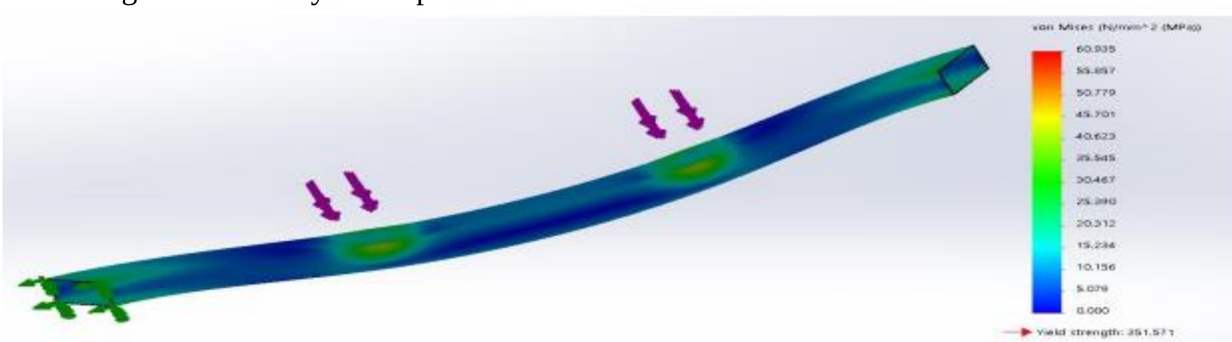


Figure 3-2-12- 8: Stress Analysis on The Width of Basket Base

Chapter 4
Controller Selection

Chapter 4: Controller Selection

4-1: PLC Selection

Now we know the importance of PLC, the architecture, and operating cycle, but we have many PLC models and different manufacturer so we need to understand what is the criteria to select suitable PLC.

1. **CPU Requirements:**
   -How many I/O can the system hold.
   -Does processor support PID and how many PID loops needed.
   -Can CPU support floating point Math or not.

2. **Environment:**
   -Temperature: most of PLC Operating temperature at 0 - 55 c, so if the environment temperature is harsh then we need to select PLC suitable to this temperature.
   - Ingress Protection (IP): does the PLC exposed to water or exposed to workers.

3. **I/O:**
   -How many input and output needed for the system.
   - Does the system need remote I/O or not.

4. **Special Module:**
   -Does the system need Analogue Input or Output
   -Does the system need thermocouple, control and monitor temperature readings.
   - High Speed Counter

5. **Type communication:**
   -Ethernet, ASCII, Modbus…etc.

6. **Software Program:**
   -Does the system have PC, handled programmer, or memory modules: chips can transfer software.

- **<u>Our system requirements:</u>**

1. **CPU Requirements:**
   - up to 244 points
   -System need PID and one Loop.
   -System can Support Floating Point Math.

2. **Environment:**
   - normal operating temperature 0-55 c
   - IP 00 no protection since PLC unit will have its own case control panel.

3. **I/O:**
   -9 input and 7 output.
   - remote not necessarily.

4. **Special Module:**
   - Can support 2 special modules for analogue and temperature readings.

5. **Type communication:**
   - Two serial communication Rs-232c and RS - 485

6. **Software Program:**
   - Support memory module

So, our choice will be LS, XBC DN20SU

Figure 4- 1: XBC DN20SU

4-2: HMI Selection

A Human Machine Interface (HMI), is a device that allows a human to give directions and receive feedback from the PLC that is controlling the manufacturing process.
What are the criteria to select suitable HMI?

1. **Screen size:**

   - 3.4 inch (8.6 cm).
   - 5.7 inch (14 cm).
   - 7 inch (17.7 cm).
   - 8.4 inch (21.3 cm).

2. **Screen:**

   - Color or (black and white).
   - Touch or (touch and buttons).

3. **Environment:**

   -Temperature: most of HMI Operating temperature at 0 - 50 c

   -Free from corrosive gases and excessive dust.

4. **Type communication:**

   -Ethernet, fieldbus, RS -485, or simple and cost-effective serial communications.

5. **Resolution.**

6. **Memory.**

- **Our system requirements:**

1. **Screen size:**

   -7 inch (17.8cm).

2. **Screen:**

   - Color.

   - Touch.

3. **Environment:**

   -Temperature: most of HMI Operating temperature at 0 - 50 c
   -Free from corrosive gases and excessive dust.

4. **Type communication:**

   - RS-485.

5. **Resolution:**

   - 800 x 600 Pixel.

6. **Memory:**

   -Flash 128MB.

   -Operating RAM 64MB.

   -Backup RAM 128KB.

So, our choice will be LS, eXP40-TTA/DC

Figure 4- 2: LS, exp40-TTA/DC

Chapter 5
Computer Vision

Chapter 5: Computer Vision

5-1: Computer Vision system:

5-1-1: Image preprocessing:

Computer-mediated fruit quality assessment and sorting systems:

A computer-mediated fruit quality assessment and sorting system has two subsystems: a computer vision system and a fruit handling system. The computer vision system has two modules, namely the image-processing module and the pattern recognition module. The technological advances in image technology and pattern recognition techniques are making it possible to automate inspection processes like fruit quality assessment. A typical computer vision system that can visually inspect fruit, assess its quality and sort it may consist of an electro-mechanical fruit handler that can place a fruit on a conveyer belt to carry the fruit through a computer vision system to the sorting bins. The computer vision system captures the image of the underlying fruit and transmits it to an image processor. The processor, after processing the image, presents it to a pattern recognizer. The recognizer performs the quality assessments and classifies the underlying fruit into pre-specified quality classes, and directs the sorter to direct the fruit to the appropriate bin either it is a valid one or not.

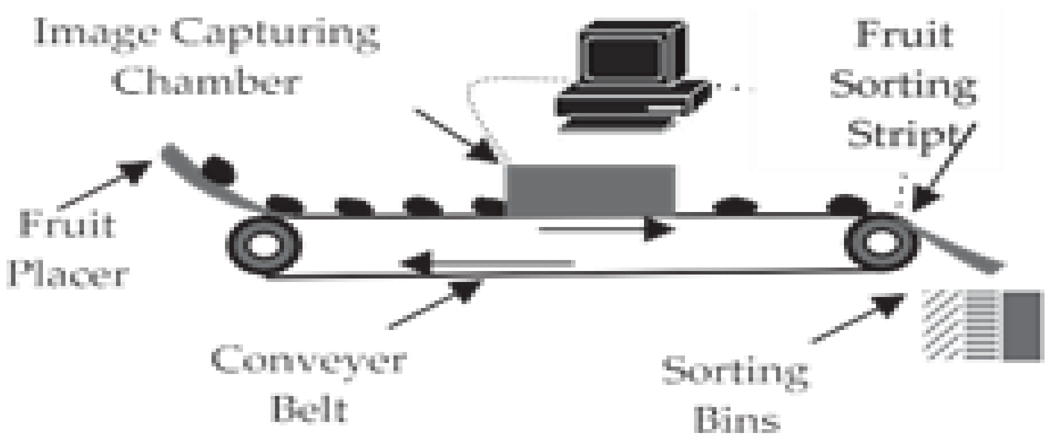


Figure 5-1-1- 1: layout of computer mediated fruit sorting system

The performances of grading systems depend on the quality factors that are used in the design. For fruit grading there are many factors that farmers use for measuring the fruit quality. These factors can be classified into two groups – the external quality factors and the internal quality factors. The external quality factors can be defined and extracted from the visual appearance of the fruit. Commonly used factors are size, shape, color, gloss, surface defects and decay, and texture (fruit surface patterns). The internal quality factors can be defined by the fruit smell like aroma, taste, flavor, sweetness and sourness, and fruit nutritive value like vitamins, minerals, nutrients and carbohydrates, and other elements like dry matter content, total soluble solids content, sugar content, and juice acidity. There are some quality factors like firmness, crispness, and toughness that can be defined by touching the fruit and may be considered external or internal factors.

For marketing purposes, fruits are generally graded based on their external quality features – the features that can be judged by visually inspecting and touching and occasionally smelling the fruit. The visual inspection, because of its practicability and simplicity, is the most frequent option in practice.

Therefore, intensive research is being conducted to automate visual inspection process. Continued advancements in image processing and pattern recognition fields are providing effective tools and techniques to build systems capable of grading and sorting almost every agricultural produce. These systems differ from one another based on image capturing processes, imaging equipment, image processing techniques and pattern recognition (mainly feature extraction and classification) methods that they are employ. However, these machines can be distinguished further from one and another based on quality factors that they extract and use, and the agricultural product for which they are designed – as every product poses unique yet different requirements.

The proposed orange fruit grading and sorting system:

In this section, we describe the orange fruit grading and sorting system that we have built. The system has a motor driven conveyer belt and a fruit placer. The fruit placer places one fruit at a time on the belt and the belt carries it to the imaging chamber where the fruit image is captured and transferred to the connected image processing and classification system (in this case a PC that is connected to the imaging chamber). The classification result is send to a sorting unit that directs the fruit to an appropriate bin by moving a strip, which is controlled by a motor.

Illumination source:

Perhaps no other aspect of vision system design and implementation has consistently caused more delays, cost overruns, and general consternation than lighting. Historically, lighting often was the last aspect specified, developed, or funded, if at all. This approach was not entirely unwarranted, as until recently there was no real vision-specific lighting on the market, meaning lighting solutions typically consisted of standard incandescent or fluorescent consumer products, with various amounts of ambient contribution.

This guide aims to present a standard method for developing sample-appropriate lighting rather than dwell on theoretical treatments. It details relevant aspects in a practical framework, with examples, where applicable, from the following areas:

- Knowledge of lighting types and application advantages and disadvantages, vision camera and sensor quantum efficiency and spectral range, illumination techniques and their application fields relative to surface flatness and surface reflectivity
- Familiarity with the four cornerstones of vision illumination: geometry, pattern or structure, wavelength, and filters
- Detailed analysis of the immediate inspection environment (physical constraints and requirements) and sample/light interactions with respect to your unique samples

  When you have accumulated and analyzed the information from these areas, with respect to the specific sample and inspection requirements, you can achieve the primary goal of machine vision lighting analysis—to provide sample-appropriate lighting that meets three acceptance criteria consistently:

- Maximize the contrast on those features of interest
- Minimize the contrast elsewhere
- Provide for a measure of robustness

  Each inspection is different, thus it is possible, for example, for lighting solutions that meet acceptance criteria one and two to be effective only provided there are no inconsistencies in part size, shape, orientation, placement, or environmental variables such as ambient light contribution

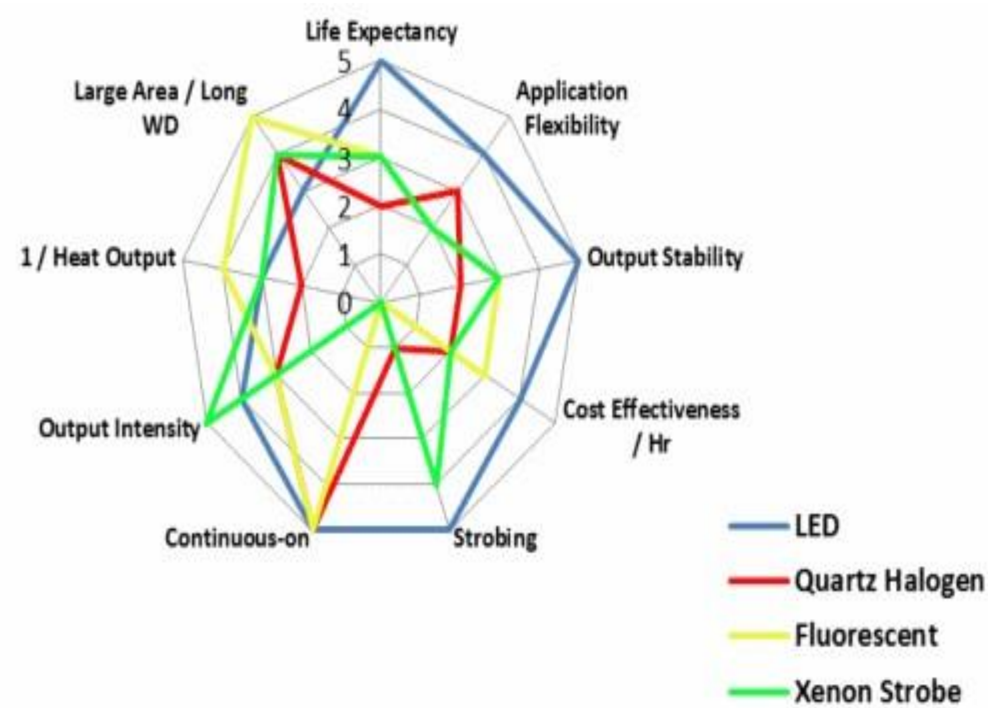
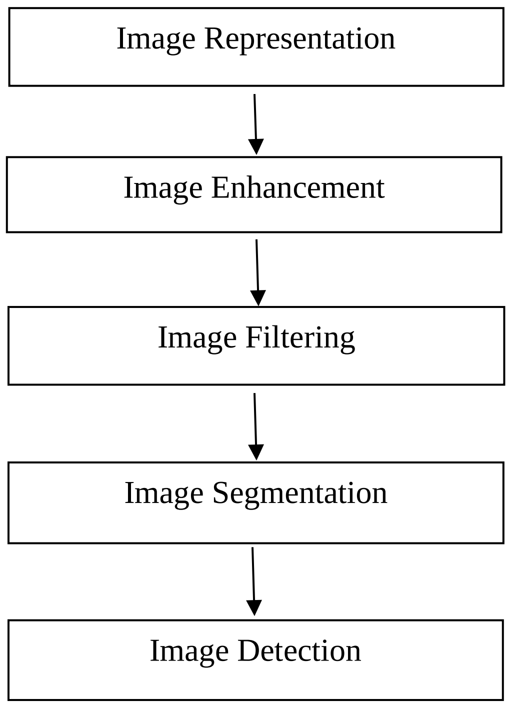


Figure 5-1-1- 2: specs of different types of illumination sources

Image capturing chamber:

The image-capturing chamber is a wooden box that was painted black inside to reduce the light reflection and shading effect.

Preprocessing module:



- **Image representation** is the first step that comes after the camera capturing of the desired object to convert the digital image into a matrix and store each element for processing. We can split each channel, process blue channel only or Red channel, and merge them to format the full image.

- **Image enhancement** is to handle the data to get the best image and use it for image filtering. Enhancement has many types such as histogram equalization and Contrast adjust. Histogram equalization improves the contrast of the image by stretching the distribution of pixels.

- **Image Segmentation** is used to define object boundaries and locate objects.it is the process of assigning a label to every pixel in an image.

- **Image detection** is the final stage in the image processing Diagram. In this stage, the features are extracted to detect the objects in the image and hence be able to identify classify them.

- **Image filtering and noise removal** is to remove the noise or bad data from the image using filters. The most important filters are the Median, Gaussian, morphological and bilateral Blurring filters. Median filter uses to remove salt and pepper noise, Gaussian filter is used to smooth the image if it is too sharp and finally bilateral is used to remove blurring and despite the existence of smoothing it keeps the edges of the object sharpened as much as it is possible. This stage is very important as if there is any possibility for noise existence in the image the result and segmentation will be degraded and many errors will appear.

5-1-2: Digital Image Processing Filtering Operations:

The use of vision systems has increased significantly across a wide variety of industries over the past number of years, several of these include automotive, manufacturing, medical industry and fruit sorting and grading. These industries require highly effective systems in place at all times to ensure quality, accuracy and safety. An inefficient or poorly designed vision system for a fruit sorting and grading system could lead to catastrophic events; therefore, the DIP hardware within these vision systems plays a significant role in ensuring optimized performance. DIP is the processing of digital images with the use of a digital computer and can be broken into three groups; image compression, image enhancement and repair and measurement extraction. Image enhancement may include filtering for noise, sharpening or magnifying an image, which is of benefit for applications such as feature extraction or image analysis. It is at this stage where image filters come into use. Image filtering operations are carried out to assist in altering or enhancing an image to either remove specific features or highlight features of interest within the image. The next Figure gives a basic step process of image processing, from when the image is captured to the output resulting image, with the main focus being on the image processing system stage, where the filtering operations will take place along with many other operations to obtain the desired output image.

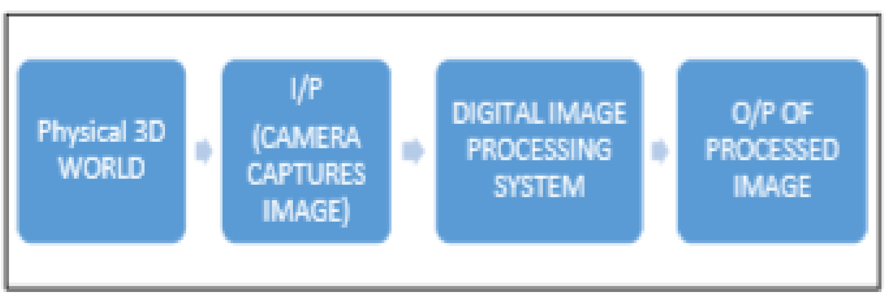


Figure 5-1-2- 1: Basic architecture of digital image processing

Filtering operations:

This section aims to give an insight into various digital image-filtering operations, in addition to a briefly discussing image quality and its importance when storing these enhanced, altered and/or restored images. Before introducing some of the filtering operations used during DIP, it is important to speak of image quality and how filtering operations play a significant role in this.

1. **Image Quality Metrics**:

Image Quality Metrics (IQM) quantifies the accuracy of a digital imaging systems (DIS) capability to capture, process, store, compress, transmit and display the signals from an image. Within DIP systems, image quality (IQ) is found to be a very challenging assessment to carry out. In a typical DIS, as an image is captured, it is converted into a digital signal within the camera and run through a processing stage (for filtering, reducing noise, compressing, storage and transmission). This is where filtering operations take place. Problems begin to occur when the image or video is then displayed on a screen as it can become distorted due to several factors such as motion blurring, gaussian noise, errors encountered during transmission and inadequate sensors. DIS's, therefore, must be able to identify the IQ before the signal is stored or transmitted to enhance or control it. This is where IQM becomes crucial to DIP. IQM can be used for a variety of applications;

- For benchmarking image processing algorithms to determine the most effective algorithm for the specific application.
- To monitor IQ in quality control systems.
- Can be embedded into an image processing system to optimize algorithms and parameter settings.

During an image quality assessment (IQA), there are two types; subjective and objective assessment methods. Subjective assessment involves human interaction to evaluate IQ. This method is the most reliable and accurate because humans are the ultimate user of multimedia applications. However, this method is also prolonged and costly as it requires constant human involvement. Objective assessment computes the IQ automatically, which is becoming more desirable.

Effectively applying filtering operations during the image processing stage is of great importance to ensure that the required quality of the image is achieved for its application before it can be compressed, stored and transmitted.

2. Smoothing Filters:

Smoothing Filters Since all edge detection results are easily affected by noise, filtering out of this noise is of great importance. Many methods of smoothing are based on an anisotropic modification of the heat conductance equation, but rather on a modification of the solution of the equation. An edge-preserving smoothing filter is essentially one which eliminates fine data points of an image while preserving those which are integral for the processing of an image. This, of course, is dependent on predetermined thresholds. Because a course structured image may contain edges, high and low frequencies, edge-preserving smoothing, therefore, cannot be achieved by the employment of linear filtering.

- **Gaussian Filter:**

  Gaussian smoothing is based on the assumption, which has been experimentally verified on numerous occasions, that bold noise is a close approximation of Gaussian distribution, therefore removing this bold noise. However, as stated above, the fine details (fine details that lie outside the Gaussian distribution) are left. Gaussian filtering has been used successfully, and remains a standard image-processing step, for space scale filtering with applications such as blur removal in photographs. It has proven popular due to its predictivity, symmetry and its decrease around the mean.

- **Median Filter:**

  The Median filter (also known as the rank filter) is used to reduce noise within an image by locating pixels in the image that have extreme, improbable intensities and replacing them with a more suitable value (the Median value). Pixel values with extreme intensities are generally a cause of impulse noise, so it is important to remove these points. Blurring is generally kept to a minimum when applying the Median filter, with only a slight loss of detail in an image after carrying out the filtering process. As its most important application is to attenuate Gaussian noise without blurring edges, the Median filter is one of the most commonly used filters within image processing applications. However, this filtering process is not perfect and does come with its disadvantages such as edge jitter, streaking, and it can result in removing important image details. This filtering process is very similar to the mean filter, with the main notable difference being that the Median pixel value is used to replace the neighboring pixel values, whereas the mean filter will use the mean value as the replacement. The Median filter has been found to effectively preserve the useful detail in the image. Generally, the Median filter will focus on a 3x3 pixel neighborhood, but to produce a more severe smoothing effect, a larger neighborhood is required. The Median is not affected by outliers, it is also a much more effective method of preserving sharp edges because the Median value will be an actual pixel value within the neighborhood and not an unrealistic new value, which is generated when carrying out mean filtering.

- **Bilateral Filtering:**

In the broadest sense of the term "filtering", the value of the filtered image at a given location is a function of the values of the input image in a small neighborhood of the same location. For example, Gaussian low-pass filtering computes a weighted average of pixel values in the neighborhood, in which the weights decrease with distance from the neighborhood center. Although formal and quantitative explanations of this weight fall-off can be given, the intuition is that images typically vary slowly over space, so near pixels are likely to have similar values, and it is therefore appropriate to average them together. The noise values that corrupt these nearby pixels are mutually less correlated than the signal values, so noise is averaged away while signal is preserved. The assumption of slow spatial variations fails at edges, which are consequently blurred by linear low-pass filtering. How can we prevent averaging across edges, while still averaging within smooth regions? Many efforts have been done in order to reduce this undesired effect. Simply, Bilateral filtering is a non-iterative filter for edge-preserving smoothing.

- **Morphological Filtering process:**

Morphological operations are originally developed for bilevel images for shape and structural manipulations. One of the Basic functions are dilation and erosion. Concatenation of dilation and erosion in different orders result in more high-level operations, including closing and opening6. Morphological operations can be used for smoothing or edge detection or extraction of other features. However, it belongs to the category of spatial domain filter.

5-2: segmentation:

5-2-1: Introduction of Image segmentation:

Digital image processing is using pc algorithms to carry out photo processing on virtual images. Image segmentation is a critical and difficult method of image processing. Image segmentation methods used to divide an image into significant components having comparable functions and homes. The major purpose of segmentation is oversimplification. Representing a photo into significant and without problems analyzable way. Image segmentation is essential first step in image analysis. The intention of photo segmentation is to divide a photo into numerous components segments having comparable functions or attributes. The primary packages of photo segmentation are: Content-primarily based totally photo retrieval, medical imaging, Object detection and Recognition Tasks, Automatic site visitors manage structures and Video surveillance, etc. The photo segmentation may be categorized into primary kinds: Local segmentation (involved with unique element or location of photo) and Global segmentation (involved with segmenting the entire photo, inclusive of massive range of pixels). The photo segmentation methods may be classified into kinds primarily based totally on homes of photo.

1. **Discontinuity detection primarily based totally method:**

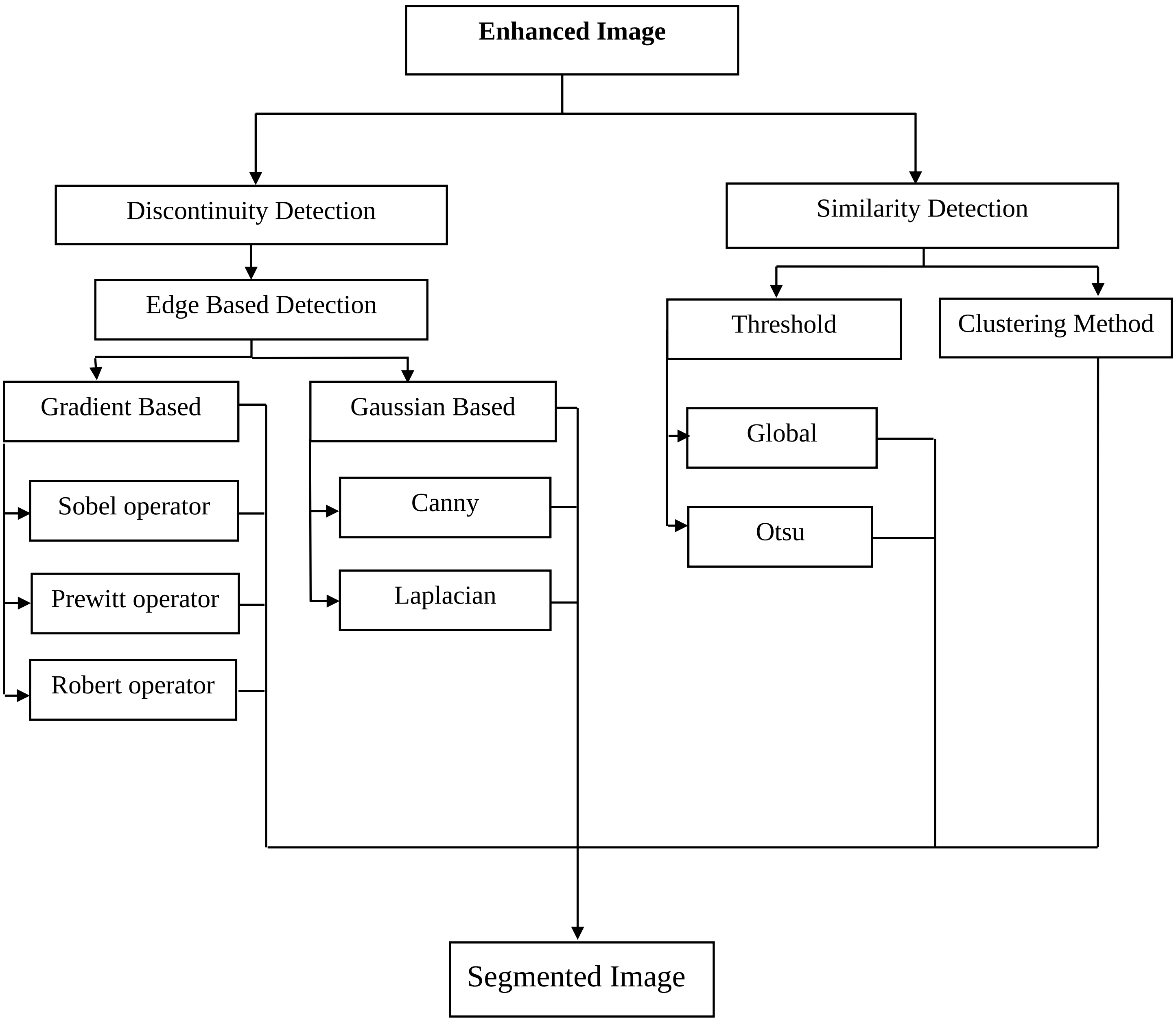
This is the method wherein a photograph is segmented into areas primarily based totally on discontinuity. The side detection primarily based totally segmentation falls on this class wherein edges fashioned because of depth discontinuity are detected and related to shape obstacles of areas.

2. **Similarity detection primarily based totally method:**

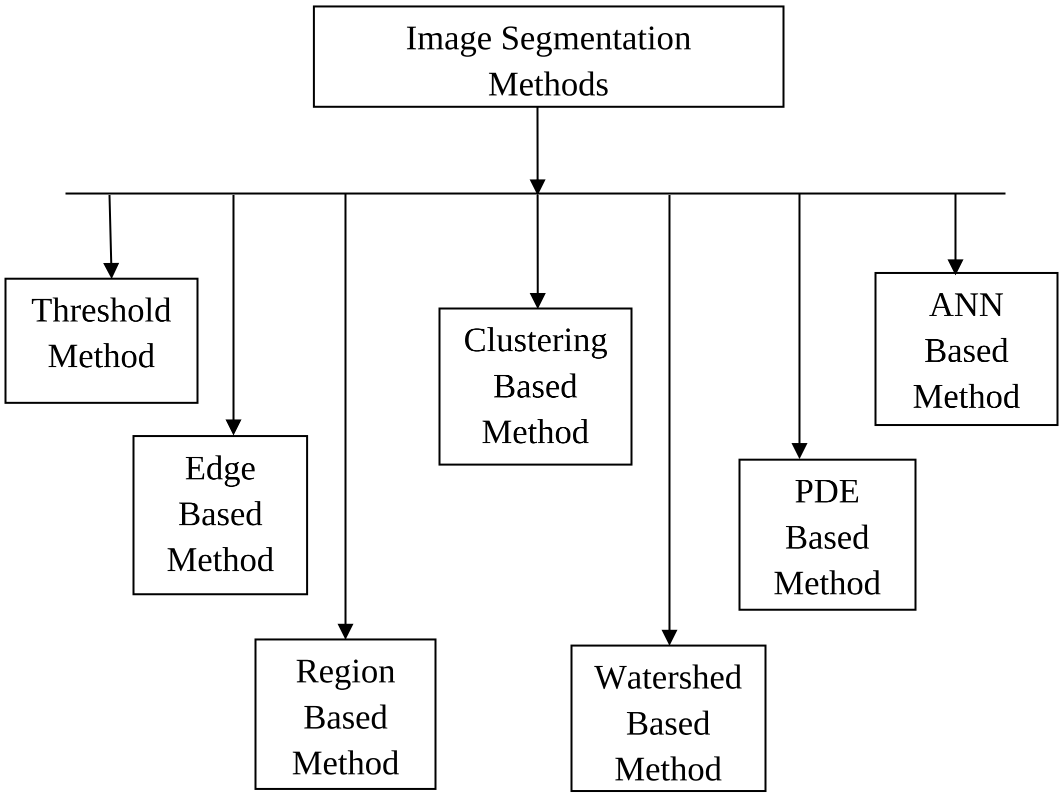
This is the method wherein a photograph is segmented into areas primarily based totally on similarity. The strategies that fall below this method are: thresholding strategies, location developing strategies and location splitting and merging. These all divide the photograph into areas having comparable set of pixels. The clustering strategies additionally use this methodology. These divide the photograph into set of clusters having comparable functions primarily based totally on a few predefined criteria.

In different words, additionally we will say that photograph segmentation may be approached from 3 perspectives: Region method, Edge method and Data clustering. The location method falls below similarity detection and side detection and boundary detection falls below discontinuity detection. Clustering strategies also are below similarity detection.

5-2-2: Image segmentation block diagram:



5-2-3: image segmentation techniques:



Threshold:

Thresholding is the best technique of photograph segmentation. From a grey scale photograph, thresholding may be used to create binary image. Binary image is made out of shadeation image with the aid of using segmentation. Segmentation is the procedure of assigning every pixel withinside the supply photograph to 2 or extra instructions. If there are extra than instructions then the standard end result is numerous binary images. In photograph processing, thresholding is used to cut up a photograph into smaller segments, or junks, the usage of as a minimum one shadeation or grey scale cost to outline their boundary. The benefit of acquiring first a binary photograph is that it reduces the complexity of the records and simplifies the procedure of popularity and classification. The maximum not unusual place manner to transform a grey stage photograph to a binary photograph is to pick unmarried threshold cost (T) The enter to a thresholding operation is usually a grey scale or shadeation photograph. In the best implementation, the output is a binary photograph representing the segmentation. Black pixels are background and white pixels correspond to foreground (or vice versa). This technique of segmentation applies an unmarried constant criterion to all pixels with inside the photograph simultaneously.

- **Thresholding Method**

1. **Global Thresholding:**

This is accomplished via way of means of the use of any suitable threshold value/T. This value of T can be consistent for complete picture. On the idea of T, the output picture may be received from authentic picture.

2. **Variable Thresholding:**

In this kind of thresholding, the value of T can range over the picture. This can in addition be of types:

- Local Threshold: In this T relies upon the community of x and y.
- Adaptive Threshold: T is a characteristic of x and y.

3. **Multiple Thresholding:**

In this kind of thresholding, there are a couple of threshold values like T0 and T1. By the use of those output picture may be computed as the values of thresholds may be computed with the assist of the peaks of the picture histograms. Simple algorithms also can be generated to compute those

– **Global Thresholding:**

Global thresholding is based on the assumption that the image has a bimodal histogram and, therefore, the object can be extracted from the background by a simple operation that compares image values with a threshold value T [32, 132]. Suppose that we have an image f (x, y) with the histogram shown on Fig 5-2-3.

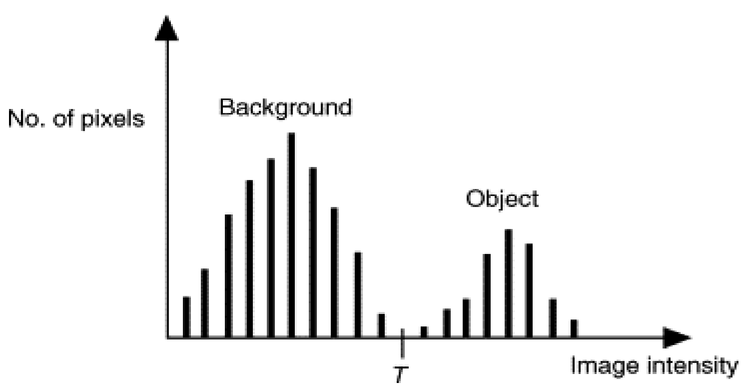


Figure 5-2-3- 1:Image histogram

The entity and background pixels have gray levels divided into two dominant modes. One clear way to extract the object from the background is to choose a threshold *T* that separates these modes.
The thresholder image *g (x, y)* is defined as *g (x, y)*

$$g(x, y) = \begin{cases} 1, & \text{if}(x, y) > T \\ 0, & \text{if}(x, y) \leq T \end{cases}$$

Otsu's method:

$$\sigma_w^2(t) = w_0(t)\sigma_0^2(t) + w_1(t)\sigma_1^2(t)$$

Weights w_0 and w_1 are the probabilities of the two classes separated by a threshold (t), σ_0^2 and σ_1^2 are variances of these two classes.

The class probability $w_{0,1}(t)$ is computed from the (L) bins of the histogram.

$$w_0(t) = \sum_{i=0}^{t=1} p(i)$$

$$w_1(t) = \sum_{i=t}^{L=1} p(i)$$

For 2 classes, minimizing the intra-class variance is equivalent to maximizing inter-class variance:

$$\sigma_b^2(t) = \sigma^2 - \sigma_w^2(t) = w_0(\mu_0 - \mu_T)^2 + w_1(\mu_1 - \mu_T)^2$$

$$= w_0(t)w_1(t)[\mu_0(t)\mu_1(t)]^2$$

Which is expressed in terms of class probabilities w and class means μ, where the class means μ_0, μ_1 and μ_T are:

$$\mu_0(t) = \frac{\sum_{i=0}^{T-1} ip(i)}{w_0(t)}$$

$$\mu_1(t) = \frac{\sum_{i=t}^{L-1} ip(i)}{w_1(t)}$$

$$\mu_T(t) = \sum_{i=0}^{L-1} ip(i)$$

- **Steps for implement Otsu threshold:**

1. Compute histogram and probabilities of each intensity level
2. Set up initial w (0) and u (0)
3. Step through all possible thresholds t=1,…… maximum intensity

1. Update w and u
2. Compute $\sigma_b^2(t)$

4. Desired threshold corresponds to the maximum $\sigma_b^2(t)$

<u>Edge detection:</u>

Types of edges

1. Step edge
2. Ramp edge
3. Line edge
4. Roof edge Edges are represented in images as sudden disparities.

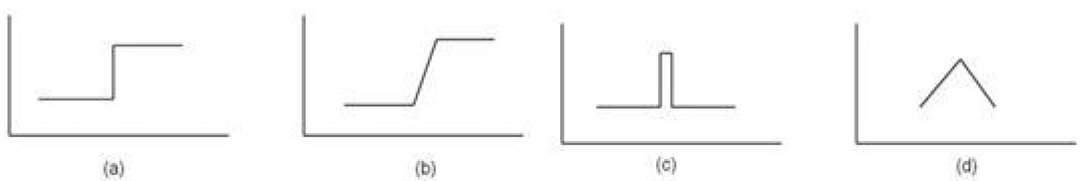
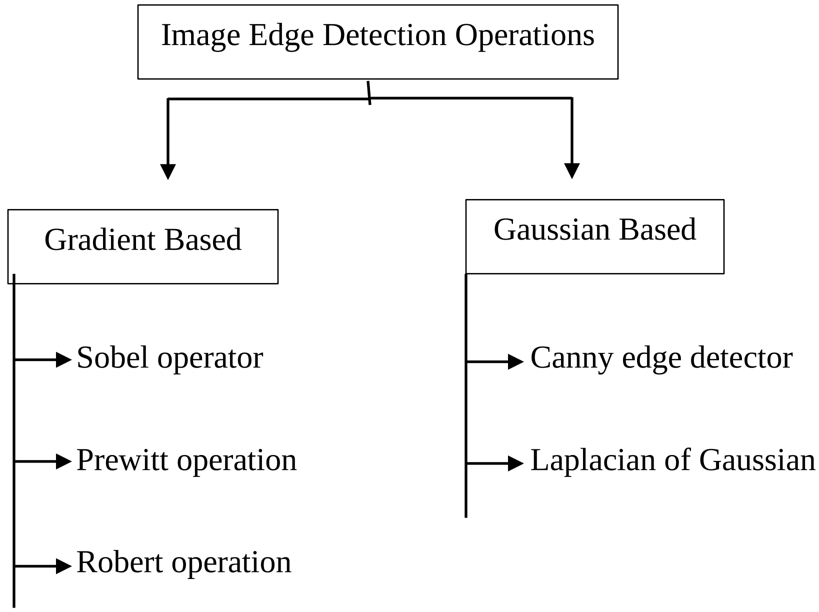


Figure 5-2-3- 2: Types of edges

- **Edge Detection Operators**:

are of two types:

- **Gradient:** major function of this operator calculates first-order derivations in a digital image and there are many operators like, Prewitt operator, Sobel operator and Robert operator.
- **Gaussian:** major function of this operator calculates second-order derivations in a digital image like, Laplacian of Gaussian, Canny edge detector.



<u>There are 5 edge detection operators they are as follows:</u>

❖ **<u>First Derivative Operators:</u>**

1. Sobel Edge Detection Operator:

The Sobel edge detection operator extracts all the edges of an image, without worrying about the directions. The main advantage of the Sobel operator is that it provides differencing and smoothing effect.
Sobel edge detection operator is implemented as the sum of two directional edges. And the resulting image is a unidirectional outline in the original image.

$$M_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \qquad M_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

The Sobel operator is the magnitude of the gradient and can be calculated as

$$M = \sqrt{g_x^2 + g_y^2}$$

Where,

$$g_x = \frac{\partial f}{\partial x} = (Z_7 + 2Z_8 + Z_9) - (Z_1 + 2Z_2 + Z_3)$$

$$g_y = \frac{\partial f}{\partial y} = (Z_3 + 2Z_6 + Z_9) - (Z_1 + 2Z_4 + Z_7)$$

The edge detection can be made selective by thresholding the gradient image. In order to highlight the principal edges as well as gaining high connectivity smoothing can be included along with threshold.

- **Sobel operator pseudocode:**

  - convert the image from an RGB scale to a Grayscale image
  - apply x-direction kernel convolution to image
  - apply y-direction kernel convolution to image
  - Magnitudes of both the X and Y kernels will then be added together to produce a final image showing all edges in the image

- **Advantages:**

1. Easy for implement and time efficient calculation
2. Simple to search for smooth edges.

- **Limitations:**

1. Diagonal direction points are not conserved for all time
2. extremely sensitive to noise
3. Not very perfect in edge detection
4. notice with thick and rough edges does not give suitable results

2. Prewitt Operator:

This operator uses masks of size 3X3 to approximate to the partial derivatives. This operator is quite accurate when compared with the Roberts operator. The Prewitt operator is given by

$$M_x = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \qquad M_y = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

The derivative in x-direction is calculated by the difference between third and first rows of 3 X 3 regions. Similarly, for y direction third and first columns difference are considered

$$g_x = \frac{\partial f}{\partial x} = (Z_7 + Z_8 + Z_9) - (Z_1 + Z_2 + Z_3)$$

$$g_y = \frac{\partial f}{\partial y} = (Z_3 + Z_6 + Z_9) - (Z_1 + Z_4 + Z_7)$$

- **Advantages:**

1. good quality performance on detects vertical and horizontal edges
2. greatest operator to find the orientation of an image

- **Limitations:**

1. coefficient magnitude is fixed and cannot be changed
2. Diagonal direction points are not conserved always

3. Robert Operator:

This gradient-based operator calculates the sum of squares of the difference between diagonally neighboring pixels in an image through discrete separation. Then the gradient approximation is made. It uses the following 2 x 2 kernels or masks

$$\mathrm{M_x} = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \qquad M_y = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$$

- **Advantages:**

1. finding of edges and orientation are very simple
2. Diagonal direction points are conserved

- **Limitations:**

1. Very sensitive to noise
2. Not very exact in edge detection

❖ <u>**Second Derivative Operators:**</u>

The 2d order by-product un earths neighborhood maxima in gradient values and considers them as edges. There may be a 0 crossing in 2dby-product of the gradient on the detected edges. For higher part performance, the operator has to be able to computing first or 2dby-product for each pixel withinside the photo and it have to be well suited for any photo scale. Compatibility with various photo scales effects in sharper part detection.

4. Laplacian Operator:

This is the simple operator used with the second one by-product technique. The Laplacian operator for a characteristic f (x, y) is given by

$$\nabla^2 = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$

Where,

$$\frac{\partial^2 f}{\partial x^2} = f(x, y+1) - 2f(x,y) + f(x, y-1)$$

$$\frac{\partial^2 f}{\partial y^2} = f(x+1, y) - 2f(x,y) + f(x-1, y)$$

The above equations are used to obtain the following mask:

$$\nabla^2 = \begin{matrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{matrix}$$

The Laplacian operator detects a border when it takes change through zero. This operator ignores homogeneous zero region, since to detect the border, 'transition across zero' is the lone suggestion but not the zero value itself. This operator will provide the point at which border is present but the actual edge place must be determined by the interpolation technique.

- **Laplacian of Gaussian (LoG) Operator**:

LoG operator uses zero crossing method for the edge detection and border location is expected using subpixel resolution by linear exclamation. LoG filter used for this reason is ∇^2G where

∇^2 is $\frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$

G is $G(x,y) = e^{-\frac{x^2+y^2}{2\sigma^2}}$

σ is space constant.

$$\nabla^2 G = \frac{\partial^2 G(x,y)}{\partial x^2} + \frac{\partial^2 G(x,y)}{\partial y^2}$$

Solving this equation yields

$$\nabla^2 G(x,y) = \left[\frac{x^2+y^2+2\sigma^2}{\sigma^4}\right] e^{-\frac{x^2+y^2}{2\sigma^2}}$$

In this approach, a picture is to be convolved with Gaussian filter to be better noise performance. The unimportant edges are unnoticed because the pixel is treated as edge if and only if it has peak value larger than several thresholds. The final output of LoG is got by convolution operation

$$h(x,y) = [\nabla^2 G(x,y)] * f(x,y)$$

where f (x, y) is an image intensity function.

Masks of any size can be generated using the Log operator by sampling it and scaling the coefficients to get their sum as zero.

- **Advantages:**

1. edges are very to be detect and a variety of orientations
2. There is set characteristics in all directions

- **Limitations:**

1. extremely sensitive to noise
2. The localization mistake may be harsh at curved edges
3. It generates noisy responses that do not match to edges, so-called “false edges

3. Canny Edge Detector Operator:

The canny facet operator is advanced to the operator blanketed until now withinside the discussion. This operator is characterized via way of means of low blunders rate, higher localization of facet factors and importantly unmarried facet factor response. For 2-dimensional edges, photograph is first smoothed via way of means of the usage of round two-dimension Gaussian function, computing the gradient of the end result after which the usage of the gradient importance and course to approximate facet power and course at each factor. The convolution of the photograph with the Gaussian clear out offers an array of smoothed data

$$f_s = [G(x,y) * f(x,y)]$$

Where, f (x, y) is the input image and

$$G(x,y) = e^{-\frac{x^2+y^2}{2\sigma^2}}$$

The next step is to compute the gradient magnitude and angle

$$M(x,y) = \sqrt{g_x^2 + g_y^2}$$ and

$$\alpha(x,y) = \tan^{-1}\left[\frac{g_y}{g_x}\right]$$

Where $g_x = \frac{\partial f_s}{\partial x}$ and $g_y = \frac{\partial f_s}{\partial y}$

Canny edge detection algorithm is carried out through the following steps

- **Filtering the image:**

The number one step of Canny facet detection set of rules is to clear out any noise there withinside the authentic photo. Filtering can be finished via using distinctive filters. A Gaussian clear out is used because Gaussian noise is the particularly not unusual place noise in photo systems. The reaction of a Gaussian clear out is a Gaussian feature. It simply smoothens the photo even as blurring the noise and maintaining the crucial features. The overall performance of smoothening relies upon on well-known deviation and clear out length. The clear out length is a good deal much less than the scale of authentic photo. Standard deviation measures the diploma of smoothening. Gaussian distribution feature in 2D shape is given by

$$G(x,y) = \left(\frac{1}{2\pi\sigma^2}\right) e^{-(x^2+y^2)}/_{2\sigma^2}$$

Where σ represents standard deviation. The smoothened image is represented by the convolution of original image and Gaussian function.

5-3: Feature Extraction:

5-3-1: Introduction of Feature Extraction:

Feature performs a completely essential function withinside the vicinity of image processing. Before getting functions, numerous image preprocessing strategies like binarization, thresholding, resizing, normalization etc. are implemented at the sampled image. After that, function extraction strategies are implemented to get functions with a purpose to be beneficial in classifying and reputation of images. Feature extraction strategies are beneficial in numerous image processing programs. individual reputation. As functions outline the conduct of an image, they display its vicinity in phrases of garage taken, performance in class and manifestly in time intake also. Here on this paper, we're going to talk about numerous forms of functions, function extraction strategies and explaining in what scenario, which functions extraction technique, can be better. Hereby on this paper, we're going to refer functions and function extraction techniques in case of individual reputation application.

- **Why use Feature Extraction:**

Feature Extraction pursuits to reduce the range of features in a dataset via way of means of growing new features from the prevailing ones (after which discarding the authentic features). These new decreased set of features must then be capable of summarize maximum of the statistics contained withinside the authentic set of features. In this way, a summarized model of the authentic features may be made from an aggregate of the authentic set. To

- Accuracy improvements.
- Overfitting risk reduction.
- Speed up in training.
- Improved Data Visualization.
- Increase in explain ability of our model.

5-3-2: Feature Extraction block diagram:

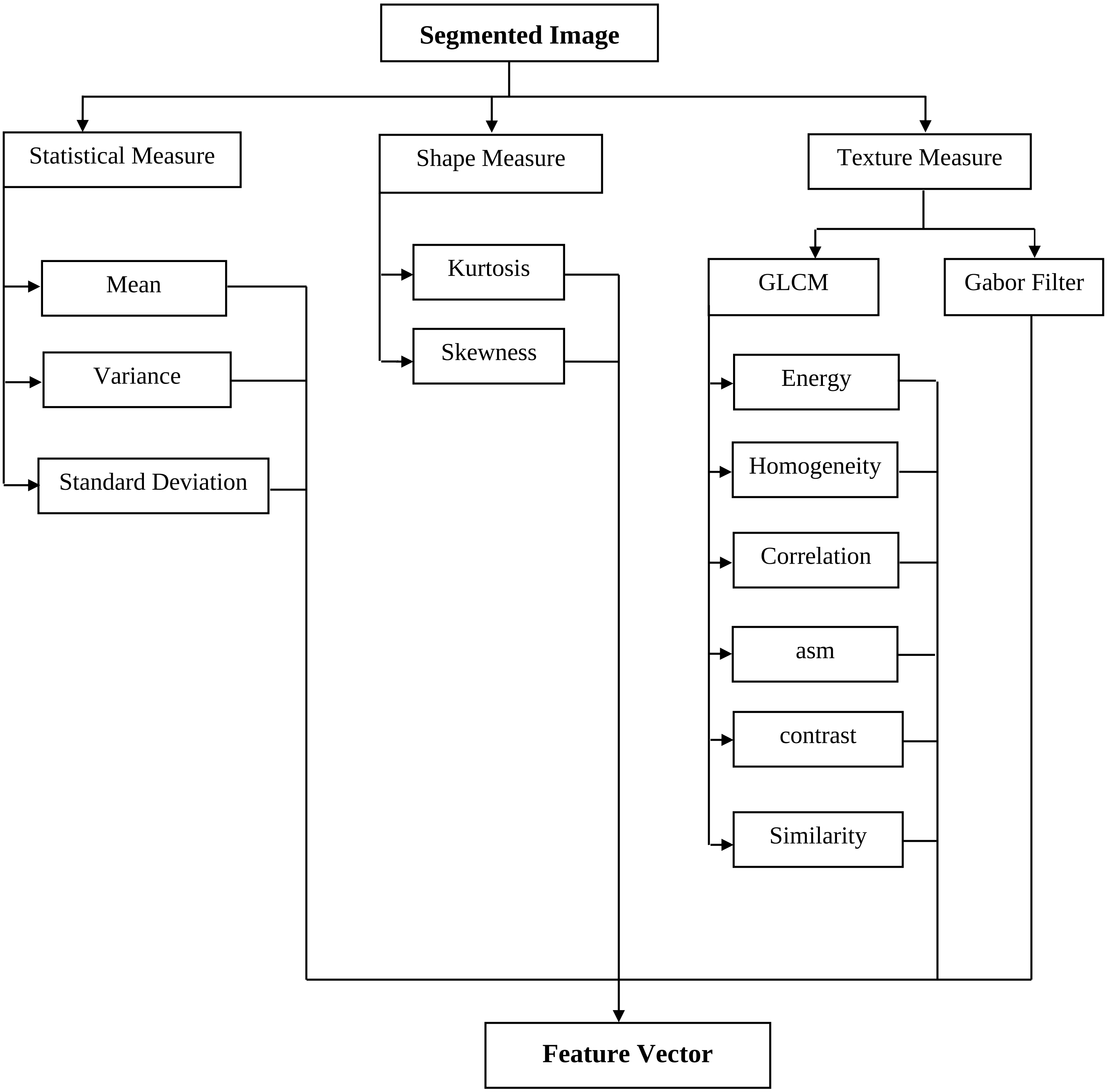


Image texture:

Everyday texture terms - rough, silky, bumpy - talk to touch. They are maximum without problems understood when it comes to a topographical floor with excessive and occasional points, and a scale well suited with a finger or other. A texture that is rough to touch has:

1. a large difference between high and low points, as compared to the size of a fingertip.
2. a space between highs and lows approximately the same size as a fingertip.

Rough textures can of path arise at any spatial scale, now no longer simply what we should touch. The example above might be taken into consideration hard whether or not it represents 1 cm or a100km in horizontal dimension. To probe it with something besides our scale-knowledgeable eyes, however, we'd need to adapt the "fingertip" used to an appropriate scale. Silky or clean has:

1. little difference between high and low points,
2. the differences would be spaced very close together relative to fingertip size.

Image texture works withinside the identical way, besides the highs and lows are brightness values (additionally known as gray levels, GL, or virtual numbers, DN) in place of elevation changes. Instead of probing a fingertip over the surface, a "window" - a rectangular field defining the dimensions of the probe - is used. And, of course, the scale (pixel size) isn't always that of a fingertip, however can be described but is handy for the photo records available. Textures in images quantify:

1. Grey Level differences (contrast)
2. Defined size of area where change occurs (neighborhood, defined by a window size)
3. Directionality, or lack of it (omnidirectional).

- **About the GLCM and textures:**

The Gray Level Co-prevalence Matrix1 (GLCM) and related texture feature calculations are image evaluation techniques. Given an image composed of pixels every with an intensity (a particular grey level), the GLCM is a tabulation of the way regularly distinctive combos of grey tiers co-arise in an image or image section. Texture feature calculations use the contents of the GLCM to offer a degree of the version in intensity (a.k.a. image texture) on the pixel of interest.

Echo view gives a GLCM Texture Feature operator that produces a digital variable which represents a specified texture calculation on an unmarried beam echogram. Algorithm:

1. The virtual variable is created withinside the following way (the using the settings on the GLCM Texture page of the Variable properties dialog box identified in bold):
2. Quantize the image data. Each sample at the echogram is handled as a single image pixel and the cost of the sample is the intensity of that pixel. These intensities are then in addition quantized right into a unique quantity of discrete grey levels specified under Quantization.
3. Create the GLCM. It might be a square matrix N x N in length in which N is the Number of levels specified under Quantization. The matrix is created as follows:

   - Let S be the sample below consideration for the calculation.

   - Let W be the set of samples surrounding sample s which fall inside a window focused upon sample s of the Size specific below Window Size.

   - Considering most effective the samples withinside the set W, outline every detail i, j of the GLCM because the range of instances samples of intensities i and j arise in specific Spatial courting (in which i and j are intensities among zero and Number of levels-1).

     The sum of all of the factors i, j of the GLCM might be the total number of times instances the desired spatial courting happens in W.

   - Make the GLCM symmetric:

     This produces a symmetric matrix wherein the connection i to j is indistinguishable for the relationship j to i (for any two intensities i and j). As a result, the sum of all of the factors i, j of the GLCM will now be two times the full variety of instances the required spatial dating takes place in W (as soon as where in the sample with depth i is the reference sample and as soon as wherein the sample with depth j is the reference sample), and for any given i, the sum of all of the factors i, j with the given i could be the full variety of instances a sample of depth i seems withinside the distinct spatial dating with any other sample.

Make a transposed copy of the GLCM.

Add this copy to the GLCM itself.

- Normalize the GLCM:

  Divide each element by the sum of all elements, The elements of the GLCM may now be considered probabilities of finding the relationship *i*, *j* (or *j*, *i*) in *W*.

4. The sample s withinside the ensuing virtual variable is changed with the aid of using the cost of this calculated feature.

- **Calculate the selected Feature.**

  This calculation uses only the values in the GLCM. See:

1. Energy
2. Entropy
3. Contrast
4. Homogeneity
5. Correlation
6. Shade
7. Prominence

1. Energy

Energy returns the sum of squared factors withinside the Grey Level Cooccurrence Matrix (GLCM). Energy is also known as uniformity. The range of energy is [0 1]. Energy is 1 for a steady image. The method for locating strength is given in underneath equation

$$\text{Energy} = \sum_{i,j=0}^{N-1} (P_{ij})^2$$

2. Contrast

Contrast returns a measure of the intensity comparison among a pixel and its neighbor over the complete image. The variety of Contrast is [0 (size (GLCM, 1)-1) ^2]. Contrast is zero for a constant image. Contrast is calculated through the use of the equation given beneath:

$$\text{Contrast} = \sum_{i,j=0}^{N-1} P_{ij}(i-j)^2$$

3. Correlation

Correlation returns a measure of how correlated a pixel is to its neighbor over the whole image. The range of correlation is [-1 1]. Correlation is 1 or -1 for a perfectly positively or negatively correlated image. Correlation is N*N (Not a Number) for a constant image. The below equation shows the calculation of Correlation

$$\text{Correlation} = \sum_{i,j=0}^{N-1} P_{ij} \frac{(i-\mu)(j-\mu)}{\sigma^2}$$

4. Homogeneity

Homogeneity returns a value that measures the closeness of the distribution of elements in the GLCM to the GLCM diagonal. The range of Homogeneity is [0 1]. Homogeneity is 1 for a diagonal GLCM. The Homogeneity is evaluated using the equation:

$$\text{Homogeneity} = \sum_{i,j=0}^{N-1} \frac{P_{ij}}{1+(i+j)^2}$$

5. Entropy

Entropy is a statistical measure of randomness that can be used to characterize the texture of the input image. Entropy, h can also be used to describe the distribution variation in a region. Overall Entropy of the image can be calculated as:

$$\text{Entropy} = \sum_{i,j=0}^{N-1} -\ln(P_{ij})P_{ij}$$

6. Inverse Difference Moment (IDM)

It is a measure of image texture. IDM ranges from 0.0 for an image that is highly textured to 1.0 for an image that is untextured. The formula for finding the IDM is given in below equation:

$$H = \sum_{i,j} \frac{P(i,j)}{1+|i-j|}$$

7. ASM

Angular Second Moment (ASM) represents the uniformity of distribution of grey level in the image ASM ranges from 1/G 2 to 1. A value of 1 indicates a constant image.

$$\text{ASM} = \sum_{i=1}^{G} \sum_{j=1}^{G} \{P(i,j)\}^2$$

- **GLCM equation:**

Energy feature

$$\textbf{Energy} = \sum_{i,j=0}^{N-1} (P_{ij})^2$$

Entropy feature

$$\textbf{Entropy} = \sum_{i,j=0}^{N-1} -\ln (P_{ij}) P_{ij}$$

Contrast feature

$$\textbf{Contrast} = \sum_{i,j=0}^{N-1} P_{ij} (i-j)^2$$

Homogeneity feature

$$\textbf{Homogeneity} = \sum_{i,j=0}^{N-1} \frac{P_{ij}}{1+(i+j)^2}$$

Correlation feature

$$\textbf{Correlation} = \sum_{i,j=0}^{N-1} P_{ij} \frac{(i-\mu)(j-\mu)}{\sigma^2}$$

Shade feature

$$\textbf{Shade feature} = sgn\,(A)|A|^{1/3}$$

Prominence feature

$$\textbf{Prominence} = sgn\,(B)|B|^{1/4}$$

where:

P_{ij} = Element *i*,*j* of the normalized symmetrical GLCM

N = Number of gray levels in the image as specified by Number of levels in under Quantization on the GLCM texture page of the Variable Properties dialog box.

μ = the GLCM mean (being an estimate of the intensity of all pixels in the relationships that contributed to the GLCM), calculated as:

$$\mu = \sum_{i,j=0}^{N-1} iP_{ij}$$

Note: This also approximates, but is not identical to, the mean of all the pixels in the data window *W* (as defined by the GLCM algorithm), and it is dependent upon the choice of spatial relationship in that algorithm.

σ^2 = the variance of the intensities of all reference pixels in the relationships that contributed to the GLCM, calculated as:

$$\sigma^2 = \sum_{i,j=0}^{N-1} P_{ij}(i-\mu)^2$$

Note: This may approximate, but is not identical to, the variance of the intensities of all the pixels in the data window W (as defined by the GLCM algorithm), and it is dependent upon the choice of spatial relationship in that algorithm.

$$A = \sum_{i,j=0}^{N-1} \frac{(i+j-2\mu)^3 P_{ij}}{\sigma^3\left(\sqrt{2(1+C}\right)^3}$$

C = The Correlation feature

Sgn(x) = Sign of a real number
x = -1 for x < 0
x = 0 for x = 0
x = 1 for x > 0

$$B = \sum_{i,j=0}^{N-1} \frac{(i+j-2\mu)^4 P_{ij}}{4\sigma^4(1+C)^2}$$

- **Gabor filter:**

A Gabor filter (in image processing), named after Dennis Gabor, is a linear filter used for texture analysis, which means that it basically analyses whether there is any specific frequency content in the image in specific directions in a localized region around the point or region of analysis.

Frequency and orientation representations of Gabor filters are claimed by many contemporary vision scientists to be similar to those of the human visual system, though there is no empirical evidence and no functional rationale to support the idea.

They have been found to be particularly appropriate for texture representation and discrimination. In the spatial domain, a 2D Gabor filter is a Gaussian kernel function modulated by a sinusoidal plane wave.

Some authors claim that simple cells in the visual cortex of mammalian brains can be modeled by Gabor functions. Thus, image analysis with Gabor filters is thought by some to be similar to perception in the human visual system.

Statistical features:

1. **Mean**

   The imply, m of the pixel values with inside the described window, estimates the value withinside the image wherein relevant clustering occurs. The imply may be calculated the use of the formulation:

$$\mu = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N} P(i,j)$$

2. **Standard Deviation**

   The Standard Deviation, σ is the estimate of the mean square deviation of gray pixel price p (i, j) from its mean value. Standard deviation describes the dispersion inside a neighborhood region. It is decided the use of the formulation:

$$\sigma = \sqrt{\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}(P(i,j)-\mu)^2}$$

3. **Variance**

   Variance is the square root of standard deviation. The formula for finding Variance

$$V_{ar} = \sqrt{SD}$$

   Where SD is the Standard Deviation.

shape feature:

1. **Skewness**

   - Skewness is a measure of the asymmetry of a distribution. This price may be tremendous or terrible.
   - A negative skew suggests that the tail is at the left aspect of the distribution, which extends toward extra negative values.
   - A positive skew suggests that the tail is at the proper aspect of the distribution, which extends toward extra positive values.
   - A value of zero suggests that there's no skewness withinside the distribution at all, which means the distribution is perfectly symmetrical.

- **Skewness equation:**

  It is a symmetrical graph with all measures of central tendency in the middle.

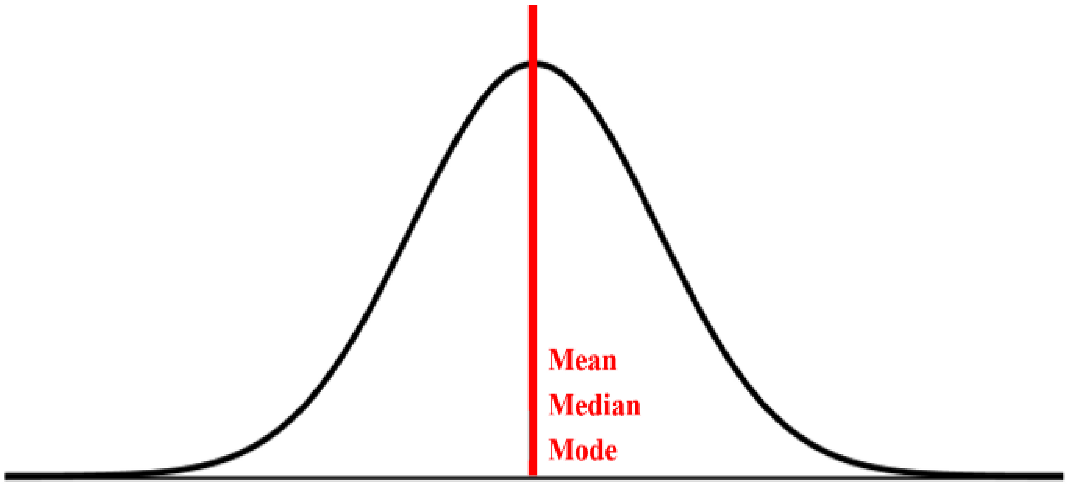


Figure 5-3-2- 1: Symmetrical distribution of image

But what if we come upon an asymmetrical distribution, how can we come across the extent of asymmetry? Let's see visually what takes place to the measures of valuable tendency whilst we come upon such graphs.

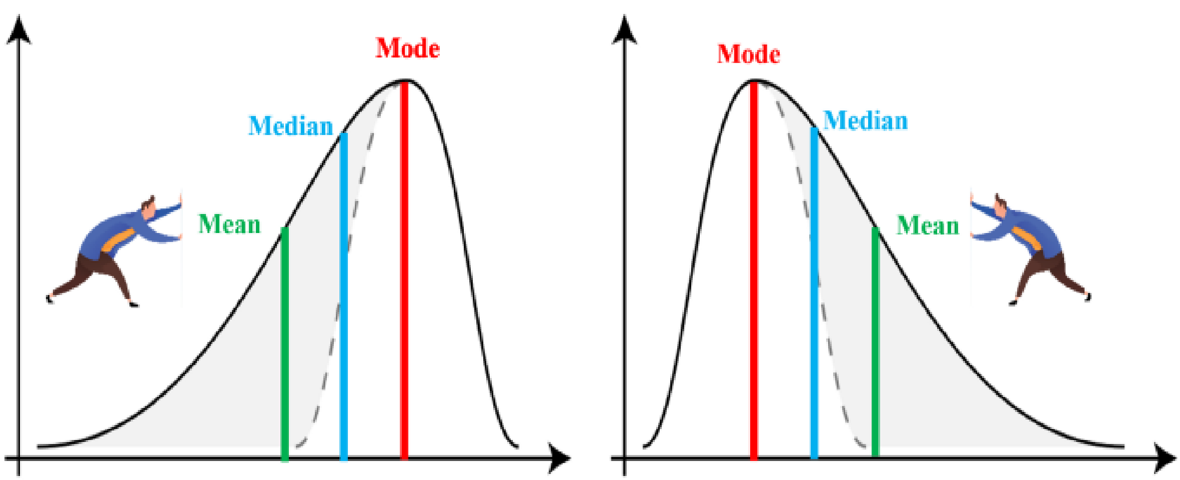


Figure 5-3-2- 2: Non-Symmetrical distribution of image

Notice how those crucial tendency measures generally tend to unfold whilst the normal distribution is distorted. For the nomenclature simply observe the course of the tail — For the left graph for the reason that tail is to the left, it's far left-skewed (negatively skewed) and the right graph has the tail to the proper, so it's far proper-skewed (definitely skewed). How approximately deriving a measure that captures the horizontal distance among the Mode and the Mean of the distribution? It's intuitive to assume that the better the skewness, the greater aside those measures will be. So, let's bounce to the formula for skewness now:

$$\text{Skewness} = \frac{\text{Mean} - \text{Mode}}{\text{Standard Deviiation}}$$

Division through Standard Deviation allows the relative contrast amongst distributions at the identical well-known scale. Since mode calculation as a crucial tendency for small records units isn't always recommended, so to reach at an improved component for skewness we can update mode with the derived calculation from the median and the mean.

$$\text{Mode} = 3\ (\text{Median}) - 2\ (\text{Mean})$$

Replacing the value of mode in the formula of skewness, we get

$$\text{Skewness} = \frac{3(\text{Mean} - \text{Median})}{\text{Standard Deviiation}}$$

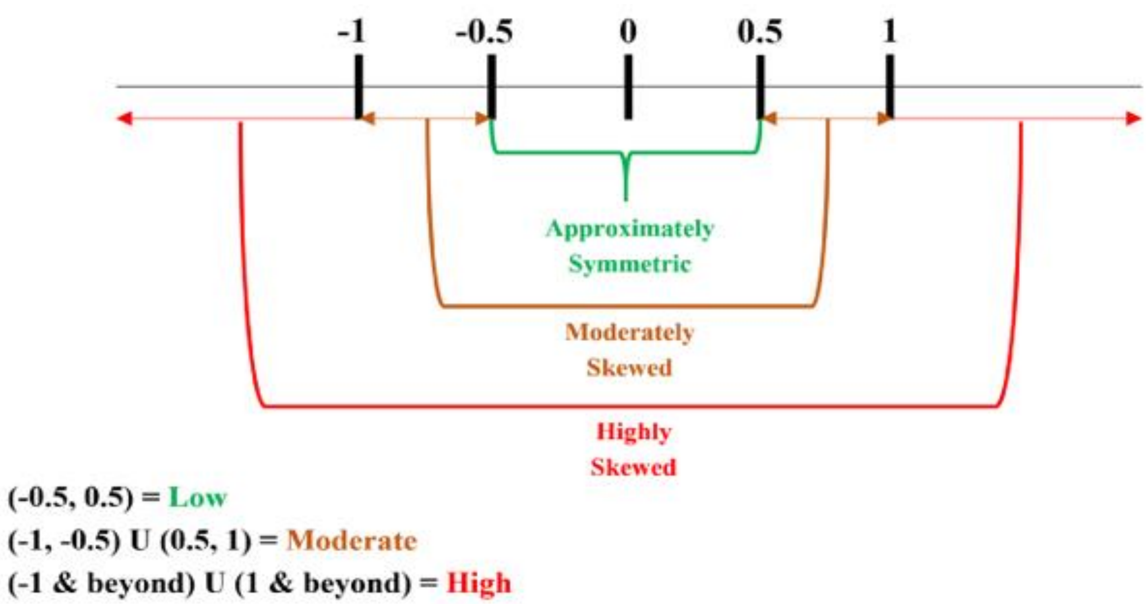


Figure 5-3-2- 3: Scale of Skewness

2. Kurtosis

Kurtosis is a measure of whether or not or now no longer a distribution is heavy-tailed or light-tailed relative to a normal distribution.

The kurtosis of anormal distribution is 3.
If a given distribution has a kurtosis much less than 3, it's far stated to be platykurtic, this means that it has a tendency to provide fewer and much less severe outliers than the normal distribution.
If a given distribution has a kurtosis extra greater than 3, it's far stated to be leptokurtic, this means that it has a tendency to provide extra outliers than the regular distribution.

- **Kurtosis equation**

  Think of punching or pulling the regular distribution curve from the top, what effect will it have at the form of the distribution? Let's visualize

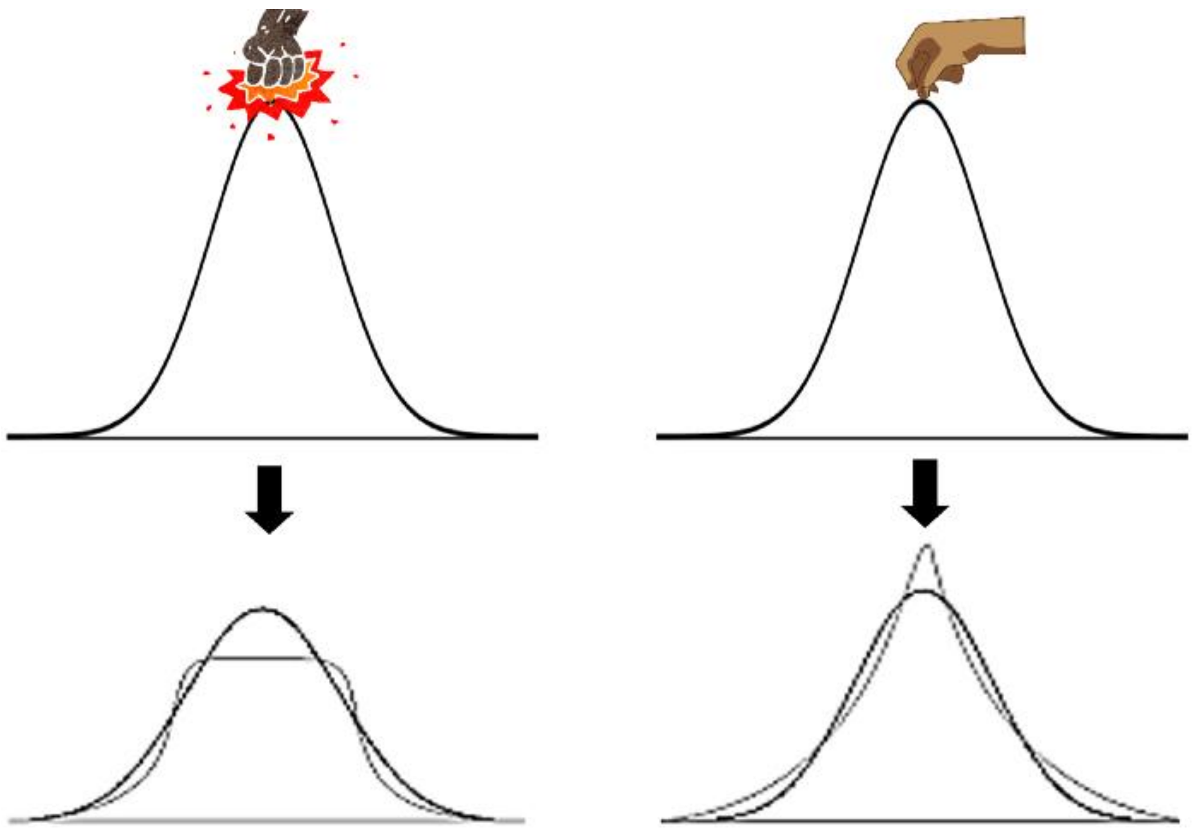


Figure 5-3-2- 4: pulling the normal distribution

So, there are two matters to notice — The height of the curve and the tails of the curve, Kurtosis measure is chargeable for taking pictures this phenomenon. The formula for kurtosis calculation is complex (4th second withinside the second-primarily based totally calculation) so we are able to persist with the idea and its visible clarity. An everyday distribution has a kurtosis of three and is referred to as mesokurtic. Distributions more than three are referred to as leptokurtic and much less than three are referred to as platykurtic. Sothe more the fee extra the peakedness. Kurtosis tiers from 1 to infinity. As the kurtosis measure for an everyday distribution is three, we are able to calculate extra kurtosis through maintaining reference 0 for everyday distribution. Now extra kurtosis will range from -2 to infinity.

- $\text{Excess Kurtosis} = \text{Kurtosis} - 3$
- Excess Kurtosis for Normal Distribution = 3–3 = 0
- The lowest value of Excess Kurtosis is when Kurtosis is 1 = 1–3 = -2

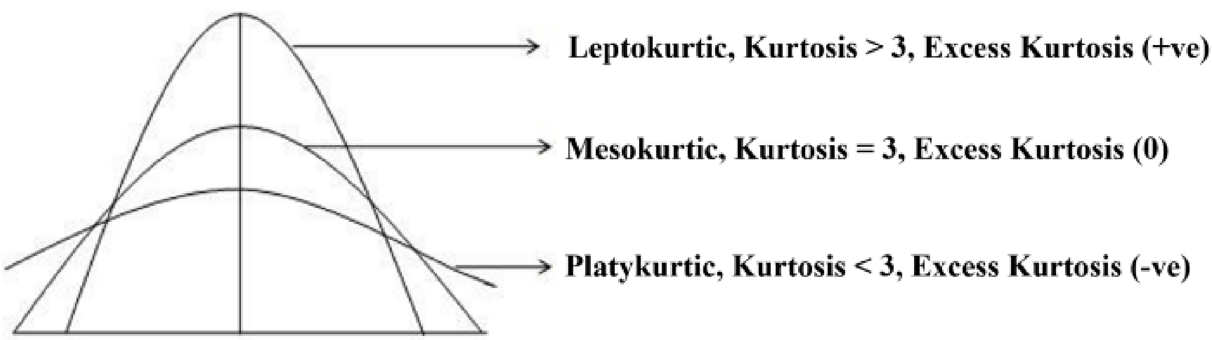


Figure 5-3-2- 5: Kurtosis types

- **After extracting the features of segmented images, then the dataset must be built withinside the right format, in order that it could receive to any of the same classifier tools.**

5-4: Classification:

5-4-1: introduction of Classification:

The essential feature for food quality evaluation is classification which contribute a structure in which artificial simulation of human thinking is done to guide humans form sophisticated judgments instantaneously, correctly and persistent. By using image-processing techniques, fruits and vegetables images can be described by set of features such as color, size, shape and texture. These features are used to form training set, and then classification algorithm is applied to extract knowledge base, which make a decision of unknown case.

Training Data Set (Labeled Data Set)

Data splicing

Testing Data Set (Labeled Data Set)

In computer vision system, a wide variety of methods: KNN, SVM, Ad boost, Fuzzy-NNeighbor, Support Vector Regression, Artificial Neural Network (ANN), Deep Learning/Convolutional Neural Network (CNN) have been developed for classification in food quality evaluation.

Our target here is to study two classical algorithms, which are KNN and SVM. IN ADDITION TO ONE BASED AI Algorithm, which is Convolution neural network. (CNN)

KNN targeted on similitude of samples measured by distance metric. It firstly selects K number of neighbors then based on Euclidian distance in each category, number of data point counted and then a new point is elected where new point can be counted. SVM is a powerful classification algorithm in which both linear and non-linear data is classified. It non-linearly maps data to a high dimensional space by using kernel functions. For 2-class problems, SVM finds the linear optimal hyper plane such that the distance between support vectors (extreme points of both the classes) can be maximized. Ad Boost can be used to boost the performance of any machine learning algorithm. It is best used with weak learners. These are models that achieve accuracy just above random chance on a classification problem (usually used with decision trees which contain one decision tree for classification). Fuzzy NNeighboris an approach to variable processing that allows for multiple values to be processed through the same variable. Fuzzy logic attempts to solve problems with an open, imprecise spectrum of data that makes it possible to obtain an array of accurate conclusions ANN are basically the computer programs which are biologically influenced to simulate the way in which the human brain process instruction. Development in deep learning and convolutional neural network are very efficient for fruit classification and recognition YHAN CLASSICAL MACHINE LEARNING ALGORITHMS since classical machine learning will reach their saturation level at one point, while deep learning algorithms are not saturated however, the amount of data existed.

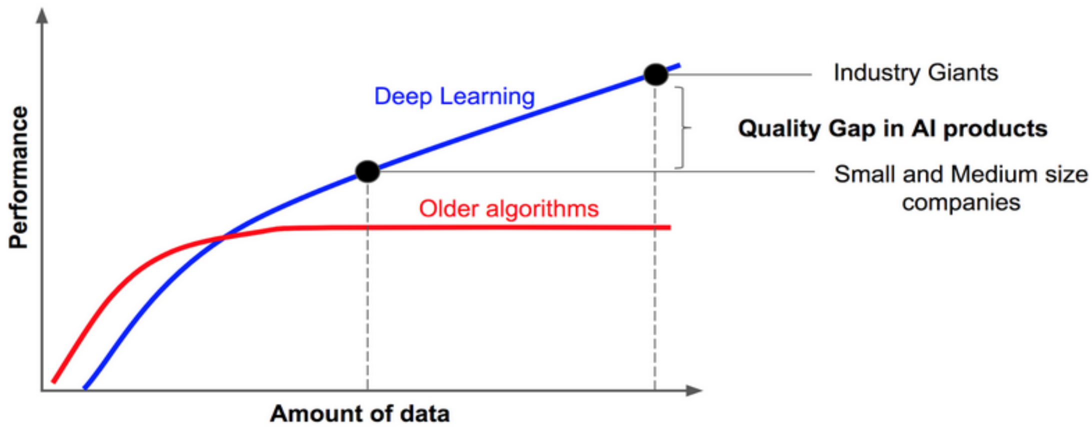


Figure 5-4-1- 1: Performance of classical algorithms with respect to the continuous growth of data

Deep learning learns the image features and extracts contextual details and global features that will help in reducing the error remarkably. Recently, the deep learning received major demand than any other machine learning algorithms. However, the associated research in fruit classification using this method is less presently.

- Popular algorithms that can be used for binary classification include:
  - Logistic Regression
  - k-Nearest Neighbors
  - Decision Trees
  - Support Vector Machine
  - SGD

- Now before getting through KNN and SVM let's have a brief understanding of classic machine learning.

- Classical machine learning has three ways to learn:

1. Supervised learning

   Simply it is a technique used to teach\train the machine using data, which is well labelled. Used with:

   - regression and classification.

2. unsupervised learning

This technique involves training the machine using unlabeled data and the model tries to act on this model without any guidance. Used with:

- clustering.

3. Reinforcement learning

In this algorithm, the machine is put in an environment and learns to behave by performing certain actions and observing the rewards, which will result from these actions.

- All kinds of classical problems are categorized to one of the following categories:
  1. Regression
     - Supervised learning.
     - Used with continuous output quantities. (continuous range of values)
     - Stock market weight graphs.
  2. Classification
     - Supervised learning.
     - Used with categorical quantities output. (used with segments\classes of data which are already well labelled)
     - differentiating between two or more classes of data.
  3. Clustering
     - Unsupervised learning.
     - Tries to assign input (unlabeled data) into groups\segments\classes.
- Now after having a brief knowledge about classical algorithms, let's discuss both KNN, SVM, Decision Trees, Support Vector Machine and SGD in details.

5-4-2: K-Nearest Neighbor Algorithm (K-NN):

Is a supervised classification algorithm that classifies a new input feature into the nearest suitable category depending on the neighboring features. (based on feature similarity of neighboring data).

- **Pseudo code:**

KNN (DATA, SAMPLE) {

1. Go to each item in the data set and calculate the distance "Euclidian Distance "from that item to the sample.
2. out of those samples we pick the "K" ones/ number of nearest samples that are most close to the new sample.
3. based on the features of the neighboring samples, the machine will classify our sample to the nearest suitable segment.

}

- **How to calculate the Euclidian distance between samples?**

The Euclidean distance between two points in Euclidean space is the length of a line segment between the two points. It can be calculated from the Cartesian coordinates of the points using the Pythagorean Theorem, therefore occasionally being called the Pythagorean distance.

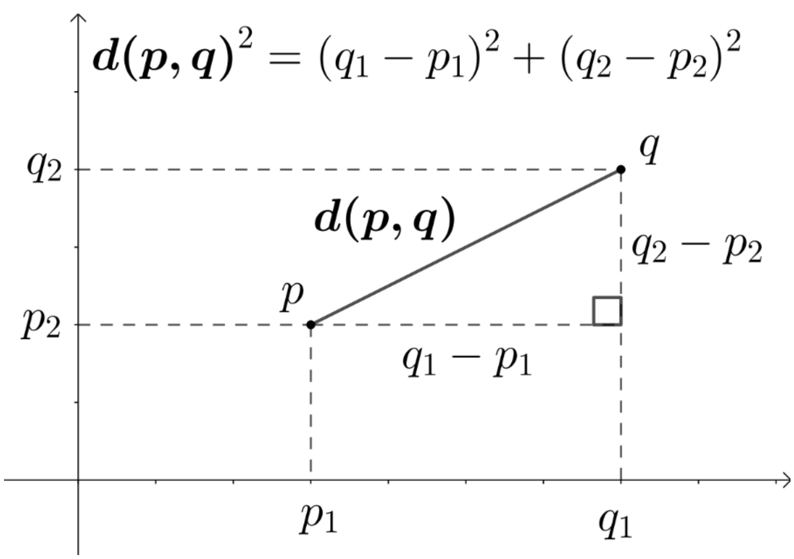


Figure 5-4-2- 1Figure 5-4-2 1: The Euclidean distance between two points

- **How to calculate the "K" factor?**

  There is no pre-defined statistical method. We just initialize it with a random value. The suitable value is that which lead to smoothing the decision boundaries. The higher the value of "K", the less the possibility of error rate.

5-4-3: Support Vector Machine Algorithm (SVM):

Is a supervised classification algorithm, which classifies/separates data using hyper planes into segments, where each segment contains only one feature? It is used with both linear data (single linear line) and non-linear data (data that cannot be separated by single linear line using kernel tricks).
Kernel: is a method to transform non-linear data into another space (dimensions) so that it can has a clear way to be classified. (Non-Linear Space into Linear Space)

- **Pseudo code:**

SVM {

1- It starts by drawing a random hyper plane.
   (Linear line for 2-D space)
2- check the distance between the hyper plane and the closest data point from each class.
3- hyper plane is drawn based on the support vectors. (Optimum hyper plane is the one that has a maximum distance from each of the support vectors)

}

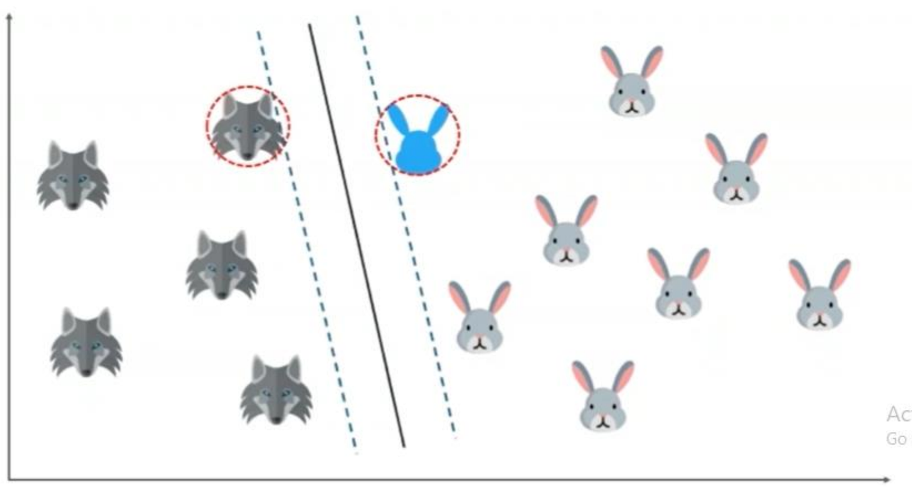


Figure 5-4-3- 1: Case of linear data

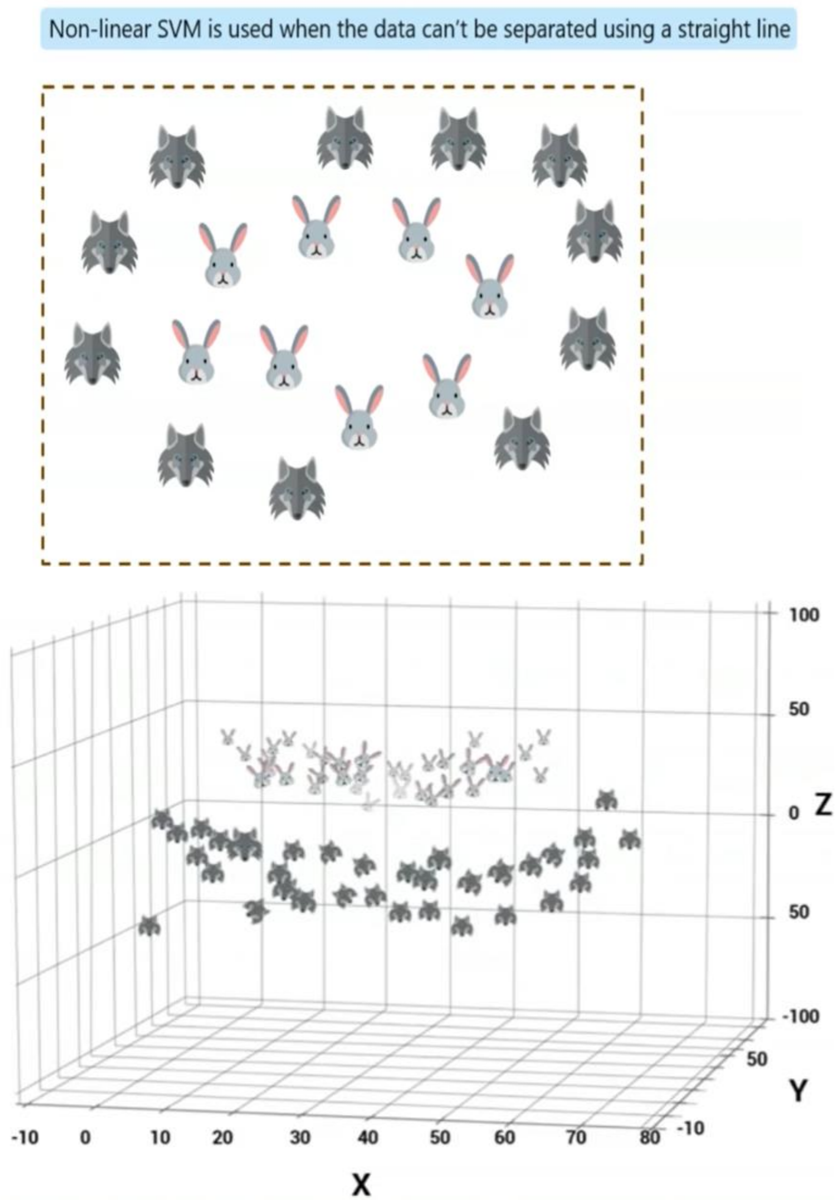


Figure 5-4-3- 2: Case of Non-linear data (need to be transferred to another space)

5-4-4: Decision Tree Algorithm:

- **What is Decision Tree Algorithm?**

Decision Tree algorithm belongs to the family of supervised learning algorithms. Unlike other supervised learning algorithms, the decision tree algorithm can be used for solving regression and classification problems too.

The goal of using a Decision Tree is to create a training model that can use to predict the class or value of the target variable by learning simple decision rules inferred from prior data (training data).

In Decision Trees, for predicting a class label for a record we start from the **root** of the tree. We compare the values of the root attribute with the record's attribute. On the basis of comparison, we follow the branch corresponding to that value and jump to the next node.

- **Important Terminology related to Decision Trees:**

1. **Root Node:** It represents the entire population or sample and this further gets divided into two or more homogeneous sets.
2. **Splitting:** It is a process of dividing a node into two or more sub-nodes.
3. **Decision Node:** When a sub-node splits into further sub-nodes, then it is called the decision node.
4. **Leaf / Terminal Node:** Nodes do not split is called Leaf or Terminal node.
5. **Pruning:** When we remove sub-nodes of a decision node, this process is called pruning. You can say the opposite process of splitting.
6. **Branch / Sub-Tree:** A subsection of the entire tree is called branch or sub-tree.
7. **Parent and Child Node:** A node, which is divided into sub-nodes is called a parent node of sub-nodes whereas sub-nodes are the child of a parent node.

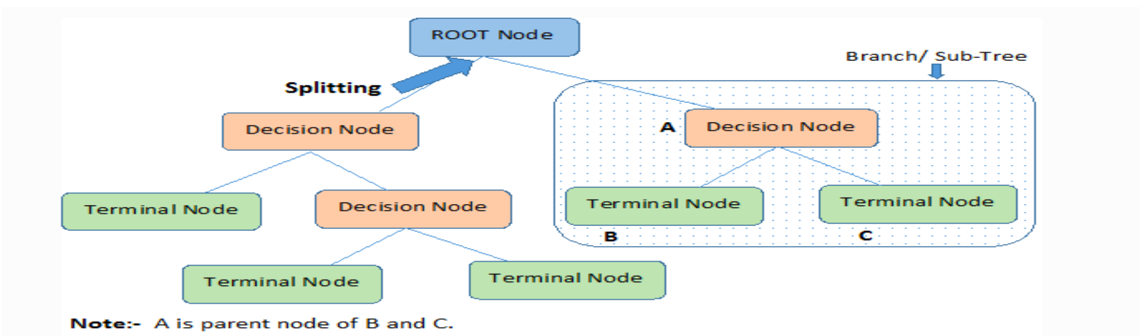


Figure 5-4-4- 1: Terminology related to Decision Trees

- **How do Decision Trees work?**

The decision of making strategic splits heavily affects a tree's accuracy. The decision criteria are different for classification and regression trees.
Decision trees use multiple algorithms to decide to split a node into two or more sub-nodes. The creation of sub-nodes increases the homogeneity of resultant sub-nodes. In other words, we can say that the purity of the node increases with respect to the target variable. The decision tree splits the nodes on all available variables and then selects the split which results in most homogeneous sub-nodes.

The algorithm selection is also based on the type of target variables. Let us look at some algorithms used in Decision Trees:

- **ID3** → (extension of D3)
- **C4.5** → (successor of ID3)
- **CART** → (Classification and Regression Tree)
- **CHAID** → (Chi-square automatic interaction detection Performs multi-level splits when computing classification trees)
- **MARS** → (multivariate adaptive regression splines)

  The ID3 algorithm builds decision trees using a top-down greedy search approach through the space of possible branches with no backtracking. A greedy algorithm, as the name suggests, always makes the choice that seems to be the best at that moment.
- **Steps in ID3 algorithm:**

1. It begins with the original set S as the root node.
2. On each iteration of the algorithm, it iterates through the very unused attribute of the set S and calculates Entropy(H) and Information gain (IG) of this attribute.
3. It then selects the attribute which has the smallest Entropy or Largest Information gain.
4. The set S is then split by the selected attribute to produce a subset of the data.
5. The algorithm continues to recur on each subset, considering only attributes never selected before.

5-4-5: Logistic Regression:

- Logistic regression is one of the most popular Machine Learning algorithms, which comes under the Supervised Learning technique. It is used for predicting the categorical dependent variable using a given set of independent variables.
- Logistic regression predicts the output of a categorical dependent variable. Therefore, the outcome must be a categorical or discrete value. It can be either Yes or No, 0 or 1, true or False, etc. but instead of giving the exact value as 0 and 1, it gives the probabilistic values which lie between 0 and 1.
- Logistic Regression is much similar to the Linear Regression except that how they are used. Linear Regression is used for solving Regression problems, whereas Logistic regression is used for solving the classification problems.
- In Logistic regression, instead of fitting a regression line, we fit an "S" shaped logistic function, which predicts two maximum values (0 or 1).
- The curve from the logistic function indicates the likelihood of something such as whether the cells are cancerous or not, a mouse is obese or not based on its weight, etc.
- Logistic Regression is a significant machine learning algorithm because it has the ability to provide probabilities and classify new data using continuous and discrete datasets.
- Logistic Regression can be used to classify the observations using different types of data and can easily determine the most effective variables used for the classification. The below image is showing the logistic function:

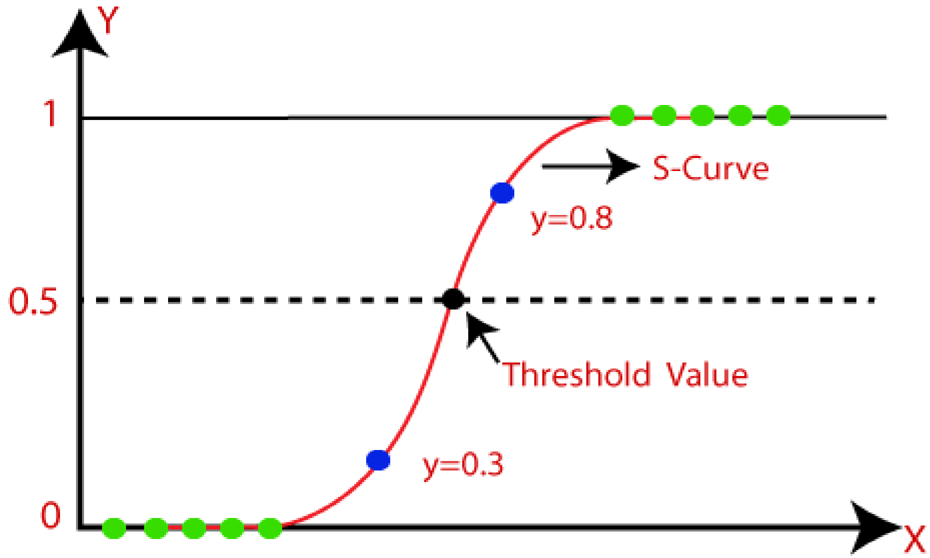


Figure 5-4-5- 1:Logistic Function (Sigmoid Function) curve

- **Logistic Function (Sigmoid Function):**

- The sigmoid function is a mathematical function used to map the predicted values to probabilities.
- It maps any real value into another value within a range of 0 and 1.
- The value of the logistic regression must be between 0 and 1, which cannot go beyond this limit, so it forms a curve like the "S" form. The S-form curve is called the Sigmoid function or the logistic function.
- In logistic regression, we use the concept of the threshold value, which defines the probability of either 0 or 1. Such as values above the threshold value tends to 1, and a value below the threshold values tends to 0.

- **Logistic Regression Equation:**

The Logistic regression equation can be obtained from the Linear Regression equation. The mathematical steps to get Logistic Regression equations are given below:

- We know the equation of the straight line can be written as:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + \cdots + b_nx_n$$

- In Logistic Regression y can be between 0 and 1 only, so for this let's divide the above equation by (1-y):

$$\frac{y}{1-y}; 0 \ for\ y = 0, and\ infinity\ for\ y = 1$$

- But we need range between -[infinity] to +[infinity], then take logarithm of the equation it will become:

$$\log\left[\frac{y}{1-y}\right] = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + \cdots + b_nx_n$$

The above equation is the final equation for Logistic Regression.

- **Type of Logistic Regression:**

On the basis of the categories, Logistic Regression can be classified into three types:

Binomial: In binomial Logistic regression, there can be only two possible types of the dependent variables, such as 0 or 1, Pass or Fail, etc.

Multinomial: In multinomial Logistic regression, there can be 3 or more possible unordered types of the dependent variable, such as "cat", "dogs", or "sheep"

Ordinal: In ordinal Logistic regression, there can be 3 or more possible ordered types of dependent variables, such as "low", "Medium", or "High".

5-4-6: Stochastic Gradient Descent (SGD):

- **What is Gradient Descent?**

Before explaining Stochastic Gradient Descent (SGD), let's first describe what Gradient Descent is. Gradient Descent is a popular optimization technique in Machine Learning and Deep Learning, and it can be used with most, if not all, of the learning algorithms. A gradient is the slope of a function. It measures the degree of change of a variable in response to the changes of another variable. Mathematically, Gradient Descent is a convex function whose output is the partial derivative of a set of parameters of its inputs. The greater the gradient, the steeper the slope.
Starting from an initial value, Gradient Descent is run iteratively to find the optimal values of the parameters to find the minimum possible value of the given cost function.

- **Types of Gradient Descent:**

Typically, there are three types of Gradient Descent:

1. Batch Gradient Descent
2. Stochastic Gradient Descent
3. Mini-batch Gradient Descent

- **SGD algorithm:**

So, in SGD, we find out the gradient of the cost function of a single example at each iteration instead of the sum of the gradient of the cost function of all the examples.

In SGD, since only one sample from the dataset is chosen at random for each iteration, the path taken by the algorithm to reach the minima is usually noisier than your typical Gradient Descent algorithm. But that doesn't matter all that much because the path taken by the algorithm does not matter, as long as we reach the minima and with significantly shorter training time.

$$for\ i\ in\ range\ (m):$$

$$\theta_j = \theta_j - \alpha\left(\hat{y}^i - y^i\right)x_j^i$$

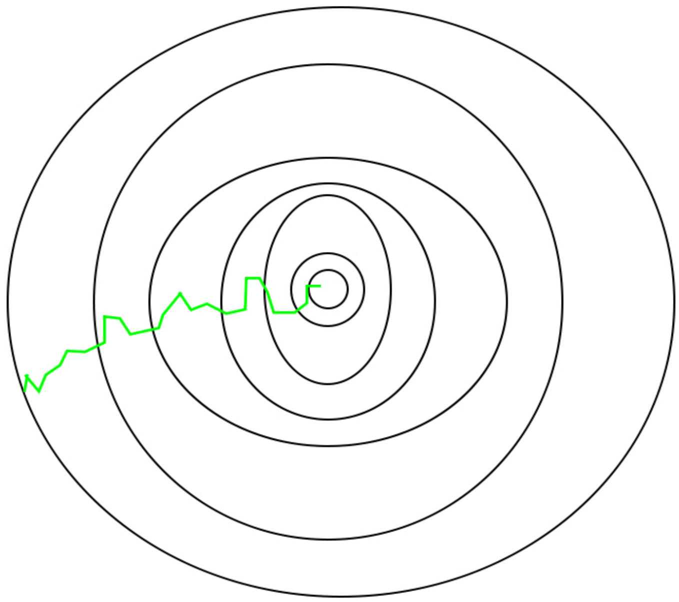


Figure 5-4-6- 1: Path taken by Batch Gradient Descent

Chapter 6
Methodology

Chapter 6: Methodology

6-1: System overview:

The system consists of three subsystems.

- The first one captures the orange's picture inside the black box,
- second one processes the image and performs the classification
- the third one places the fruit already classified in the desired container.

Oranges move in the conveyor belt and enter one by one in the inspection chamber. In there, camera get images from a lot of angles, except the bottom view which is fruitless by the conveyor belt.

Then the images are processed and the oranges are classified. A diagram of this mechanism is shown in Figure 6.1

Once a fruit is classified, the system has to take an action according to the obtained results.

Therefore, the actuator contains a series of gates placed at the closing stages of the conveyor belt to

redirect the fruit according the classified quality level, and deposit it in the preferred container.

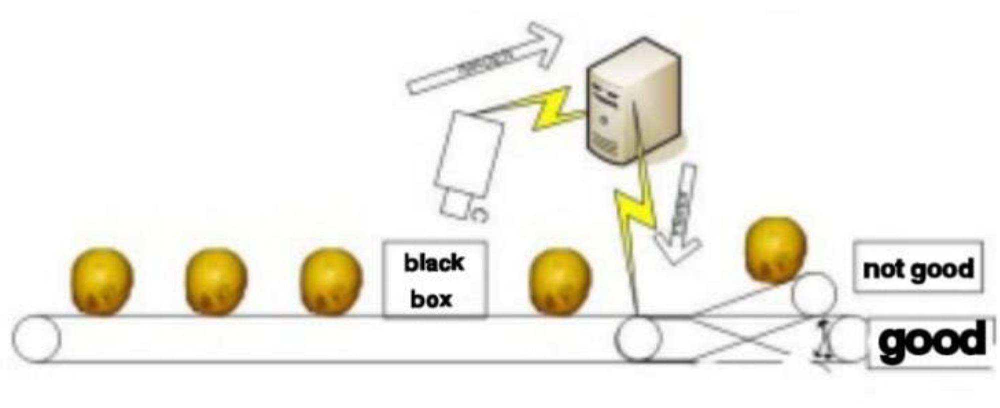


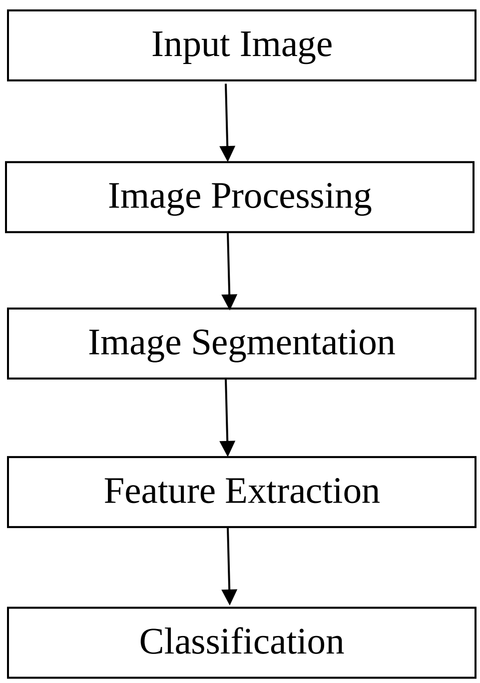
Figure 6- 1: capturing mechanism

6-2: Processing:

The processing system is divided into the following steps:

- Pre-processing
- segmentation
- Features extraction
- Classification

as show in block diagram



6-3: Pre-processing:

Digital image processing deals with manipulation of digital images through a digital computer. It is a subfield of signals and systems but focus particularly on images. DIP focuses on developing a computer system that is able to perform processing on an image. The input of that system is a digital image and the system process that image using efficient algorithms, and gives an image as an output. But, in high-level image processing-with computer vision applications- we give an input image to the machine and the output is an understanding to that machine so that it can easily make a decision about something based on the features of the captured image's objects.

- It thought that we are going to face either one, two, three or none of the following:

1. Blurring

   Now if we looked at our design, it is clear that we are going to use a slow-motion motor, which will extremely minimize the effect of blurring. For more assurance some filters were tested as Gaussian, median and bilateral filters. It was found that the best choice is bilateral but it has both advantages and disadvantages. Thus, it will not be applied unless it needed.

2. Shading

   Shading effect depends on the illumination system (amount of light reflected and absorbed by the object), which is a try and error method. On the other side, if exists it can be removed during segmentation process.

3. Glaring effect

   glare may be caused due to the poor illumination positioning and can be reduced by a well adjustment of the illumination system and using a histogram equalizer for adjusting and spreading out the intensities (pixels) and enhancing the image's contrast.

6-4: Segmentation:

Digital image processing is the use of computer algorithms to perform image processing on digital images. Image segmentation is an important and challenging process of image processing. Image segmentation technique is used to partition an image into meaningful parts having similar features and properties. The main aim of segmentation is simplification. representing an image into meaningful and easily analyzable way. Image segmentation is necessary first step in image analysis. The goal of image segmentation is to divide an image into several parts/segments having similar features or attributes.

- the segmentation is done by two techniques:
  1. first similarity detection like Otsu threshold
  2. second discontinuity detection like Sobel operator

1. **First by using Otsu threshold**

   This is done by using any appropriate threshold value/T. This value of T will be constant for whole image. On the basis of T, the output image can be obtained from original image

- select initial threshold value.
- Divide the original image into two portions;
  - Pixel values that are less than or equal to the threshold; background
  - Pixel values greater than the threshold; foreground
- Find the average mean values of the two new images
- Calculate the new threshold by averaging the two means.
- If the difference between the previous threshold value and the new threshold value are below a specified limit, you are finished. Otherwise apply the new threshold to the original image keep trying

$$T_{new} = \frac{m_1 + m_2}{2}$$

If $|T - T_{new}| > \Delta T$, back to step 2, otherwise stop.

As shown below First image for un healthy and healthy orange before segmentation

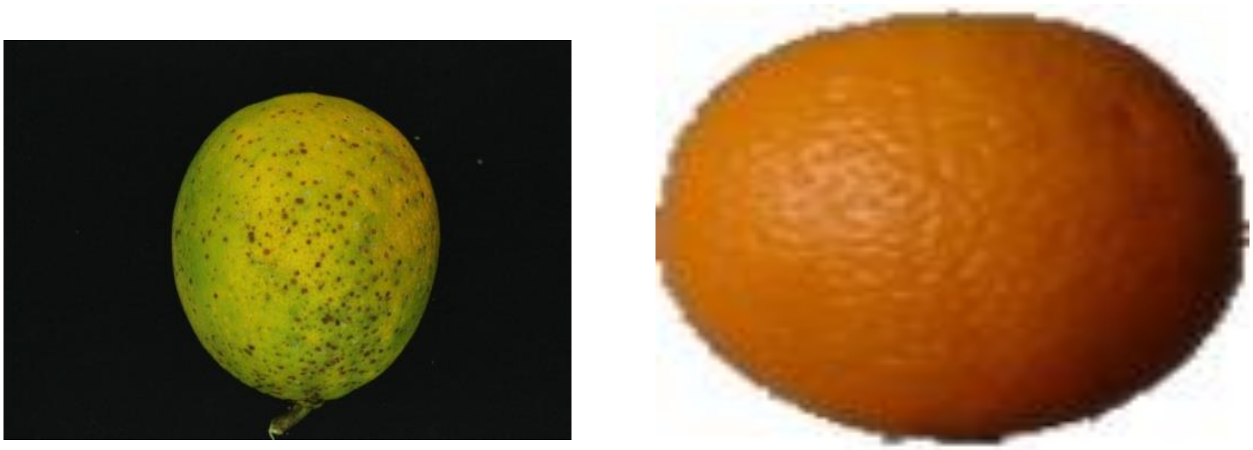


Figure 6-4- 1: Un healthy orange and healthy orange

❖ Working with our datasets

- **Techniques of thresholding:**

1. binary threshold: background represented by black, while the object (orange) represented by white.
2. Binary inverting threshold: background represented by white, while the object (orange) represented by black.

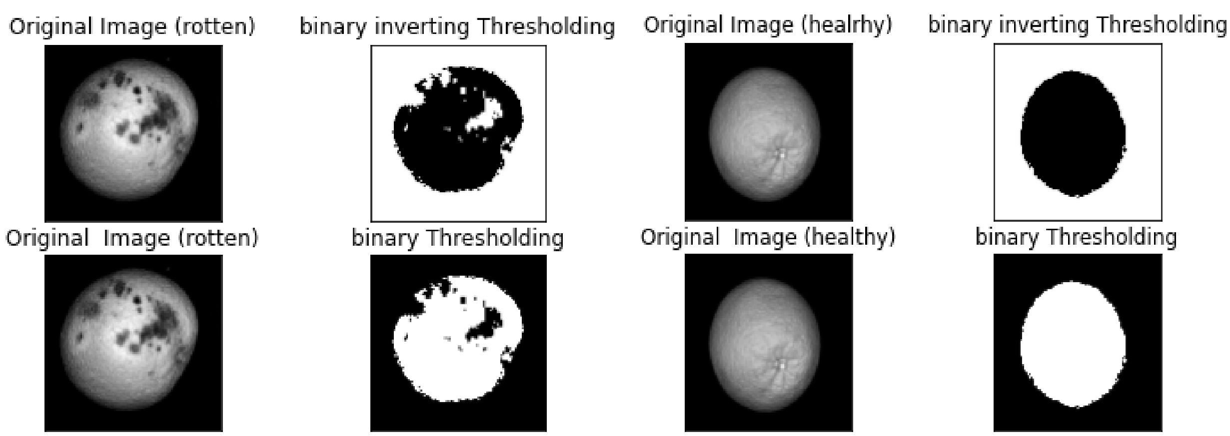


Figure 6-4-2: The result of image after segmentation by using binary & binary inverting threshold

It's no difference between binary inverting threshold and binary threshold, so we used binary inverting threshold.

❖ Methods to specify threshold value:

First image for un healthy and healthy orange before segmentation

- We used Otsu threshold because it faster and more accurate than global threshold, As shown below.

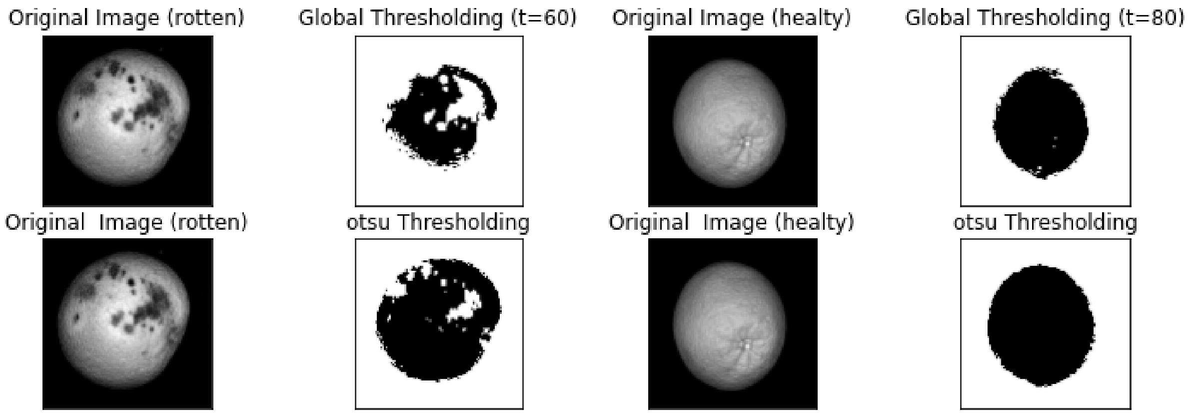


Figure 6-4-3: The result of image after segmentation by using Otsu threshold

2. Second by using Sobel

The Sobel edge detection operator extracts all the edges of an image, without worrying about the directions. The main advantage of the Sobel operator is that it provides differencing and smoothing effect. Sobel edge detection operator is implemented as the sum of two directional edges. And the resulting image is a unidirectional outline in the original image

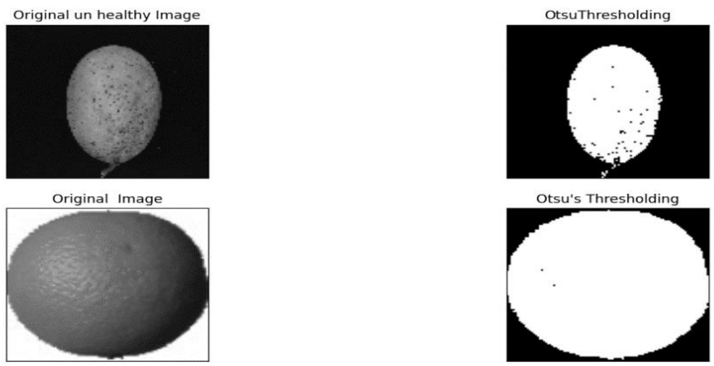


Figure 6-4- 4: The result of image after segmentation by using Otsu threshold

- **Sobel operator pseudocode**

  - convert the image from an RGB scale to a Grayscale image
  - apply x-direction kernel convolution to image
  - apply y-direction kernel convolution to image
  - Magnitudes of both the X and Y kernels will then be added together to produce a final image showing all edges in the image

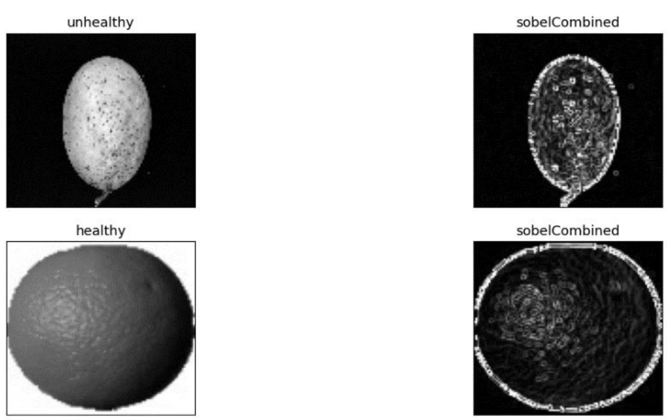


Figure 6-4- 5: The result of image after segmentation by using Sobel

❖ Working with our datasets

- **Discontinuity detection:**

we use Sobel operator do detect the edges of image

1. Sobel x operator to detect the horizontal edges

2. Sobel y operator to detect the vertical edges

3. Sobel combined to combine between vertical and horizontal edges

As show in figures

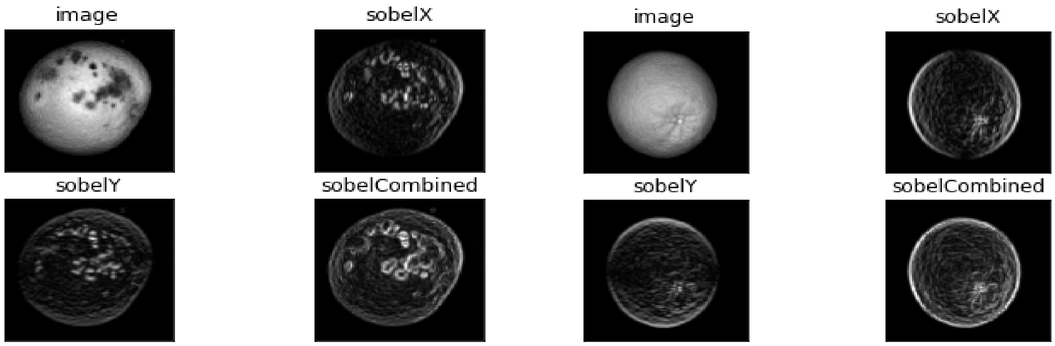


Figure 6-4- 6: The result of image after segmentation by using Sobel

From the result we note that the threshold results are better than Sobel.

6-5: Feature extraction:

- **Working with the previous data sets**

Feature plays a very important role in the area of image processing
Feature extraction techniques are helpful in various image processing applications. character recognition. As features define the behavior of an image, they show it place in terms of storage taken, efficiency in classification and obviously in time consumption also. Here in this paper, we are going to discuss various types of features
We used statistical feature, texture feature, shape feature Then make vector feature from them.

6-5-1: Statistical feature:

We used mean, standard deviation and variance to get 3 number from the segmented image.

Sample of healthy and nonhealthy images

Segmentation technique	mean	variance	Standard deviation	Label of fruit 2 for healthy 4 for un healthy
Threshold	74	116	13488	4
	76	116	13608	4
	73	115	13289	4
	71	114	13065	4
	193	108	11843	2
	200	104	10970	2
	198	105	11212	2
	197	106	11288	2
Sobel	24	44	1990	4
	28	50	2567	4
	27	46	2166	4
	27	46	2166	4
	37	50	2588	2
	37	50	2554	2
	37	50	2594	2
	37	50	2595	2

Table 6-5-1- 1: Sample of Statistical feature for image

6-5-2: Shape feature:

By using skewness and Kurtosis

- Each feature makes a vector contain 100 elements as shown in figure below
  Example The vector of kurtosis

```
[ 1.11674644e+00  1.71046597e+00  8.20238771e-01  1.20127302e+00
  3.01817215e-01  2.63904925e+00  1.71278052e+00  1.44212113e+00
  1.50600576e-01  1.08880919e+00  3.94007654e-01 -9.25779008e-01
 -2.64742049e-01  1.79104252e+00  3.40750453e-01  1.65024973e+00
  1.22968464e+00  8.16260431e-01  8.00643133e-01  2.88775330e+00
  1.14961241e+00  1.60973665e+00  4.18249948e-01 -5.04993760e-01
 -6.85359827e-01 -3.54256159e-01  1.83248830e+00  1.74147883e+00
  1.51386880e+00  5.88902989e+00  2.36182626e+00  2.70878037e+00
  3.15024488e+00  2.01025832e+00  1.08375893e+00  3.24569220e+00
  3.40111948e+00  3.98130330e+00  2.84358044e+00  2.97736816e+00
  3.27308877e+00  3.69468832e+00  1.28625082e+00  1.90967027e+00
  1.13755975e+00  2.75500075e+00  1.50736000e+00  4.78685284e-01
  6.79508307e-01  6.51818706e-01  9.57876833e-01 -1.59963458e-01
 -4.09390620e-02 -6.07112839e-02  5.93014852e-01  3.22849049e-01
  5.38979921e-01  7.22500831e-01  3.27670740e-01  3.29161756e-01
  7.54700206e-01  1.78443678e+00  1.51511950e+00  1.92750984e+00
  2.63661736e+00  1.53767916e+00  1.07143550e+00  4.31810165e+00
  3.34775446e-01  9.33103371e-01  1.48641370e+00  2.03724399e+00
  1.28022816e+00  1.67921161e+00  5.72216353e-01  1.32534383e+00
  4.51495984e-01  4.04660860e+00 -3.40577251e-01  5.52884045e-01
 -6.62425615e-03  1.12099432e+00  3.02523483e+01  3.29724744e+01
  2.77604647e+01  3.89062059e+00  1.11991604e+00  1.33057425e+00
  5.90977043e-01  9.49361535e-01  3.00452127e+00  1.03380932e+00
  1.07253120e+00  1.31001432e+00  1.62342421e+00  2.44873398e-01
 -1.74639048e-01  2.59546812e+00  2.50510046e+00  3.03006053e+00]
```

Figure 6-5-2- 1: Example of the vector of skewness

```
[1.08964708 1.22572545 0.83158702 1.01013555 0.79599438 1.14319477
 0.98982373 1.10164518 0.61701503 1.00960069 0.74924935 0.43034133
 0.68512474 1.23328423 0.77559071 0.90309094 0.78718353 0.70583423
 0.87764363 1.32137325 0.70686629 1.16260768 0.83778228 0.40103999
 0.44799924 0.50459471 1.15418748 1.22700662 1.3046987  2.38732769
 1.74744876 1.87101094 2.02051852 1.59695315 1.28234944 1.87163762
 1.92908346 1.91894897 1.74821019 1.69043728 1.71392558 1.95886644
 1.42674406 1.56904973 1.46387873 1.77041883 1.41768087 1.23192408
 1.3101011  1.08075373 1.12518306 0.88818308 0.76528328 0.95344144
 1.08678588 0.98372344 1.10977453 0.94989911 0.78866957 0.88519284
 1.04470084 1.51062959 1.2123231  1.46312999 1.6119185  1.21525877
 1.19375533 1.96000449 1.16042597 1.29719431 1.37649813 1.6124323
 1.5164715  1.56023197 1.27445758 1.56121171 1.49749486 2.38231275
 0.31364582 0.86472273 0.65883057 0.95537426 5.02764729 5.50177878
 5.05449111 1.31333561 0.75425537 1.0385159  0.64278057 0.55695841
 1.3938141  1.08430137 0.89445685 1.20488676 1.32438547 0.71878111
 0.42374056 1.30064391 1.43590682 1.3550286 ]
```

Figure 6-5-2- 2: Example of the vector of kurtosis

- Then reduce these 200 numbers which get from skewness and kurtosis to only 3 number
- By get the mean and variance of the vector of kurtosis and the mean of vector of skewness
- Then get the absolute of the three numbers

Sample of healthy and non-healthy images

Segmentation technique	kurtosis	Kurtosis	Skewness	Label of fruit 2 for healthy 4 for non-healthy
Threshold	0	2	0	4
	0	2	1	4
	0	2	1	4
	0	1	10	4
	1	5	64	2
	2	9	227	2
	2	6	108	2
	2	6	75	2
Sobel	1	3	14	4
	1	2	29	4
	1	4	30	4
	1	4	30	4
	2	7	16	2
	2	7	14	2
	2	7	16	2
	2	8	19	2

Figure 6-5-2- 3: Sample of shape feature for image

6-5-3: Texture feature:

By using Gabor filter which applied to the Segmentate image, Sample of effect of Gabor filter after Otsu segmentation

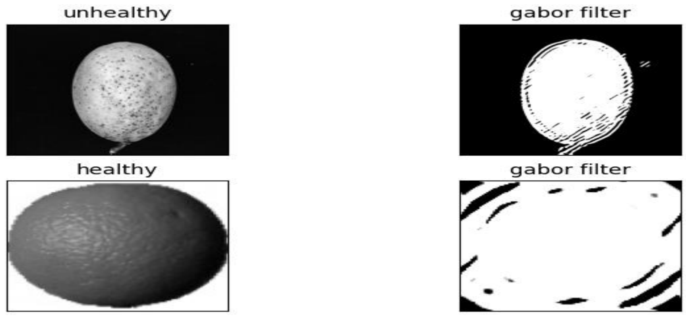


Figure 6-5-3- 1: Result of Gabor filter

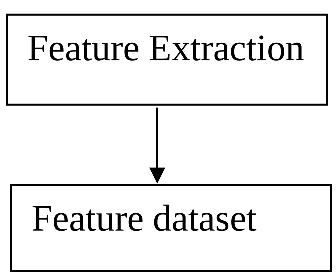
Then by get vector contain 3 numbers by get the mean and variance and standard deviation of the Gabor vector

Sample of healthy and non-healthy images

Segmentation technique	Gabor	Gabor	Gabor	Label of fruit 2 for healthy 4 for un healthy
threshold	74	116	13488	4
	76	116	13608	4
	73	115	13289	4
	71	114	13065	4
	193	108	11843	2
	200	104	10970	2
	198	105	11212	2
	197	106	11288	2
Sobel	24	44	1990	4
	28	50	2567	4
	27	46	2166	4
	27	46	2166	4
	37	50	2588	2
	37	50	2554	2
	37	50	2594	2
	37	50	2595	2

Table 6-5-3- 1: Sample of Gabor for image

- **feature data set**
  So, the final feature vector contains 9 element which describe statistical, shape, texture feature
  Then make feature data set by convert the image data set to feature data set as shown in block



Sample of healthy and non-healthy feature data set

Segmentation technique	Statistical feature	Statistical feature	Statistical feature	texture feature	texture feature	texture feature	shape feature	shape feature	shape feature	Label of fruit
Threshold	74	116	13488	120	125	15781	0	2	0	4
	76	116	13608	123	125	15845	0	2	1	4
	193	108	11843	229	74	5607	1	5	64	2
	200	104	10970	230	74	5561	2	9	227	2
Sobel	24	44	1990	111	109	11916	1	3	14	4
	28	50	2567	115	110	12121	1	2	29	4
	37	50	2588	155	117	13814	2	7	16	2
	37	50	2554	157	115	13410	2	7	14	2

Table 6-5-3- 2: Sample of Statistical, texture and shape feature for image

6-5-4: Working with our datasets(feature):

In the previous dataset we use nine feature which extracted from

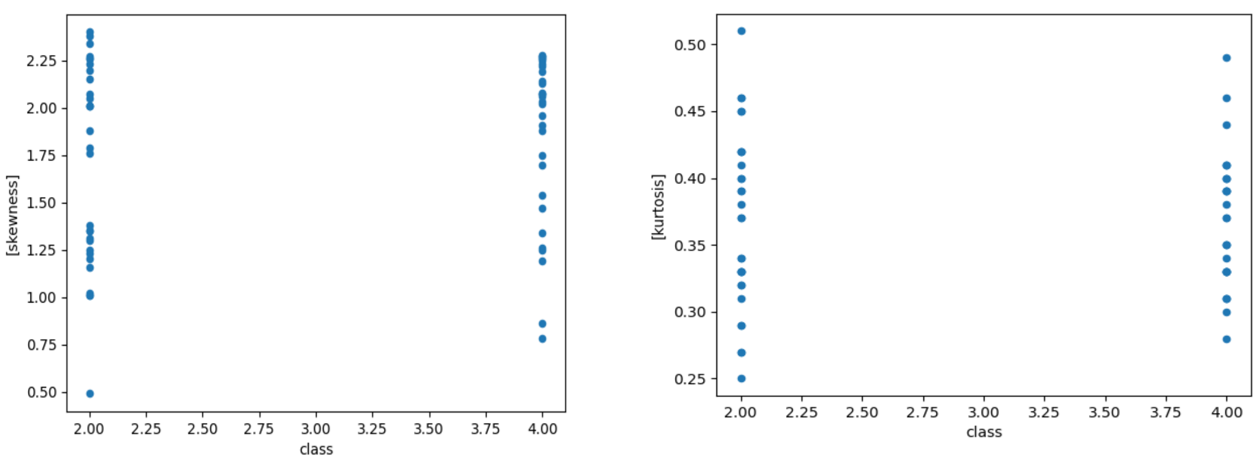
1. Statistical feature (mean, variance, standard deviation)
2. Shape features (skewness, kurtosis)
3. Texture feature (Gabor filter)

We use these features because it with suitable for the data set and there was variation between the range of features that extracted between healthy and non-healthy oranges so the classifiers have a high accuracy, but when we apply this features in our data set some of this feature is good to our data set and same is not good (such as shape feature)

- **Why shape feature is not suitable to our data set?**

When we apply the skewness and kurtosis in same of our data set, we observed that the distribution of feature that extracted from healthy and non-healthy images is random and there is a big interface between them so this will cause a low accuracy when use it to classification

The figure below is illustrating the distribution of this features



Figuer6-5-4-1: Distribution of skewness & kurtosis feature on segmentate image

as shown from the figures there are big interface between the features of label 2 (healthy orange) and label 4(un healthy orange)

so, we don’t use the shape feature extraction in our data set so, in our data set we use

1. Statistical feature
2. Texture feature (GLCM)

In our data set we use GLCM to extract texture of image because it will increase the number of features that can be extracted from the image and it gives us also higher accuracy in classifiers as we use

- **Extract statistical feature from data set**

We used mean and standard deviation to get 2 number from the segmented image Sample of healthy and non-healthy vector feature, From the table there is an interference in some feature.

Segmentation technique	mean	Standard deviation	Label of fruit 2 for healthy 4 for un healthy
Threshold	8.043	5.753	4
	8.105	5.573	
	8.069	4.807	
	8.072	4.943	
	7.753	7.22	2
	7.766	7.164	
	7.801	7.004	
	7.787	7.37	
Sobel	0.204	2.875	4
	0.207	3.389	
	0.233	3.481	
	0.263	2.456	
	0.311	3.648	2
	0.393	3.689	
	0.366	2.554	
	0.299	3.033	

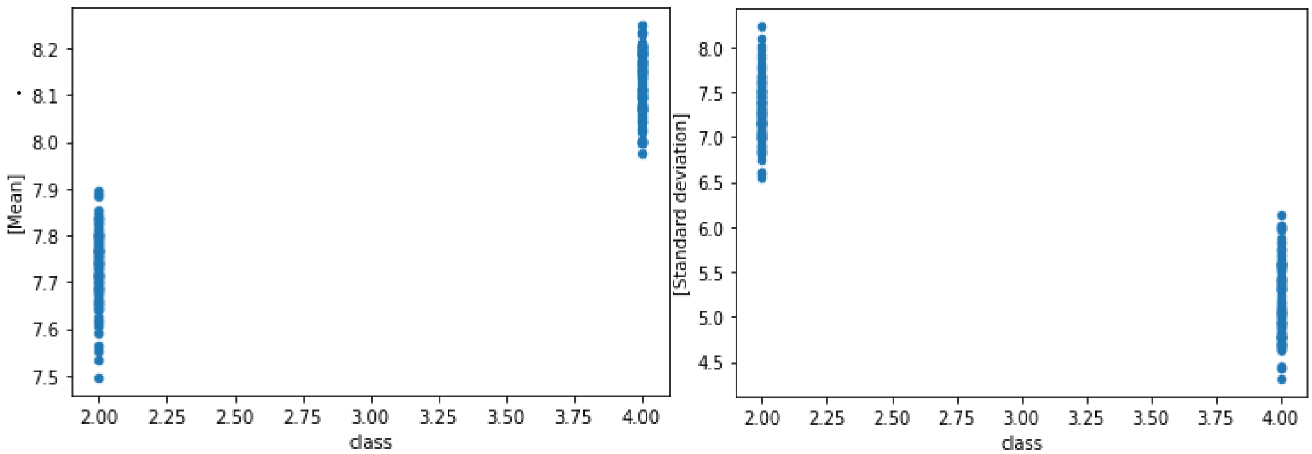
Table 6-5-4-1: Sample of healthy and non-healthy vector feature

The figures below are illustrating the distribution of this features

- **Threshold:**

- **Mean & Standard deviation**:

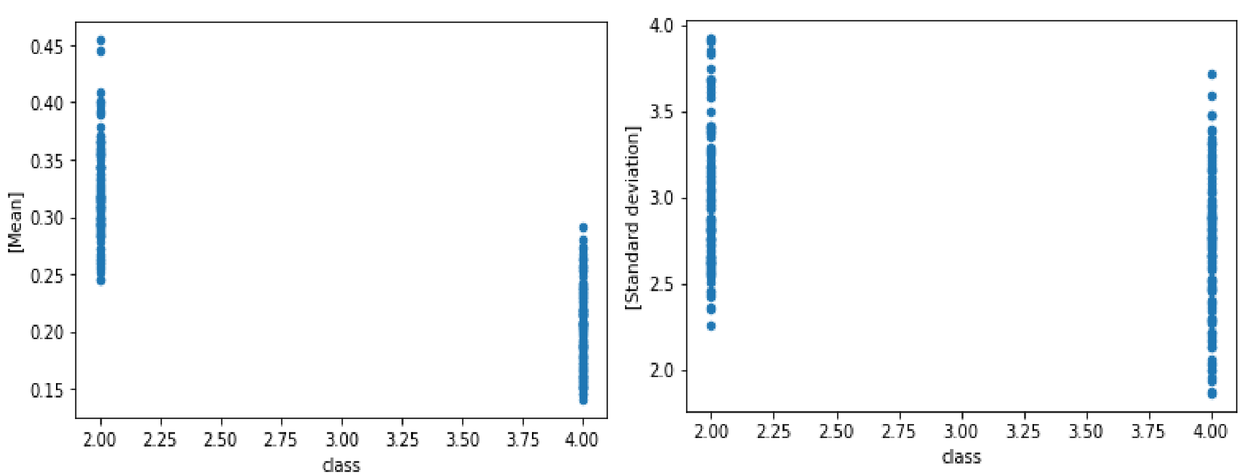
There is no interference between the features of label 2 (healthy orange) and label 4(un healthy orange)



Figuer6-5-4-2: Distribution of Mean & Standard deviation feature on segmentate image (Threshold)

- **Sobel:**

- **Mean:** there is simple interference between the features of label 2 and label 4
- **Standard deviation:** there is high interference between the features of label 2 and label



Figuer6-5-4-3: Distribution of Mean & Standard deviation feature on segmentate image (Sobel)

- **Extract texture feature from data set:**

We use GLCM technique to extract texture feature by using following algorithms

1. contrast
2. dissimilarity
3. energy
4. ASM
5. correlation

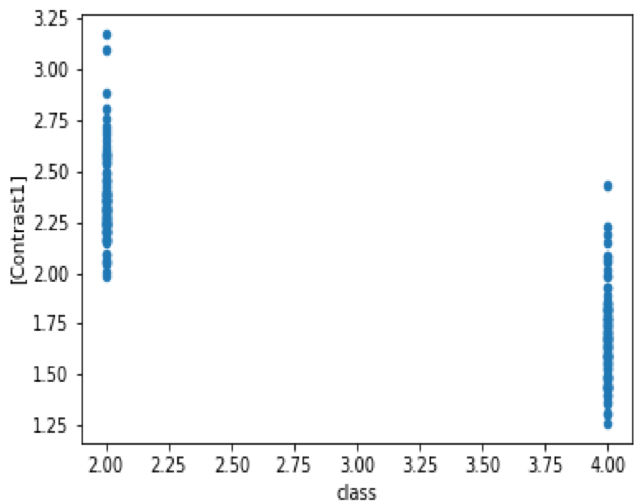
Each of this algorithm will extract four feature vectors from the image, so the total number of features that can extracted from image by use GLCM is 20 features but we will decrease the number of features by get the mean of feature vector of (contrast, dissimilarity, energy, ASM, correlation) And std of feature vector of (contrast, dissimilarity, correlation), So now the total texture feature that extracted from image is 8 features

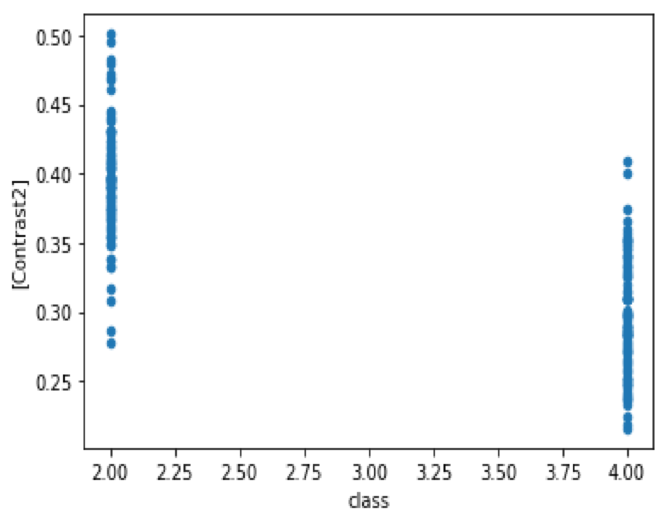
The figures below are illustrating the distribution of this features

- <u>**Threshold:**</u>

- **Contrast 1 & Contrast 2:**

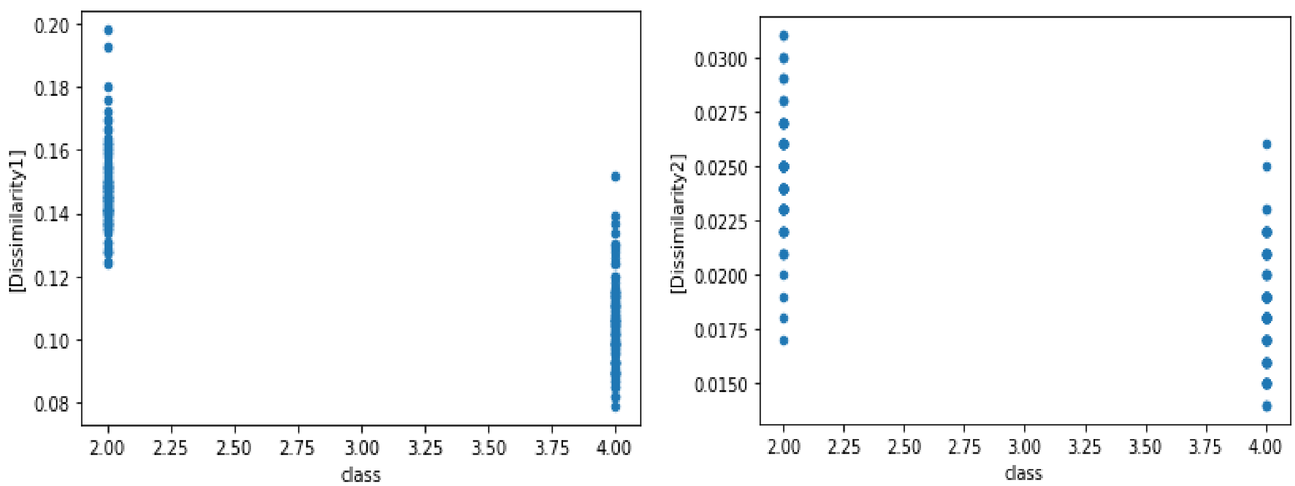
There is medium interference between the features of label 2 and label 4





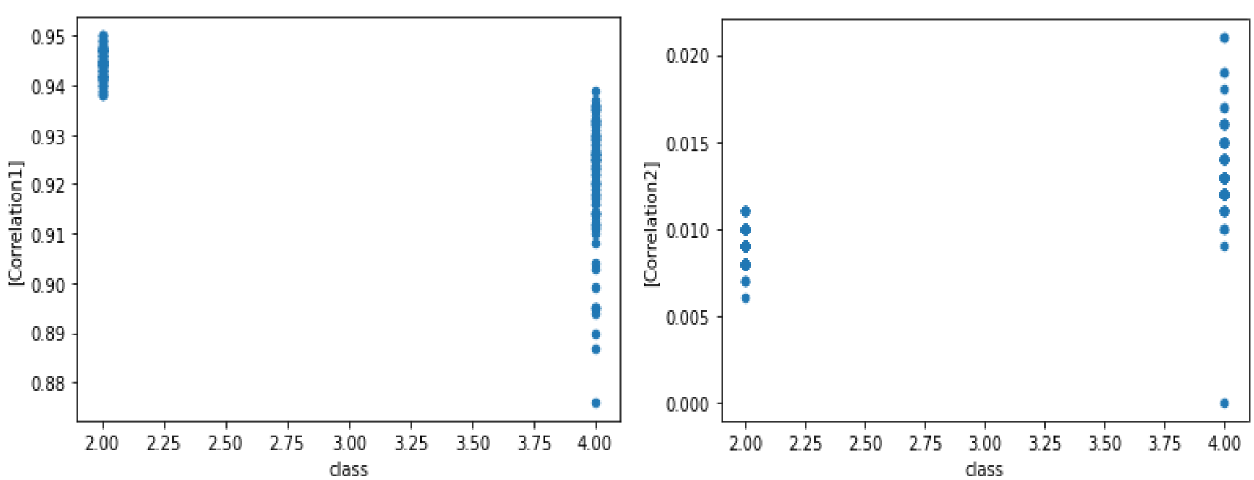
Figuer6-5-4-4: Distribution of contrast1 & contrast2 feature on segmentate image

- **Dissimilarity 1:** there is simple interference between the features of label 2 and label 4
- **Dissimilarity 2:** there is high interference between the features of label 2 and label 4



Figuer6-5-4-5: Distribution of $dissimilarity1$ & $dissimilarity2$ feature on segmentate image

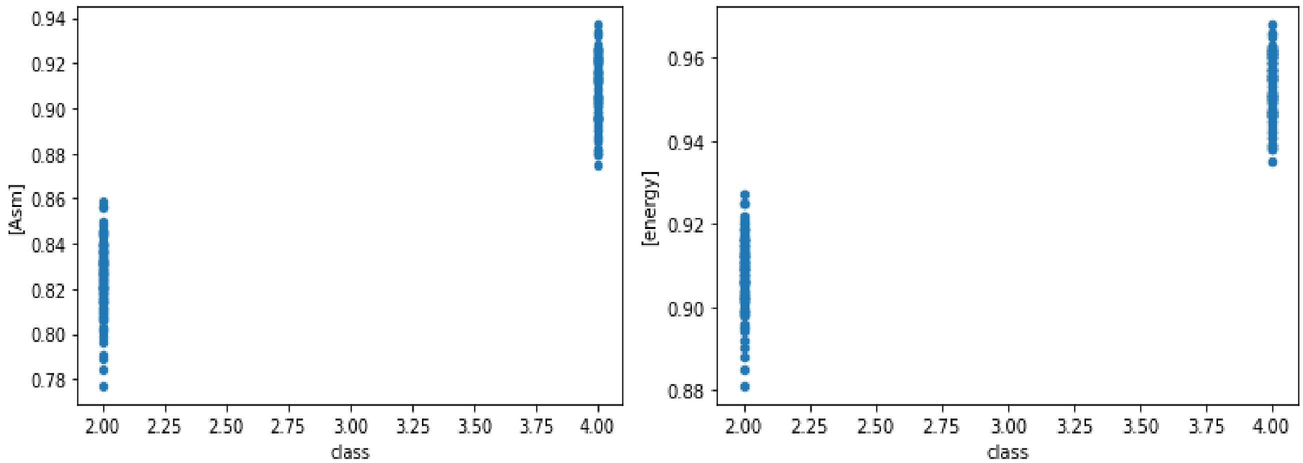
- **Correlation 1:** there is no interference between the features of label 2 and label 4
- **Correlation 2:** there is medium interference between the features of label 2 and label 4



Figuer6-5-4-6: Distribution of $correlation\ 1$ & $correlation\ 2$ feature on segmentate image

- **Asm and Energy:**

There is no interference between the features of label 2 and label 4

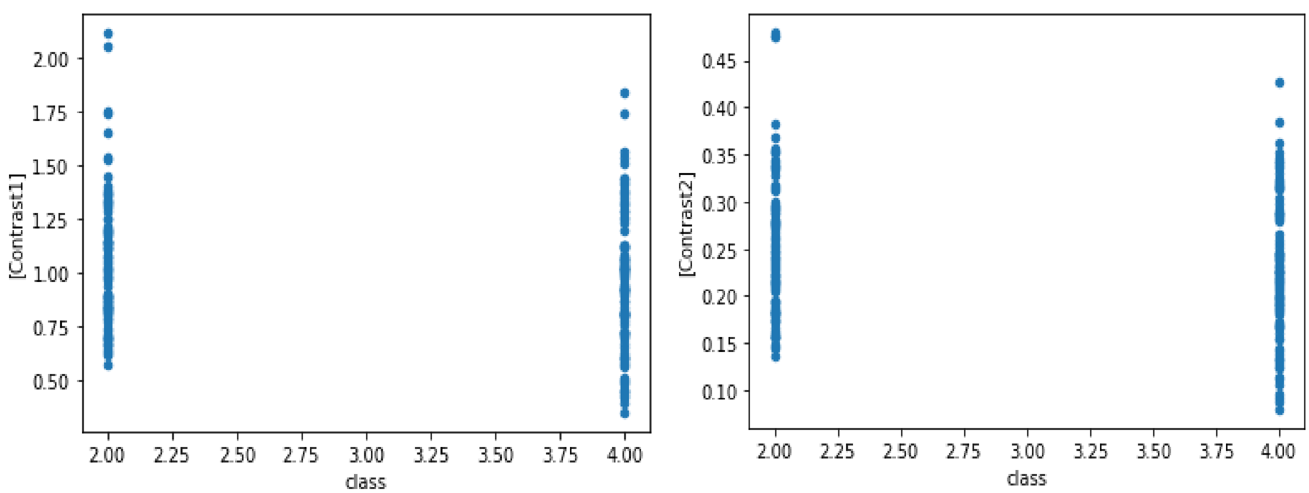


Figuer6-5-4-7: Distribution of Asm & energy feature on segmentate image

- <u>**Sobel:**</u>

- **Contrast 1 & Contrast 2:**

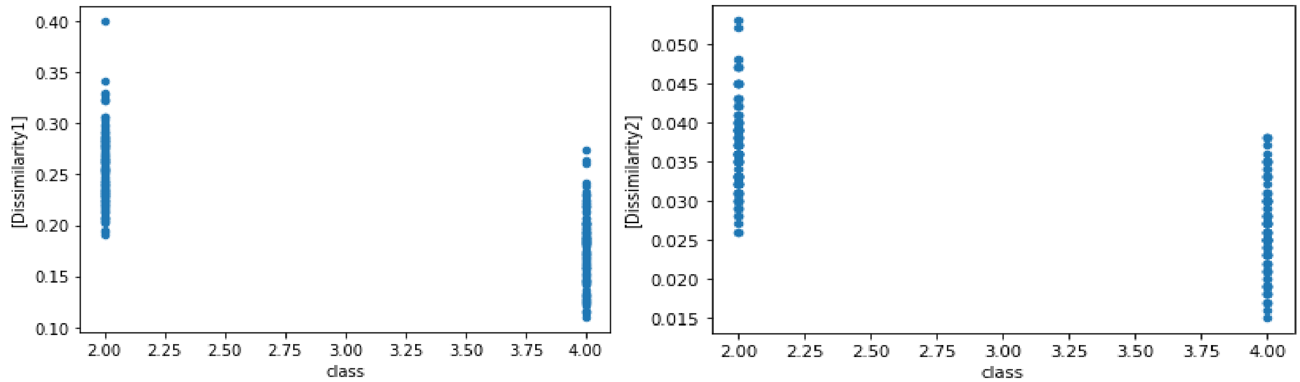
There is high interference between the features of label 2 and label 4



Figuer6-5-4-8: Distribution of contrast1 & contrast2 feature on segmentate image

- **Dissimilarity 1 and Dissimilarity 2:**

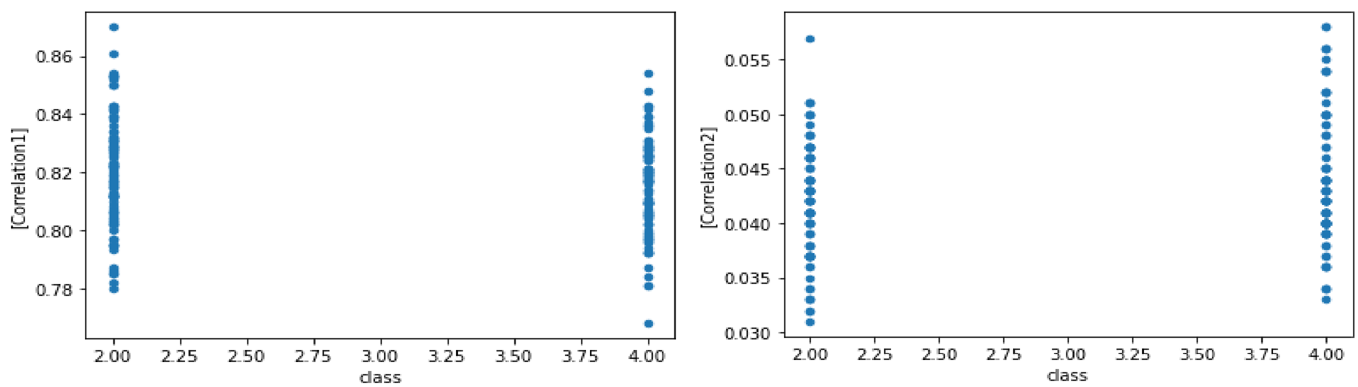
  There is medium interference between the features of label 2 and label 4



Figuer6-5-4-9: Distribution of dissimilarity1 & dissimilarity2 feature on segmentate image

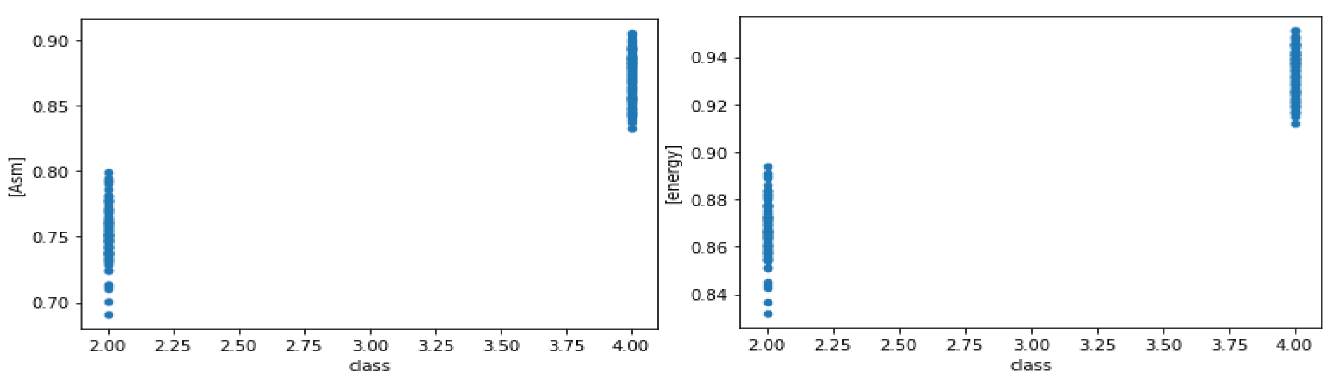
- **Correlation 1 and Correlation 2:**

  There is high interference between the features of label 2 and label 4



Figuer6-5-4-10: Distribution of correlation 1 & correlation 2 feature on segmentate image

- **Asm and Energy:** there is no interference between the features of label 2 and label 4



Figuer6-5-4-11: Distribution of Asm & energy feature on segmentate image

- **Feature's data set:**

Now features dataset contain 1035 sample 515 for healthy and 520rotten each sample contain 10 features

1. first column contains the id of fruit
2. Last column contains the label of fruit
3. The reminder columns contain the statistical and texture features

- **Sample of the feature data set for threshold segmentation**

id	Contrast1	Dissimilarity1	Asm	energy	Correlation1	Contrast2	Dissimilarity2	Correlation2	Mean	Standard deviation	class
1	2.224	0.139	0.888	0.942	0.916	0.400	0.025	0.015	8.043	5.753	4
2	1.990	0.124	0.902	0.950	0.914	0.366	0.023	0.016	8.105	5.369	4
3	2.081	0.130	0.894	0.946	0.917	0.353	0.022	0.014	8.069	5.594	4
1	2.458	0.154	0.830	0.911	0.940	0.396	0.025	0.009	7.766	7.164	2
2	2.250	0.141	0.829	0.910	0.946	0.480	0.030	0.011	7.753	7.220	2
3	2.276	0.142	0.831	0.912	0.944	0.356	0.022	0.008	7.766	7.164	2

Figuer6-5-4-12: Sample of the feature data set for threshold segmentation

- **Sample of the feature data set for Sobel segmentation**

id	Contrast1	Dissimilarity1	Asm	energy	Correlation1	Contrast2	Dissimilarity2	Correlation2	Mean	Standard deviation	class
1	1.024	0.202	0.848	0.921	0.816	0.246	0.029	0.044	0.233	2.875	4
2	1.427	0.230	0.860	0.927	0.821	0.325	0.035	0.040	0.263	3.389	4
3	0.977	0.192	0.853	0.924	0.820	0.222	0.024	0.040	0.229	2.838	4
1	0.674	0.213	0.746	0.864	0.853	0.145	0.028	0.031	0.313	2.715	2
2	0.623	0.213	0.732	0.855	0.850	0.146	0.031	0.035	0.311	2.608	2
3	0.670	0.220	0.737	0.858	0.831	0.173	0.036	0.043	0.299	2.554	2

Figuer6-5-4-13: Sample of the feature data set for threshold segmentation

6-6: Classification:

- We firstly made our data set, which consisted of 200 samples 100 sample for healthy orange and 100 for unhealthy orange.
- Secondly, we trained the data set on KNN, decision tree, SGD, logistic regression and SVM. However, we kept 20% of the data set away for testing that mean 180sample are used for train the different classifier and 20 sample are used for test.
  - here are the results and accuracies we get as a result when testing with different segmentation algorithms, different features and different classification

segmentation	Feature used	KNN train accuracy	SVM train accuracy	Decision tree train accuracy	SGD train accuracy	Logistic regression train accuracy
		KNN test accuracy	SVM test accuracy	Decision tree test accuracy	SGD test Accuracy	Logistic regression test accuracy
Sobel	statistical	93.7	85	100	50	97.5
		87.5	83	97.5	50	97.5
	Texture Gabor filter	95	87.5	100	51.87	100
		90	86.25	100	42.5	100
	Shape kurtosis, skew	99.37	100	100	100	100
		97.5	95	97.5	95	99.375
	Shape texture	95.625	87.5	100	51.8	100
		92.5	85.6	100	42.5	95.3
	Statistical, shape	92.5	93.7	100	54.3	100
		90	90	99	50	97.5
	Statistical, texture	95.6	86.8	100	76.2	100
		90	82.5	96.8	70	99.8
	Statistical, shape, texture	96.8	90	100	53.1	100
		90	85	100	32.5	97.5
Threshold	Statistical	93.7	85	100	100	100
		90	80	100	95	100
	Texture Gabor filter	100	100	100	100	100
		95	95	100	95	95
	Shape kurtosis, skew	95	86.25	100	85.6	100
		85	85	100	77.5	100
	Shape, texture	100	100	100	100	100
		95	95	96.8	90	95
	Statistical, shape	95	87.5	100	100	100
		95	70	100	100	100
	Statistical, texture	100	100	100	100	100
		98.75	98.75	100	100	100
	Statistical, Texture, shape	100 0.9875	100 0.9875	100	100	10
		98.7	98.7	100	100	100

Table 6-6- 1: Sample of feature data set

Through the results, we note the high efficiency of the classification algorithms in distinguishing healthy oranges and unhealthy oranges, and this is due to the following reasons:

- There is a large divergence in the color, size and texture of healthy and unhealthy oranges due to this, resulted in a large divergence in the features extracted from the images which helped the difference classifiers to work well.

❖ Working with our datasets:

- **Classical classifiers:**

After split the data into train and test sample, we use the test sample to evaluate the classifiers

1. Classifiers used the test sample to predict the label of this sample
2. Then compare the predict label of classifier to the real label to see if it works properly or not
   - here are the results and accuracies we get as a result when testing different classifiers with different segmentation algorithms and different features

Segmentation	Feature used		KNN accuracy	SVM accuracy	Decision tree accuracy	SGD Accuracy	Logistic regression accuracy
Threshold	Texture	Contrast	98	97.2	97.3	97.2	97.2
		Dissimilarity	95.9	95.1	97.3	94.8	95.1
		Correlation	99.4	54.1	100	54.1	54.1
		Asm / energy	100	100	100	100	100
		All Texture	99.1	97.5	100	92.3	97.2
	Statistical	Mean	100	100	100	100	100
		Standard deviation	100	100	100	100	100
		All Statistical	100	100	100	100	100
	All Feature		100	100	100	100	100
		Contrast	70.3	52.8	76.1	61.4	61.4

Sobel	Texture						
		Dissimilarity	89.1	87.7	92.3	87.7	87.7
		Correlation	65.5	51.3	67.6	51	51.6
		Asm / energy	100	100	100	100	100
		All Texture	99.7	100	100	100	96.2
	Statistical	Mean	93.4	95.5	96.7	96.4	93.7
		Standard deviation	67.3	65.2	79.8	63.6	95.4
		All Statistical	99.4	71.9	100	96.1	78.7
	All Feature		99.1	93.9	100	99.4	97.2

Table 6-6- 2: results of accuracy classical classifiers accuracy (our data set)

From the table we have got different accuracy same are high and some are low

1. Accuracy of threshold segmentation is better than Sobel
2. Asm / energy give the higher accuracy between the texture feature
3. Mean give the higher accuracy between the statistical feature
4. KNN /decision tree give the higher accuracy between the classifiers

- **Neural network classifier**

we use K- folds to test the model with k=10 that mean

1. The classifier uses every run 1-fold to test the model
2. Return 10 different result of the test to every fold
3. We can get the accuracy by get the mean of the 10 values that got from classifier

here are the results and accuracies we get as a result when testing different classifiers with different segmentation algorithms and different features

Segmentation	Feature used		NN accuracy
Threshold	Texture	Contrast	94.50%
		Dissimilarity	95.05%
		Correlation	83.55
		Asm / energy	97.00%
		All Texture	96.50%
	Statistical	Mean	61.23%
		Standard deviation	100.00%
		All Statistical	100.00%
	All Feature		100.00%
Sobel	Texture	Contrast	55.36%
		Dissimilarity	84.59%
		Correlation	54.45%
		Asm / energy	100.00%
		All Texture	100.00%
	Statistical	Mean	91.09%
		Standard deviation	56.36%
		All Statistical	98.50%
	All Feature		100.00%

Table 6-6- 3: results of neural network classifier accuracy

From the table we have got different accuracy same are high and some are low

- ## Characteristic of data set:

  - **Why choosing black?**

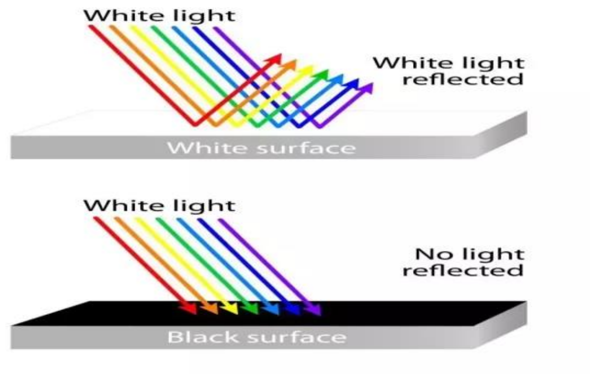


Figure 6-6- 1: impact of light on black and white surface

When light strikes a surface, some of its energy is reflected and some is absorbed. The color a person perceives indicates the wavelength of light being reflected. White light contains all the wavelengths of the visible spectrum, so when the color white is being reflected, that means all wavelengths are being reflected and none of them absorbed, making white the most reflective color. If the color of a surface is anything other than white, it means that it absorbs light of some wavelengths. For example, a surface that appears red absorbs yellow, green, blue and violet light, while reflecting red light. A surface that appears green absorbs all colors except green. White light is a combination of all colors as is apparent when you shine a white light through a prism so anything that appears white reflects all wavelengths of light. Black is the least reflective color, it's the color of a surface that absorbs all light. If a surface isn't white, then the closer its color is too white, the lighter it reflects. Pastel and off-white colors reflect more light than deep tones. Adding white to a color is called tinting the color, and it increases the color's reflectivity. The contrasting procedure is to add black to decrease the reflectivity. This is called shading.

- **specification of black box**

  - the length is the distance between an orange and an orange that follows =25.4 cm
  - we must select a suitable height of box to cover all area of the box and it depend on the specification of camera (field of view)
  - angle of FOV of selected camera is =62.2 =α and size =24.5cm so by sub in equation: size =2*tan (α / 2) * height
  - height =21.0530cm

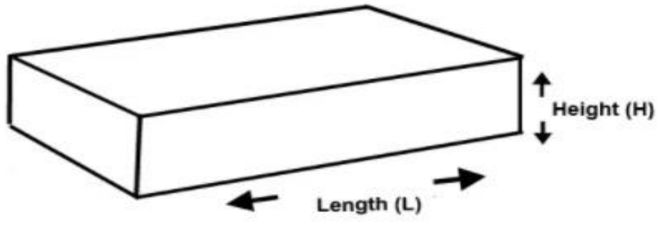


Figure 6-6- 2: Box dimension

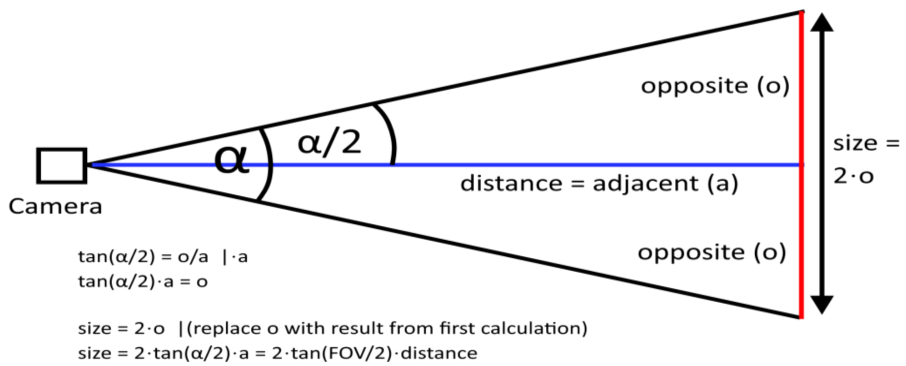


Figure 6-6- 3: FOV of the camera

- **illumination source inside box (white light)**

  Definition of White Light:
  The electromagnetic spectrum is comprised of a variety of types of electromagnetic waves, each with different wavelengths or frequencies. For example, x-rays, gamma rays, infrared radiation and ultraviolet radiation are examples of electromagnetic waves. Only a small portion of the spectrum of wavelengths can be seen by the human eye. This visible portion of the electromagnetic spectrum is called the visible spectrum. This shows the full spectrum of electromagnetic radiation and highlights the small part of the spectrum that can be called the visible spectrum.

- **Why use white light?**

  White light is defined as the complete mixture of all of the wavelengths of the visible spectrum. This means that if I have beams of light of all of the colors of the rainbow and focus all of the colors onto a single spot, the combination of all of the colors will result in a beam of white light.
  When our eyes detect the color of an object, that means that all other colors of the spectrum were absorbed by the object except for the color you see. For example, when you see a blue shirt, every color except blue was absorbed by the shirt (as a result of pigment molecules of the shirt or any object for that matter).

- **Orange dataset:**

  It's consisted of a two classes of oranges photo good and rotten oranges. illumination source.

❖ <u>Camera selection:</u>

- **What is Exposure in Cameras?**

  Exposure is the amount of light which reaches your camera sensor or film. It is a crucial part of how bright or dark your pictures appear.

  There are only three camera settings that affect the actual "luminous exposure" of an image: shutter speed, aperture and camera ISO.

➢ **Exposure mode options:**

- Auto
- Night
- Night preview
- Backlight
- Spotlight
- Sports
- Snow
- Beach
- Very long
- Fixedfps
- Antishake
- fireworks

Auto mode:

Auto exposure depends on the lighting in the center of the box.

Night mode:

Night exposure depends on the low light in the box.

Snow mode:

Snow exposure depends on the normal light in the box.

In this case, the best exposure mode (snow) was chosen based on the lighting conditions

- **What is Shutter Speed?**

Shutter speed is the length of time the camera shutter is open, exposing light onto the camera sensor. Essentially, it's how long your camera spends taking a photo. This has a few important effects on how your images will appear.

When you use a long shutter speed (also known as a "slow" shutter speed), you end up exposing your sensor for a significant period of time. The first big effect of it is motion blur. If your shutter speed is long, moving subjects in your photo will appear blurred along the direction of motion.

➢ **How Shutter Speed is Measured**

Shutter speeds are typically measured in fractions of a second when they are under a second. For example, 1/4 means a quarter of a second, while 1/250 means one-two-hundred-and-fiftieth of a second (or four milliseconds).

➢ **Fast, Slow and Long Shutter Speeds**

- A fast shutter speed is typically 1/100th second or less, no motion blur.
- Slow shutter speeds from 1/100th second to 1 second, motion blurry.
- Long shutter speeds are typically above 1 second, motion very blurry.

In this case, a fast shutter speed (1/10000) was chosen to avoid motion blur caused by belt speed

- **What is ISO?**

In very basic terms, ISO is simply a camera setting that will brighten or darken a photo. As you increase your ISO number, your photos will grow progressively brighter. For that reason, ISO can help you capture images in darker environments, or be more flexible about your aperture and shutter speed settings.

➢ **Common ISO Values**

Every camera has a different range of ISO values (sometimes called *ISO speeds*) that you can use

- ISO 100 (low ISO): sunny mode
- ISO 200: parity cloudy mode
- ISO 400: overcast mode
- ISO 800: indoor or normal mode

- ISO 1600: very dark lighting mode
- ISO 3200(high ISO): night mode

In this case, ISO 800 was chosen to match the lighting chosen

- **Video port:**

  The use video port parameter controls whether the camera's image or video port is used to capture images. It defaults to False which means that the camera's image port is used. This port is slow but produces better quality pictures. If you need rapid capture up to the rate of video frames, set this to True

Finally, the camera requirements were chosen to get the best image:

Camera resolution = (500,500)

Camera shutter speed = 10000

Camera iso = 800

Camera exposure mode = 'snow'

video port=True

quality=100

❖ Orange dataset:

It's consisted of a two classes of oranges photo good and rotten oranges. illumination source.

- **How we made it:**

Fruits were putted in the box in many different faces of the oranges and in different places in the box and take photo to all faces in different places by the Camera Module v2. Behind the fruits we placed a black sheet of as background as we illustrate why

- **Dataset properties:**

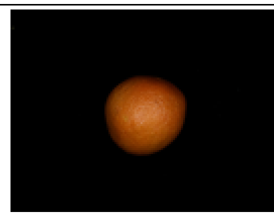
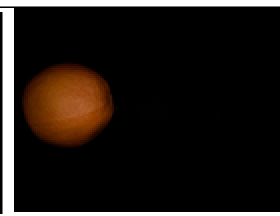
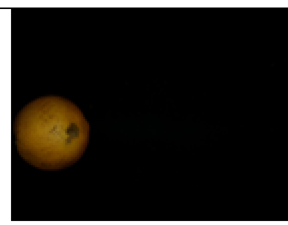
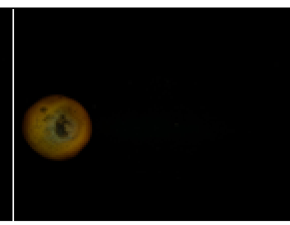
Total images	**684**
Number of classes	2
Good orange	514
Rotten orange	170
Image size	2000*2000
Image on the left side of box	228
Image on the center of the box	228
Image on the right side of the box	228
Sample of good orange	 
Sample of rotten orange	 

Table 6-6- 2: implemented Dataset properties

6-8: How we classify the orange on the machine:

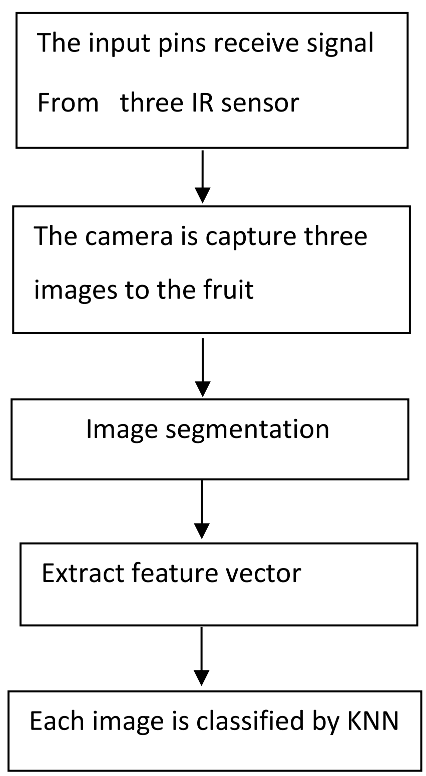
1. Use 3 pin of raspberry pi and define it as input pins
2. Another 2 pins are defined as output pin
3. Each of input pins connected to the IR sensor]
4. Each of output pins connected to the PLC
5. The function of the IR sensor to detect the orange inside the black box
6. When the raspberry pi receive signal from the IR sensor the camera is capture image of fruit inside the box so we get three images of each fruit inside the box to make sure that the orange fruit is captured from all direction
7. Each captured image it classifies alone by the following steps
   - Segmentation
   - Extract feature vector
   - Pass to KNN classifier to decision if it rotten or not

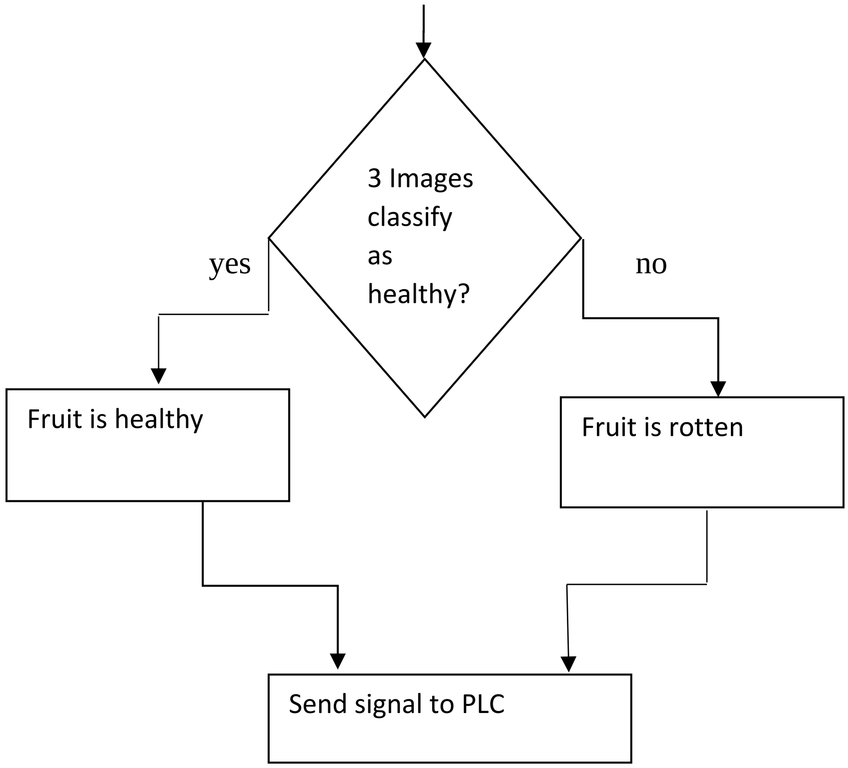
8. If the classifier decision that the three images are healthy orange

The raspberry pi pass signal to plc by output pin from raspberry pi

9. If the classifier decision that any of the three images are rotten orange

The fruit is classified as rotten orange The raspberry pi pass signal to plc by output pin from raspberry pi





- **Raspberry pi code explanation:**

1. First import the libraries

Library	Function
picamera	to control the raspberry pi camera
skimage	To extract GLCM features
sklearn	To use KNN classifier
pandas	To load dataset
RPi.GPIO	To control the pins
cv2	To read captured image and for segmentation
numpy	To extract statistical features

Table 6-8-1: show import the libraries in Raspberry pi

```
#load the libraries
import numpy as np
import cv2
import pandas as pd
from picamera import PiCamera
from sklearn import neighbors
from sklearn import model_selection
import RPi.GPIO as GPIO
from skimage.feature import greycomatrix, greycoprops
from skimage import io, color, img_as_ubyte
```

2. Load the dataset and split the features to a variable and the label to another variable

```
#load dataset
df = pd.read_csv('/home/pi/new/testf.txt')
df.replace('?', -99999, inplace=True)
df.drop(['id'], 1, inplace=True)
# x is features of the dataset
x = np.array(df.drop(['class'], 1))
# Y is label of  fruit
y = np.array(df['class'])
```

3. Split the data set into train and test then use KNN classifier to train it

```
#split the dataset into train and test
x_train, x_test, y_train, y_test = model_selection.train_test_split(x, y, test_size=0.1)
clf = neighbors.KNeighborsClassifier()
#train the KNN classifier
clf.fit(x_train, y_train)
```

4. Define three input pins that will receive signal from IR sensors when the sensor detects the orange inside the box to take image to the orange and define two outputs pin will be connected to the PLC to send signal to PLC whether orange is healthy or not

```
#define the inputs and outputs pins
GPIO.setmode(GPIO.BOARD)
GPIO.setup(12,GPIO.OUT)
GPIO.setup(37,GPIO.OUT)
GPIO.setup(36,GPIO.IN)
GPIO.setup(15,GPIO.IN)
GPIO.setup(13,GPIO.IN)
```

5. Define the camera specification to take a suitable image in fast time to orange by try to reduce the blur of image this is done by change the camera shutter speed, exposure mode, resolution and ISO

```
#define the camera specification
camera = PiCamera()
camera.resolution = (500,500)
camera.shutter_speed = 10000
camera.iso = 800
camera.exposure_mode = 'snow'
```

6. Define the function that will take the captured images to classify it by make segmentation and features extraction then pass the feature vector to the KNN classifier
   - Read the capture image and make resize, segmentation and extract statistical features

```
def tamtom (r):
#read on resize the image
  img=cv2.resize(r,(100,100))
  #segmentation by use otsu threshold
  ret2,th2 = cv2.threshold(img,0,255,cv2.THRESH_BINARY_INV+cv2.THRESH_OTSU)
  #extract statistical features
  b=round(np.mean(th2)/30,3)
  c=round(np.std(th2)/10,3)
```

- Extract texture features

```python
#extract texture features (GLCM)
gray = color.rgb2gray(th2)
image = img_as_ubyte(gray)
bins = np.array([0, 16, 32, 48, 64, 80, 96, 112, 128, 144, 160, 176, 192, 208, 224, 240, 255]) #16-bit
inds = np.digitize(image, bins)
max_value = inds.max()+1
matrix_coocurrence = greycomatrix(inds, [1], [0, np.pi/4, np.pi/2, 3*np.pi/4], levels=max_value, normed=False, symmetric=False)
contrast = greycoprops(matrix_coocurrence, 'contrast')
dissimilarity = greycoprops(matrix_coocurrence, 'dissimilarity')
energy = greycoprops(matrix_coocurrence, 'energy')
correlation = greycoprops(matrix_coocurrence, 'correlation')
asm = greycoprops(matrix_coocurrence, 'ASM')
aa=round(np.mean(contrast),3)
bb=round(np.mean(dissimilarity),3)
cc=round(np.mean(asm),3)
dd=round(np.mean(energy),3)
ff=round(np.mean(correlation),3)
mm=round(np.std(contrast),3)
nn=round(np.std(dissimilarity),3)
uu=round(np.std(correlation),3)
```

- Make feature vector and classify the vector

```python
#make the features vector
y=np.array([aa,bb,cc,dd,ff,mm,nn,uu,b,c])
z1=(y.flatten())
yyy1= np.reshape(z1, (1, -1))
test_example=yyy1
#pass the feature vector to the classifier
n=clf.predict(test_example)
return n
```

7. Define infinite loop that will take captured three images to the orange and define three variables to make sure only one image captured by each sensor and to ensure that the sensor cannot give a signal to photograph without making sure that the previous sensor has given a signal to ensure that three pictures are taken of each fruit inside the box. when received signal from IR sensor and then call the function that in the previous step to classify the fruit and then send signal to the plc This process is repeated over and over to each fruit inside the box

- First take the three images

```
#define three variable that will Organize the photographing process
T,R,O=1,0,0
while(1):
    #to receive signal from the first sensor to take first image
    a=GPIO.input(36)
    Y=1-a
    T=1
    if(Y==1 & T==1):
      camera.start_preview()
      camera.capture('/home/pi/Desktop/image11.jpg',use_video_port=True,quality=100)
      camera.stop_preview()
      T=0
      R=1
    B=GPIO.input(15)
    P=1-B
    if(P==1 &R==1 ):
        camera.start_preview()
        camera.capture('/home/pi/Desktop/image12.jpg',use_video_port=True,quality=100)
        camera.stop_preview()
        R=0
        O=1
    C=GPIO.input(13)
    i=1-C
    if(i==1 &O==1 ):
        camera.start_preview()
        camera.capture('/home/pi/Desktop/image13.jpg',use_video_port=True,quality=100)
        camera.stop_preview()
        T=1
        O=0
```

- Call the function to classify the three images

```
#call the function to classify the three images
r =cv2.imread('/home/pi/Desktop/image11.jpg',0)
#classify the first image
prediction=(tamtom(r))
r =cv2.imread('/home/pi/Desktop/image12.jpg',0)
#classify the second image
prediction2=(tamtom(r))
r =cv2.imread('/home/pi/Desktop/image13.jpg',0)
#classify the third image
prediction3=(tamtom(r))
```

- When the three image of the fruit is classified as healthy so the fruit is classified as healthy and if any image of the three images classified as rotten so the fruit is unhealthy

```
#send signal to plc by pin 12 when the fruit is healthy
if (prediction==2 & prediction2==2 & prediction3==2):
    print('healthy and bin 12 is activated now')
    GPIO.output(12,0)
    GPIO.output(12,1)
#send signal to plc by pin 37 when the fruit is healthy
else:
    print('non healthy and bin 37 is activated now')
    GPIO.output(37,0)
    GPIO.output(37,1)
```

Chapter 7
Manufacturing Process

Chapter 7: Manufacturing Process

The implementation process was done in different factories for 21 days, with a lot of calculation there was a lot of details and challenges, a lot of different parts was done in different machines depend on function and operation of each part, in this chapter we go through a sample of parts that was done on different machine.

First the, there was some parts the was in need for accurate dimensions that will play big role for latter use in the mechanism as the parts of chain since the chain 80 percent was manufactured, also the motor fixation.

So, we get steel sheet and the operation was done on laser machine to get accurate dimensions.

The sample of files given to the machine as shown in Figure 7-1.

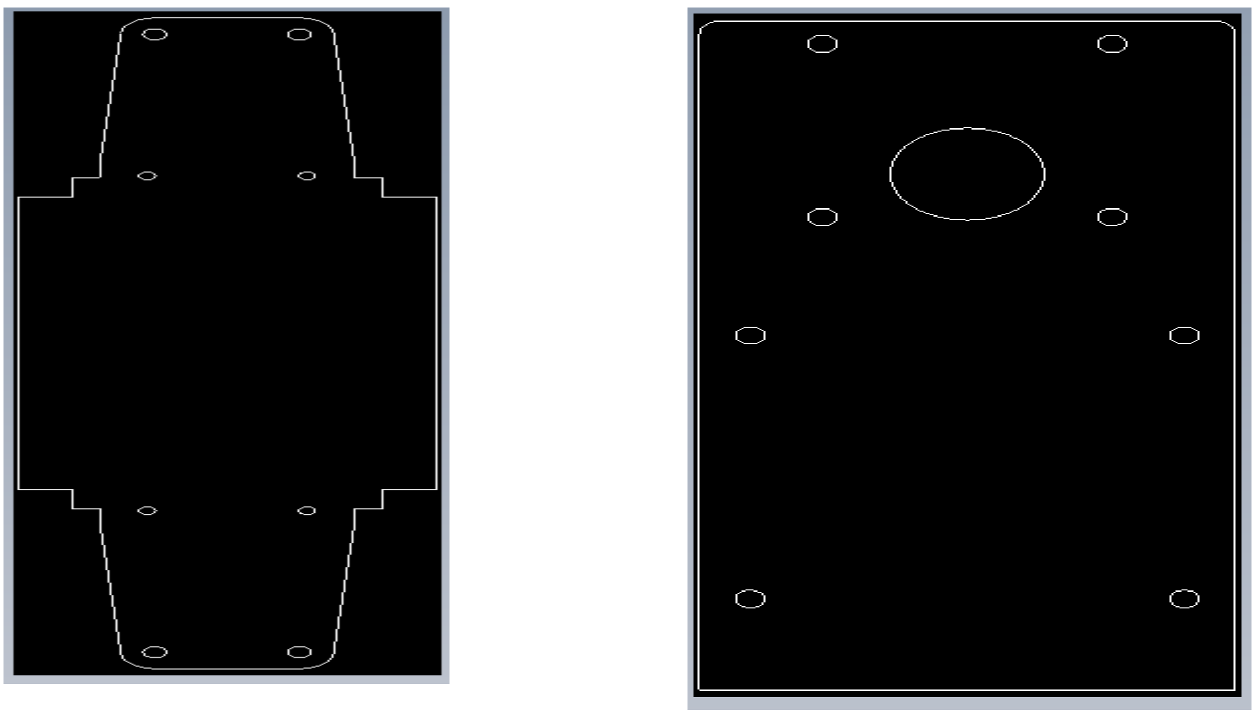


Figure 7- 1: Sample of parts that was done on laser machine

To get the final shape that is needed after the part is cut on laser machine it goes to bending machine for forming the final shape.

Second, the bars from chassis in both the first stage and second stage was done on cutter machine to get each bar that is then wield together to form the chassis for both first and second stage.

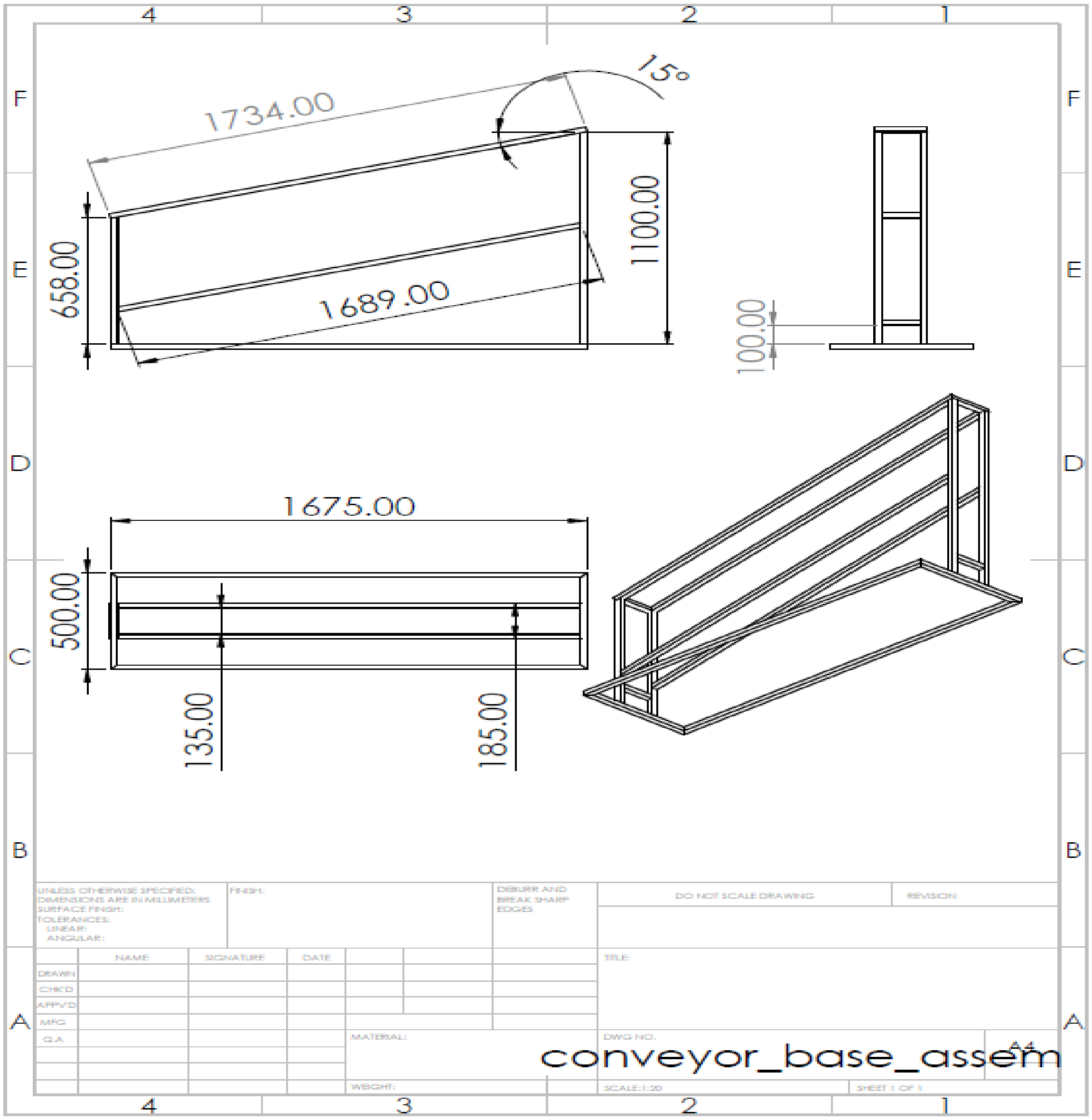


Figure 7- 2: Sample of parts that was done on Cutter machine

Lastly, some parts have different step and shapes as pins of sprocket, Artellon, and axis of motors, all was done on lathe machine but depend on the curvature and shape it can be CNC machine or normal one it can be 5 axis or 2 depend on the shape.

Here are some examples of the files that was handed to the worker,

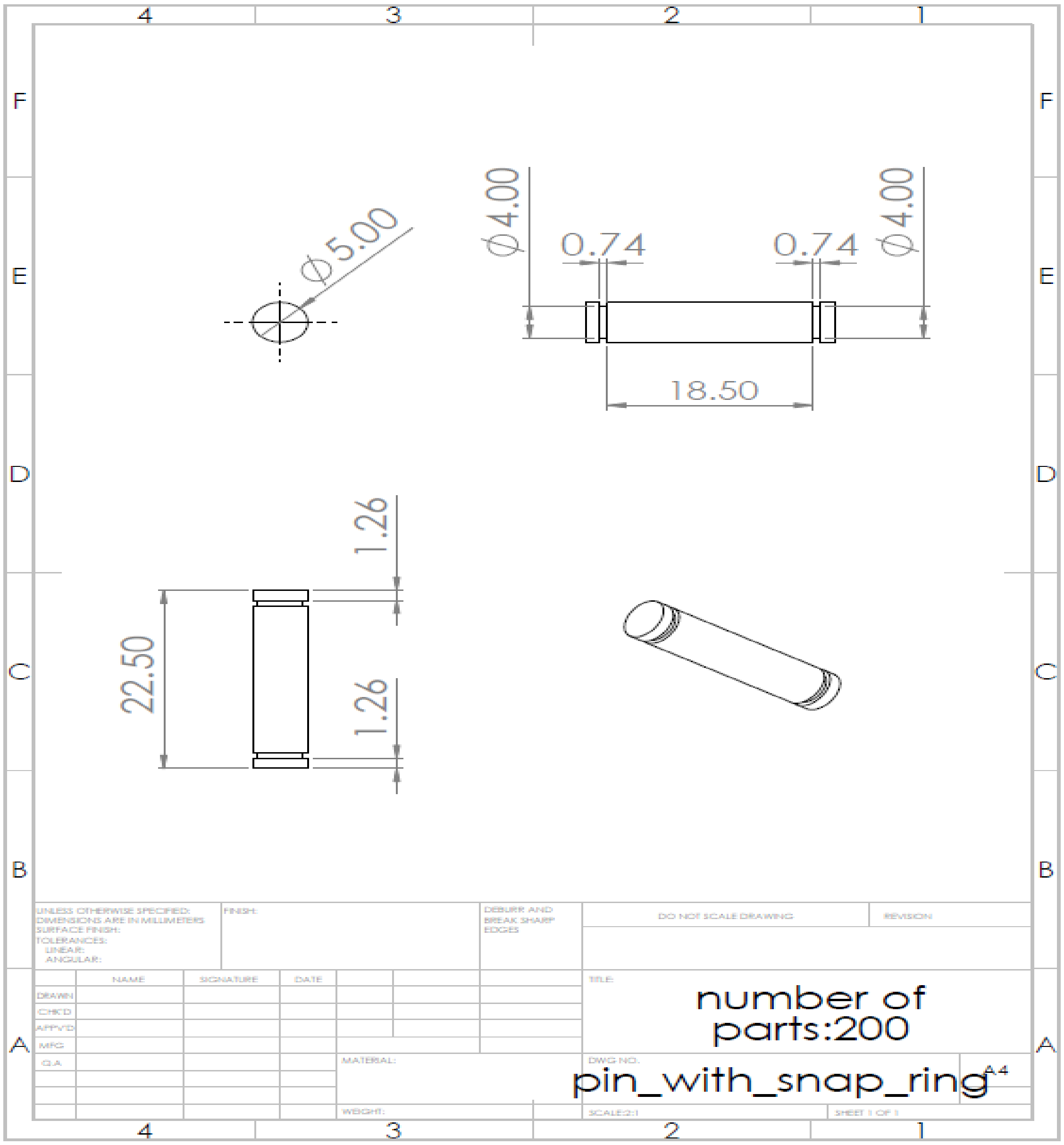


Figure 7- 3: Pins that was done on normal lathe machine

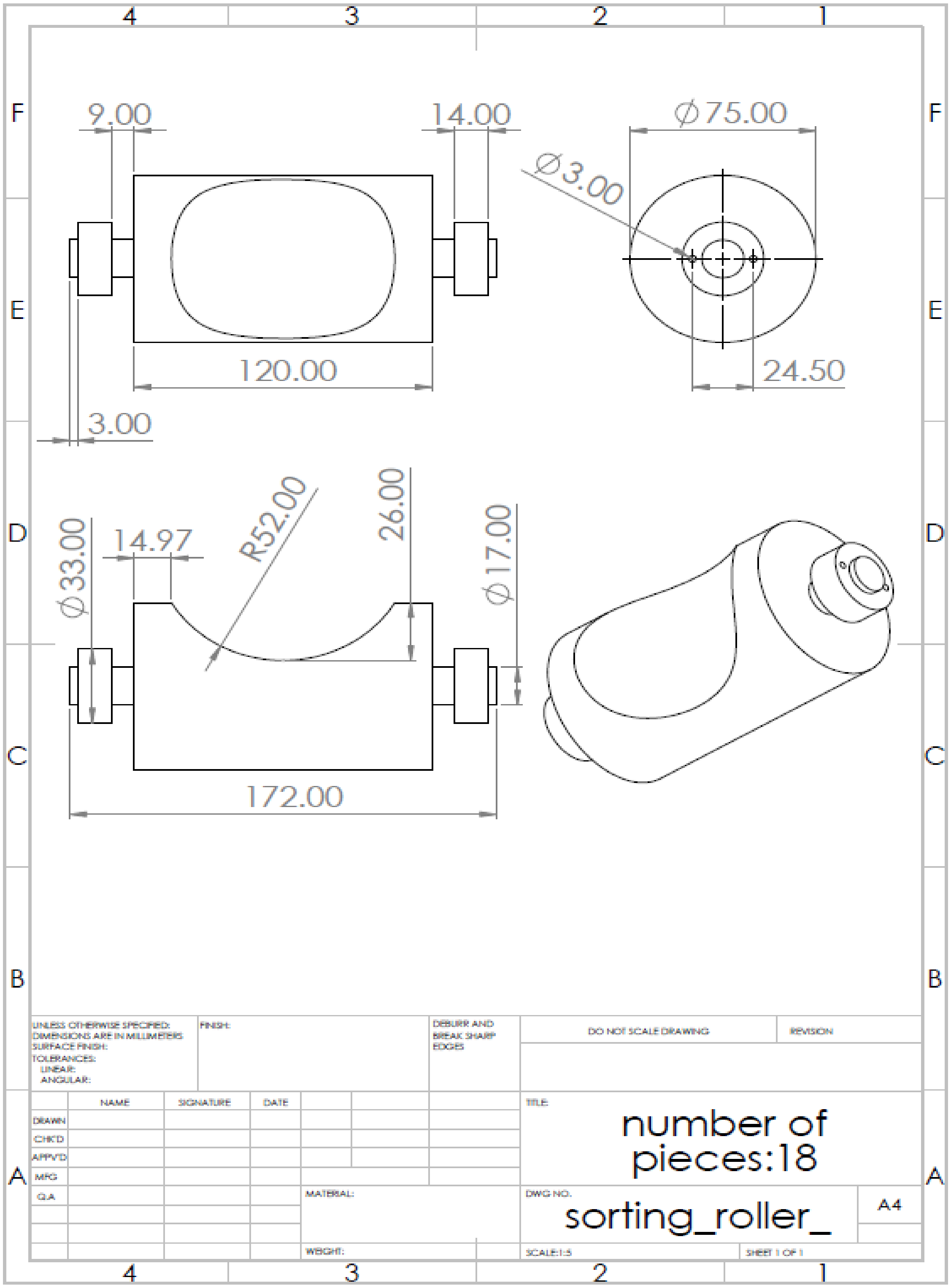


Figure 7- 4: Artellon that was done on 5 axis CNC lathe machine

Chapter 8
Implementation Problem and Solution

Chapter 8: Implementation Problem and Solution

8-1: First Stage:

In this stage we faced three problems,

1- Since the conveyor chain not tensioned well and there is a distance between the chain and base of first stage so the orange is crushed.
So, to ensure no orange is crushed we want to limit the orange space to not freely moving on the two sides.
Therefore, by adding plates of wood in the side of roller to prevent the orange from dropped or crushed from chain conveyor, as shown in Figure 8-1-1.

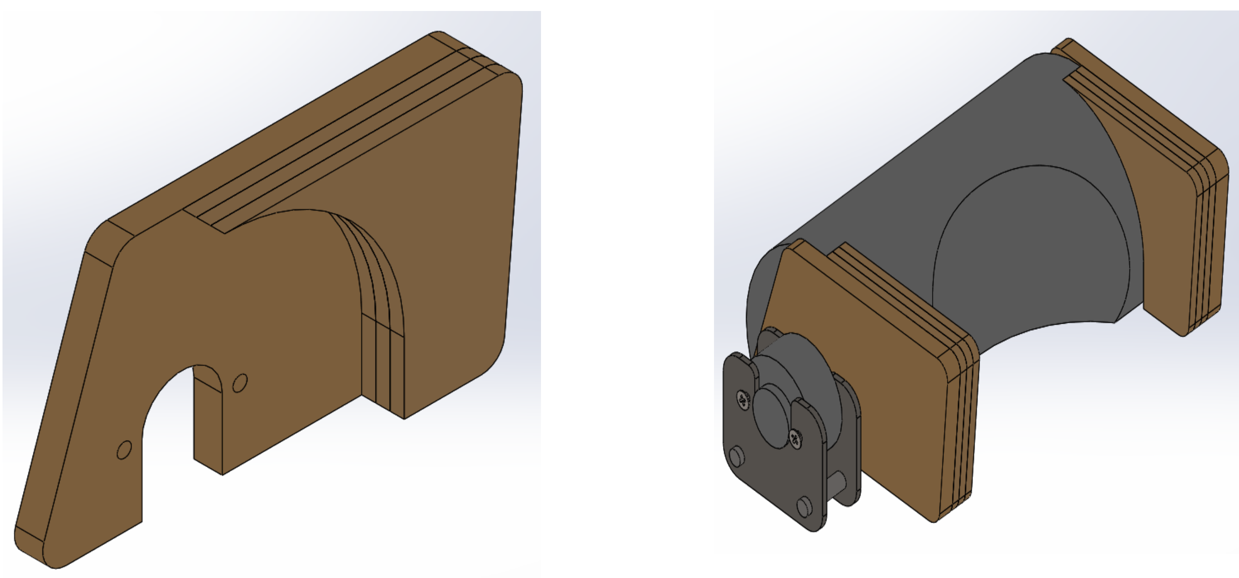


Figure 8-1- 1: Problem one on first stage solution

2- When to many oranges the tank there will be a chance where orange will be on top of another orange.
So, to prevent the potting more than one orange above each other on the bucket of rollers, the curtain of linoleum with load fixed with it and this curtain fixed on the feeding tank which used to prevent this problem, as shown in Figure 8-1-2.

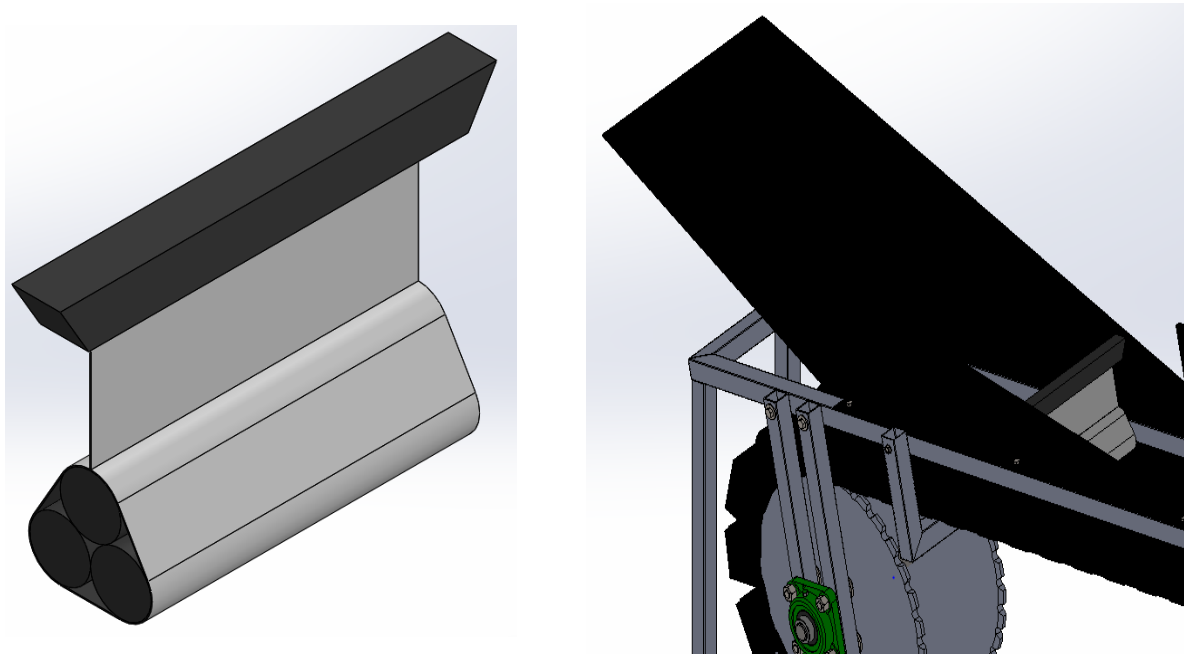


Figure 8-1- 2: Problem two on first stage solution

3- The speed of conveyor is high so some oranges will not go to rejection plate naturally, so it need an external force to let it go to rejection plate without blocking the conveyor.
So, we put a spring that will be flexible and will do the job as shown in Figure 8-1-3.

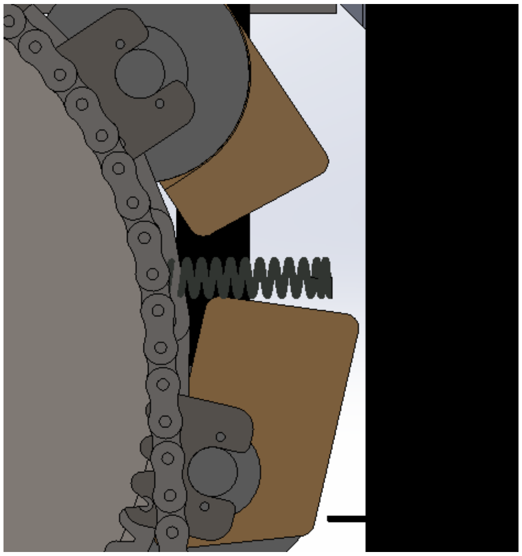


Figure 8-1- 3: problem three on first stage solution

8-2: Second Stage:

The orange that came from first stage will go to second stage to be classified so it must be between the two bars as disused in **Chapter 3,** there is a possibility the orange will not go between the two bars and will deviate from the right path.

So, to make sure that the orange will not deviate we'll block the pass that can go to, so only the right path can the orange go through.

Therefore, two plates of wood were added at the beginning of the stage to ensure the orange classification path as shown in Figure 8-2-1.

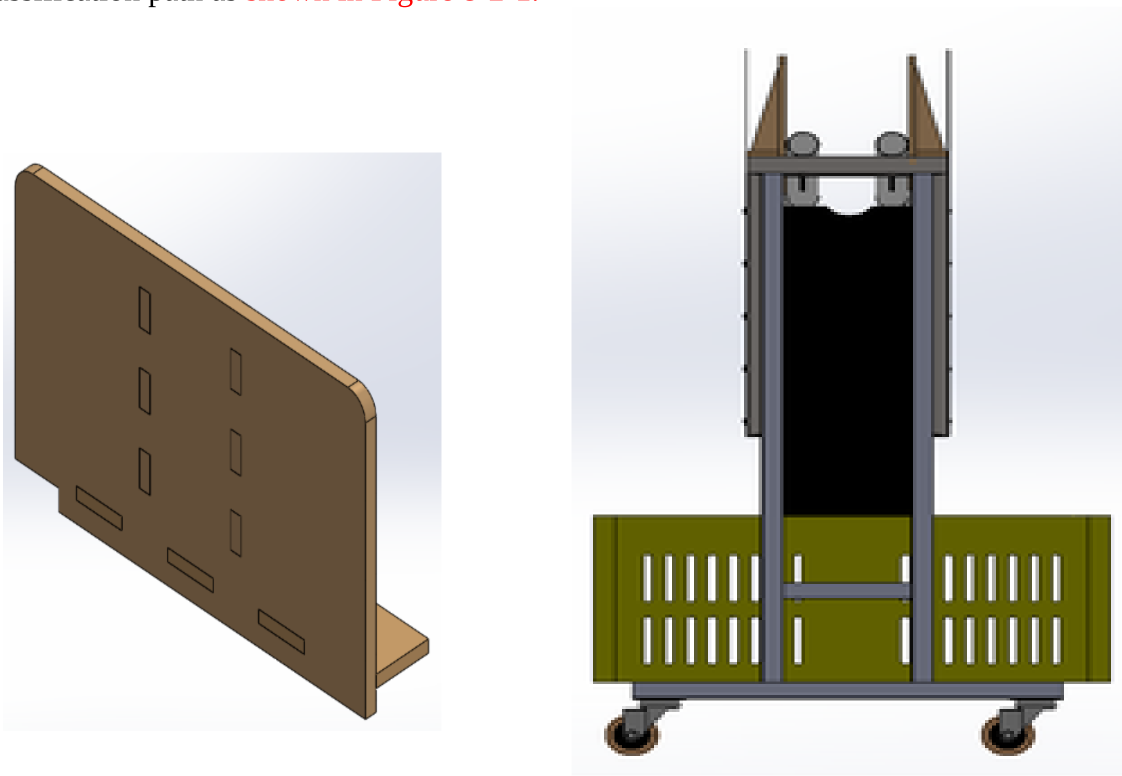


Figure 8-2- 1: Problem solution on stage two

Chapter 9
Mechatronics System

Chapter 9: Mechatronics System

Mechatronics system consist of different fields all together to form one field, as electronics, mechanics, computers, and control, as shown in fig 9-1.

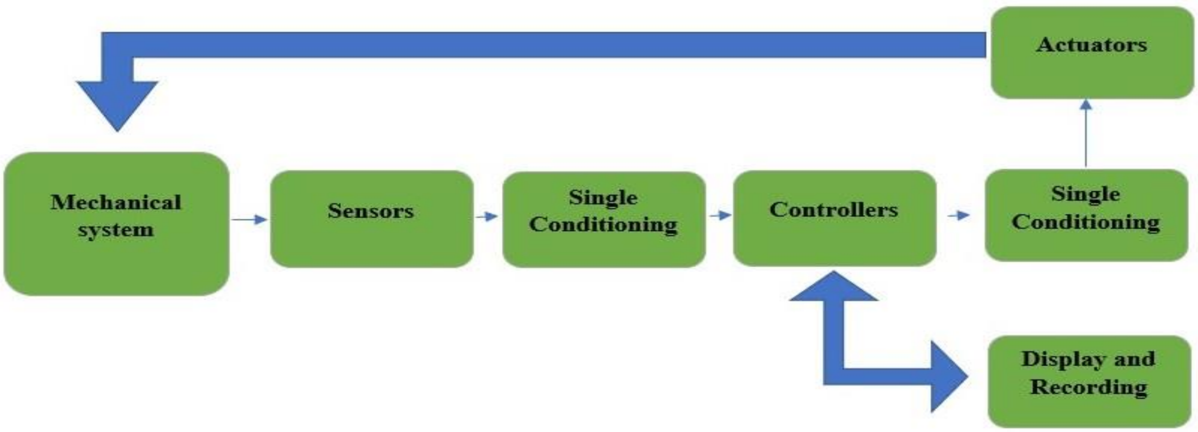


Figure 9- 1: Mechatronics Block Diagram

In our project we try so hard to apply our field into practice.

Mechanical system is mention in details in **Chapter 3**, also the selection of actuators and controllers, so in this chapter we will discuss the control and electronics.

9-1: Sensors:

In sensors responsible for converting the physical data from mechanism into electrical signal that can be used, the signal from sensor helps in control, protect the mechanism or even can be used for moving the actuators depend on the circumstances.

9-1-1: Camera Sensors:

The use of sensor in our machine is to detect the presence of fruit in the required positions, it will be used to detect the fruit in 3 different positions to take 3 different images in order to make the decision according to these images for every fruit.

There are a lot of sensors that can be used and most of them is under cafeteria of proximity sensors, where proximity sensors are non-contact devices which detect the presence of nearby objects.

There are different aspects to talk about proximity sensors to choose the suitable one for our project as,

- **Sensing Basics:**
  Proximity sensing involves detection of objects within a finite field. Proximity sensors are designed to output a value (typically a simple ON signal) when a prescribed object passes within their sensing range. The definitions and specifications below can be used to describe the sensing environment and a sensor's capabilities. The target refers to the object is to be detected. Because different sensor types are capable of detecting different objects, the object's material, size, surface characteristics, and rate of speed must be carefully considered.

- **Sensing Range with Response time and Frequency:**

  Ranges are the most important proximity sensor specifications to be considered.
  A device's sensing distance refers to the distance in which an object triggers an ON signal. It may be considered as sensor's maximum possible sensing range. Set distance is defined as the maximum stable detection range when temperature and voltage factors are considered.

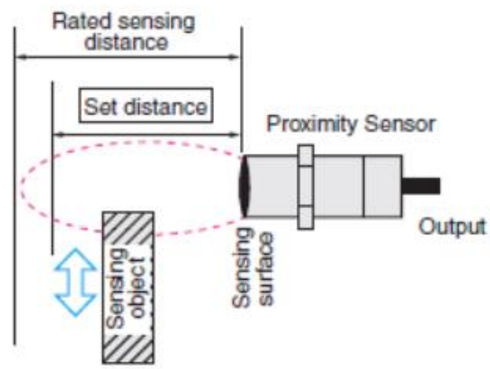


Figure 9-1-1- 1: Proximity sensor range

Response time and frequency specifications describe a sensor's speed. Response time (t1) refers to the time between an object moving into a sensor's range and the point when the sensor outputs an ON signal. Conversely, (t2) describes the time between an object moving out of a sensor's range and the point when the sensor registers an OFF signal.

Frequency (f) describes the number of possible sensing repetitions per second and measured in hertz (Hz).

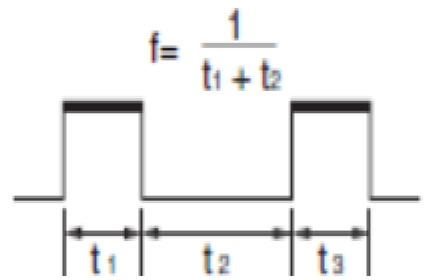


Figure 9-1-1- 2: Frequency and time period

➢ Advantages of Proximity Sensor:

- The proximity sensor belongs to non-contact measurement, so it wouldn't wear or damage the detection objects.
- As the proximity sensor adopts non-contact output, its service life can be extended. The NPN/PNP output it adopts has no effect on the service life of contacts.
- The proximity sensor is not affected by the stains, oil and water on the detection objects.
- High-speed response of the proximity switch can be 3 kHz.

➢ Proximity sensor types:

Proximity sensors are typically classified by the sensing technology they employ. These types are described as shown in Table 9-1-1-1.

Type	Description	Range	Target	Speed	Application
Capacitive	Constructed with two parallel plates as an open capacitor, targets induce changes in capacitance	3-60 mm	Non-ferrous materials	Relatively slow	Close-range, non-ferrous sensing, tank liquid level detection, sight glass monitoring
Inductive	Involve a wound iron core, coil inductance changes with presence of object within sensing range	4-40 mm	Ferrous materials	Average	Close-range detection of ferrous materials, hazardous environments
Magnetic	Measures the presence or absence of object based on an external magnetic field	4-40 mm	Ferro magnetic	High	Measurement of fast rotational velocity
Eddy-current	Similar to inductive sensors, could be considered high-end inductive types	Relatively short	Ferrous materials	Average	Precision, high-resolution sensing in contaminated environments
Photo-electric	Use laser emitters and reflectors or receivers; targets cut off or reflect emissions	1-60 mm	Many types	Average	Long-range detection of small or large objects automatic faucets, color-dependent sensing
Ultra-sonic	Similar to photoelectric types, but use sound waves instead of visible emissions.	Up to ~400 mm	Many types	Relatively high	Long-range detection of multi-colored objects with varying surface properties machine automation, continuous level control

Table 9-1-1- 1: Types of proximity sensors

Proximity sensors selection guide:

1. Detection object:
   The target to be detected is the fruit.
2. Dimension:
   Our sensor dimensions are relatively small due to the confined space between the camera box and the conveyor chain.
3. Detection range:
   The range is #########################
4. Shielded or unshielded:
   Unshielded proximity sensor can achieve the biggest action distance, high-Precision and high-resolution.
5. Output signal:
   DC proximity sensor outputs DC signal. DC output signal can be further divided into NPN output and PNP output.
6. Switching frequency:
   Switching frequency determines the response speed of the proximity switch, it refers to the shifting number of the switch from on to off per minute. The switching frequency of DC proximity sensor can be 200 kHz.
   Since the speed is important for us so we need a high switching speed.
7. Supply voltage of the proximity sensor:
   Supply voltages available for us is 3.3-5V DC.

After considering these aspects we choose an *infrared photo electric sensor.*

IR Sensor Module:

Infrared (IR) Sensor Module is a distance proximity sensor "switch". When there is an object or obstacles that are close enough to block the view in front of 2 LEDs, it uses the electromagnetic reflection principle where when the reflective surface (object) is closer, the receiver will receive stronger signal from transmitter due to shorter distance traveled of reflected of wave.

When there is an object that is close enough, the IR electromagnetic detection received by the IR receiver is higher than the threshold level (user pre-set level), the sensor will change the output switch mode so that microprocessor can execute what is going to do next. IR Sensor Module has only 1 main output signal which is Digital Output. Digital Output either go high (5V or 3.3V depends on the input voltage) or low (0V), thus this module cannot be used as a distance measurement but just as a trigger switch.

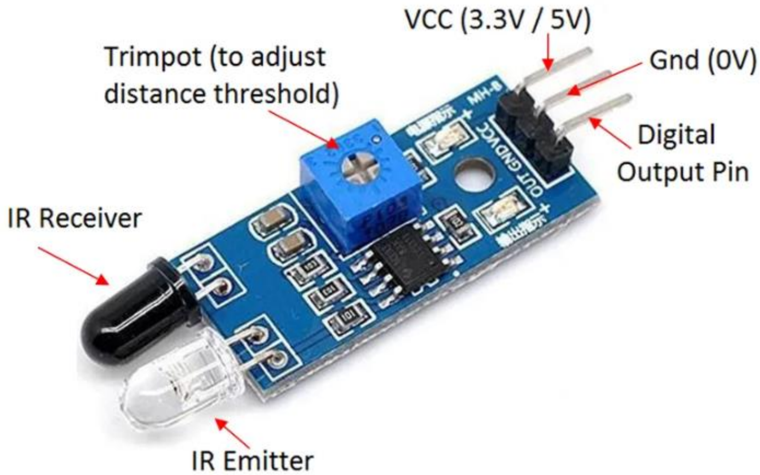


Figure 9-1-1- 3: IR sensor module

When there is no object within the detection distance, the output is at HIGH position (5V or 3.3V). When the distance shorter than or equal to the threshold set, the output signal will change to position LOW (0V). The distance threshold can be set by adjusting the potentiometer on the board. This sensor module only able to detect distance between 1-30 mm within the view of the IR LED and Photo-resistor. The trigger distance is somehow very subjective to object's surface material, color and shape.

9-1-2: DC motor Sensor:

In DC motor, the control that will be done on it depend on the speed so we use encoder to measure the speed, there a lot of types of encoders but for the one that is suitable for our project is optical encoder.

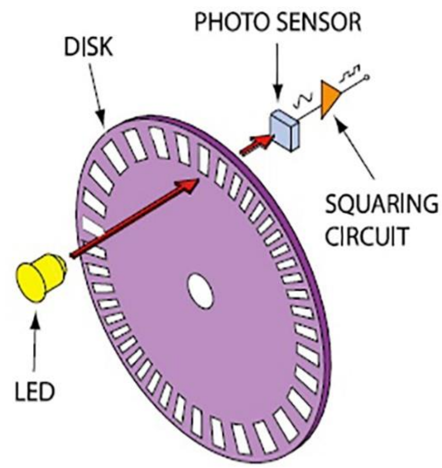


Figure 9-1-2- 1: Optical Encoder

The number of pulses per revolution is selected depend on some calculations.

$$E_{rr} = \frac{1}{T_s} pulse/sec$$

$$if\ we\ take\ the\ sample\ every\ 1sec$$

$$T_s = 1\ sec$$

$$E_{rr} = 1\ pulse/sec$$

$$E_{rr} = \frac{1}{RE} rev/sec = \frac{60}{RE} rev/min$$

$$let: E_{rr} = 0.1\ rev/min$$

$$RE = 600\ pulse/rev$$

$$So, the\ encoder\ selection\ is\ encoder\ 600\ PPR$$

Figure 9-1-2- 2: Omron encoder with 600 PPR

Where,

RE: encoder sensor resolution pulse / rev

Ts: sampling period sec

V: speed rev / sec

Err: speed error rev / sec

9-1-3: Stepper motor Sensor:

In stepper motor we need a feedback sensor to get more accurate positions, to ensure that the orange either good or rotten to go to its direction with precision.

We have a lot of types of sensors that can be used for example proximity sensors but for cost effective and we can use the simple form of sensor which is Limit switches, a normal normally open can be used.

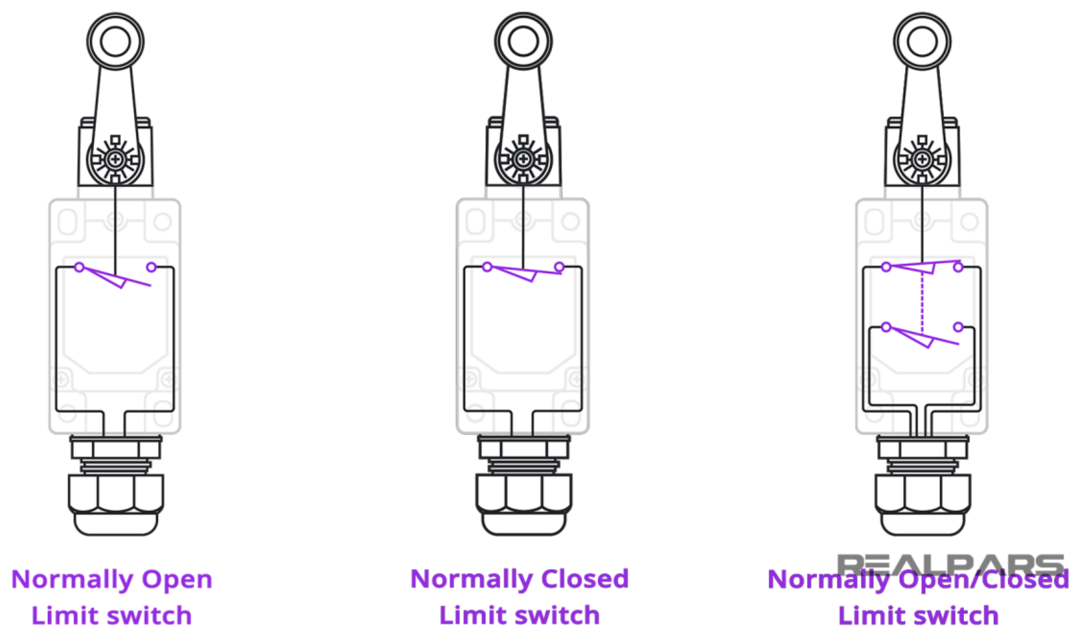


Figure 9-1-3- 1: Limit Switch types

9-2: Single Conditioning:

Single conditioning in general is used for filtering or amplification, to put it simply to be suitable for later use depend on the circumstances.

In this project, we have used some circuits to change the voltage by lowering or increasing the voltage.

There are Four circuits used:

1- Circuit raising the voltage from 3.3 V to 24 V:

Circuit with input signal (3.3V) and outputs (24V).

- **Component:**
    1) Optocoupler(4n35).
    2) Resistance 100Ω.
    3) 3* Resistance 5 $k\Omega$.
    4) Source of $24V$.
- **Design of circuit:**

From Data Sheet of optocoupler:

$$20\ mA\ =<\ I(led) =<\ 60\ mA$$
$$V(led) =\ 0.8\ V$$

Circuit:

Input:

$$Vin =\ 3.3\ V$$
$$So\ R1 = \frac{3.3 - 0.8}{0.02} =<\ 125\Omega$$
$$So, we\ use\ Resistance\ input\ 100\Omega$$
$$P(res) =\ 0.5\ W$$
$$I.max(res) = \frac{0.5}{3.3 - 0.8} =\ 0.2\ Ac$$
$$So, resistance\ 100\Omega\ don't\ cut - off$$

Output:

$$I(collector) =\ 60\ mA$$
$$V(out) =\ 24\ V$$
$$P(res) =\ 0.5\ W$$
$$I.max(res) = \frac{0.5}{24} = 0.0208\ A\ =\ 21\ mA$$
$$So, we\ using\ 3\ Resistance\ Parallel.$$

- **<u>Circuit in Multisim:</u>**
  (1) Input (1) Output

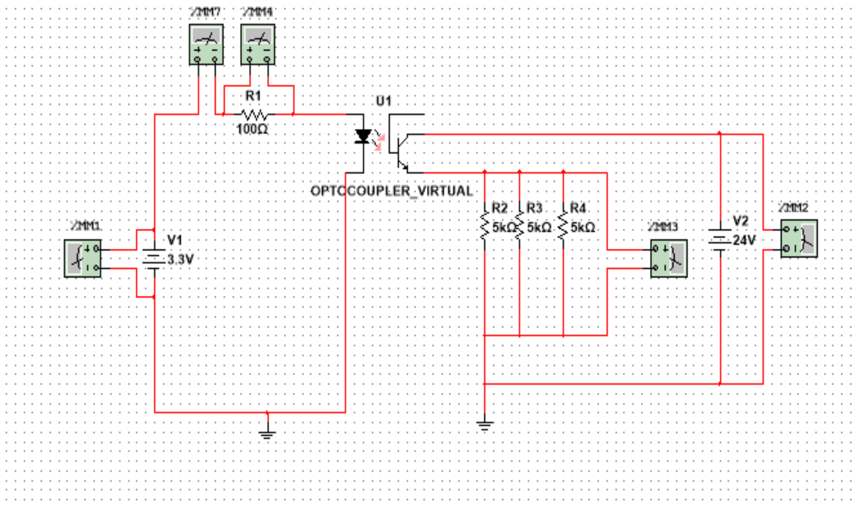


Figure 9-2- 1: Multisim of Circuit one

- **<u>Circuit in PCB:</u>**
  (2) Inputs (2) Outputs

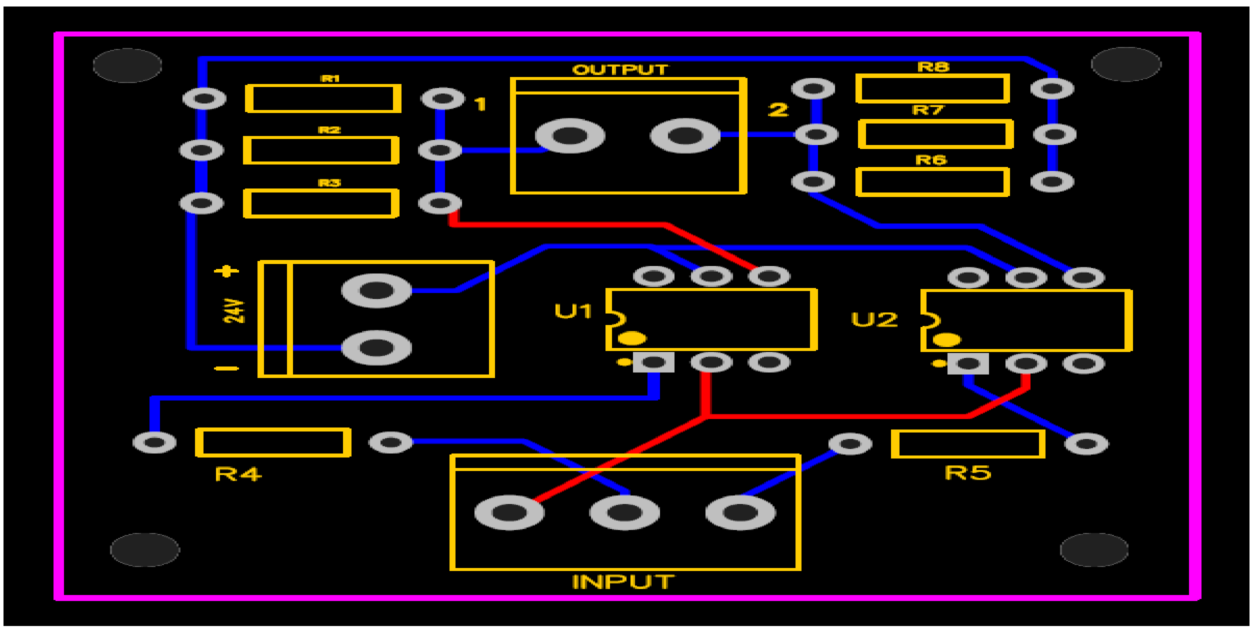


Figure 9-2- 2: PCB of circuit one

2- Circuit voltage reduction from 12 V to 5 V:

Circuit with input signal (12V) and output (5V)

- **Component:**
  1. Optocoupler(4n35).
  2. 4* Resistance 1 $k\Omega$.
  3. Source of 5 V.

- **Design of circuit:**

From Data Sheet of optocoupler:

$$20\,mA\ =<\ I(led) =<\ 60\,mA$$

$$V(led) =\ 0.8\,V$$

Circuit:

Input:

$$Vin =\ 12\,V$$

$$P(led) =\ 0.5\,W$$

$$V(res) =\ 12\ -\ 0.8\ =\ 11.2\,V$$

$$So\ R1 = \frac{11.2}{0.02} =<\ 560\,\Omega$$

$$So\ we're\ using\ 3\ Resistance\ 1\ k\Omega\ , R1 = \frac{1000}{3} =\ 333\,\Omega$$

Output:

$$I(collector) =\ 60\,mA$$

$$V(out) =\ 5\,V$$

$$P(res) =\ 0.5\,W$$

$$I.max(res) = \frac{0.5}{5} = 0.1\,A\ =\ 100\,mA$$

$$R2 = \frac{5}{0.06} >=\ 85\,\Omega$$

$$So\ resistance\ value\ is\ 1000\Omega$$

- **Circuit in Multisim:**

(1) Input (1) Output

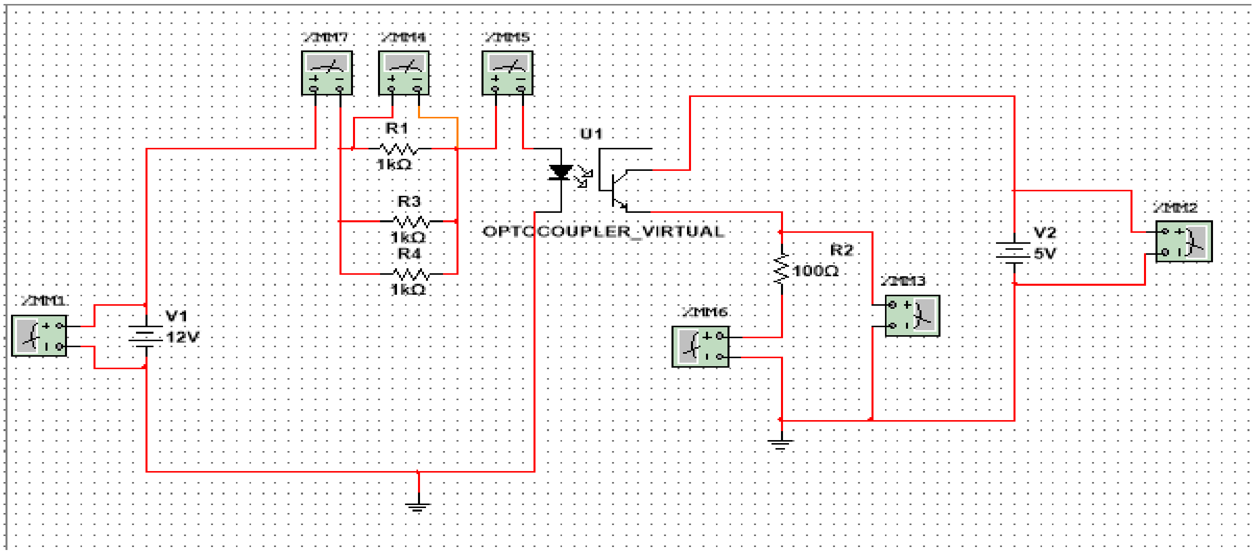


Figure 9-2- 3:Multisim of Circuit two

- **Circuit in PCB:**

(4) Inputs (4) Outputs

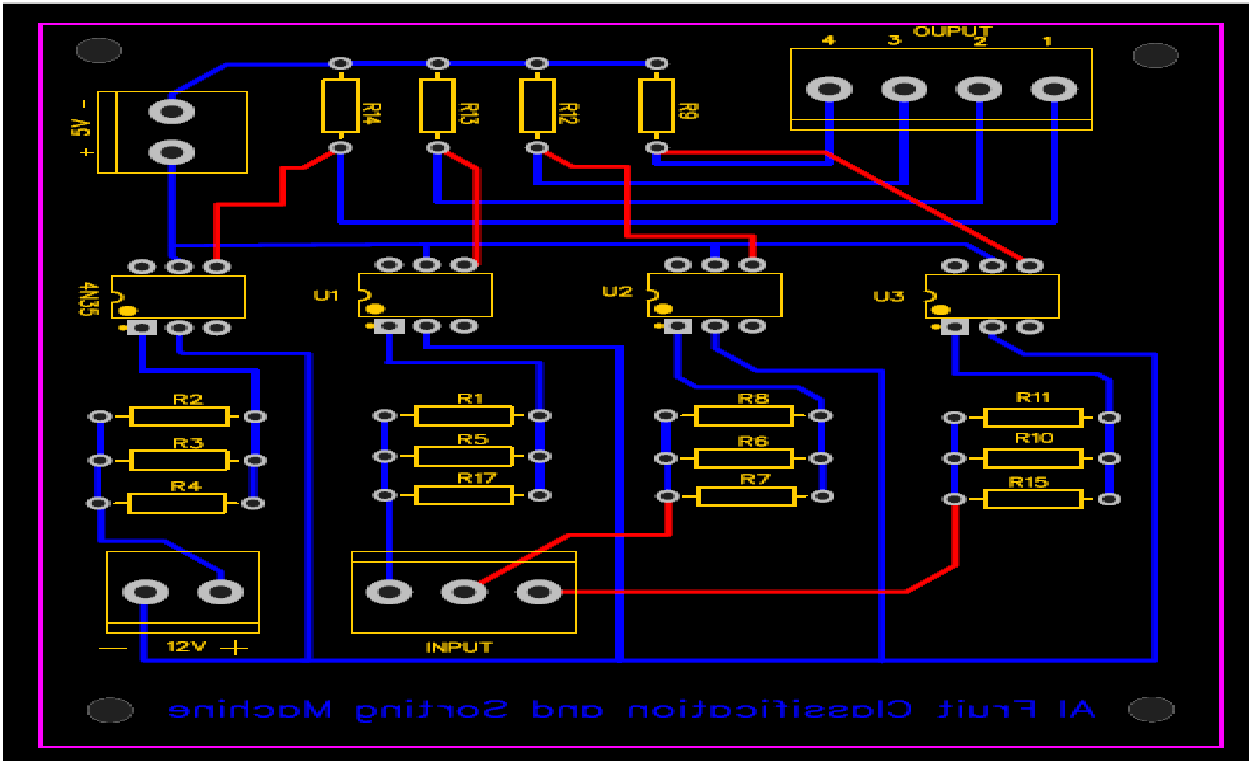


Figure 9-2- 4: PCB of circuit two

3- Circuit voltage reduction from 12 V to 5 V with Gain:

In this Circuit we using op-amp because we need the gain.

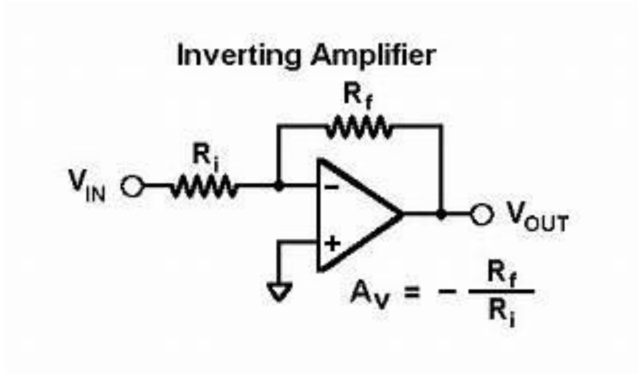


Figure 9-2- 5: Inverting Op amp

- **<u>Component:</u>**
  1) Op-amp (lm741CN).
  2) Resistance $10k\Omega$.
  3) Resistance $24k\Omega$.

- **<u>Design of circuit:</u>**

Using op-amp inverting mood to decrease the voltage.

$$When\ V(in) = 12\ V.$$
$$We\ need\ V(out) = 5V.$$
$$Gain(Av) = \frac{V(out)}{V(in)} = -\frac{Rf}{Ri}$$
$$Av = \frac{5}{12} = 0.41667$$
$$Assume\ Rf = 10\ k\Omega.$$
$$So, Ri = \frac{10 * 103}{0.41667} = 24000\ \Omega = 24\ k\Omega$$
$$The\ V(out) = -\left(\frac{Rf}{Ri}\right) * V(in) = -\left(\frac{10k}{24k}\right) * 12 = -5\ V$$

Note:
when we use first circuit with one Inverting op-amp the output voltage is negative (-5v)
So, we use the second circuit with one inverting op-amp then connected it series with the first circuit.
The second circuit use to make negative output is positive so the gain will be,

$$Gain\ (Av) = 1$$
$$Assume\ Rf = 1\ k\Omega$$
$$So, Ri = \frac{1 * 103}{1} = 1000\ \Omega = 1\ k\Omega$$
$$Then\ V(out) = -\left(\frac{Rf}{Ri}\right) * V(in) = -\left(\frac{1k}{1k}\right) * -5 = 5\ V$$

- **<u>Circuit in Multisim:</u>**

(1) Input (1) Output

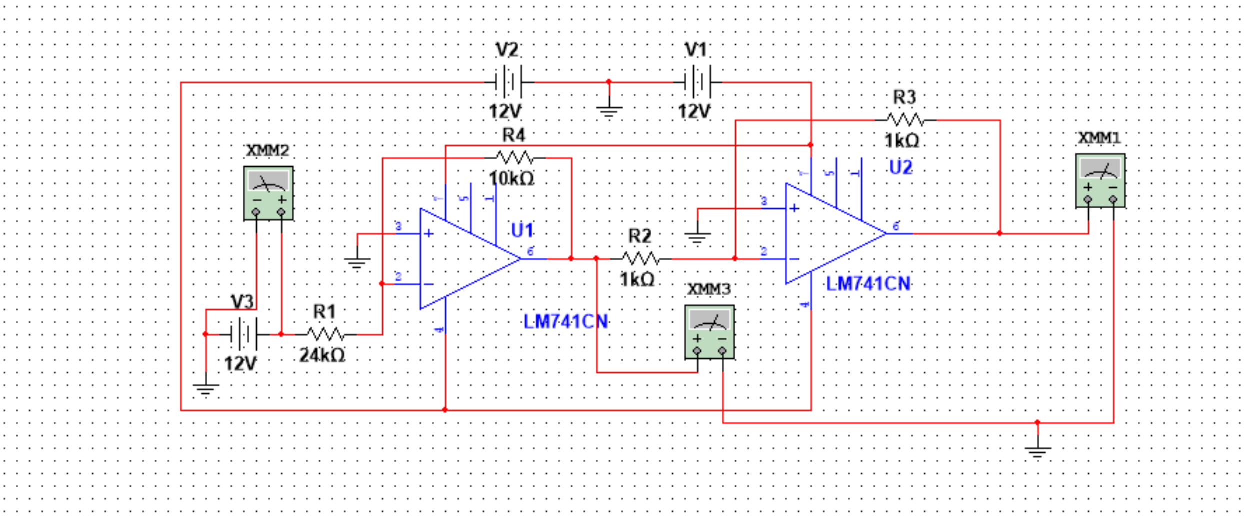


Figure 9-2- 6: Multisim of Circuit three

- **Circuit in PCB:**
  (1) Input (1) Output

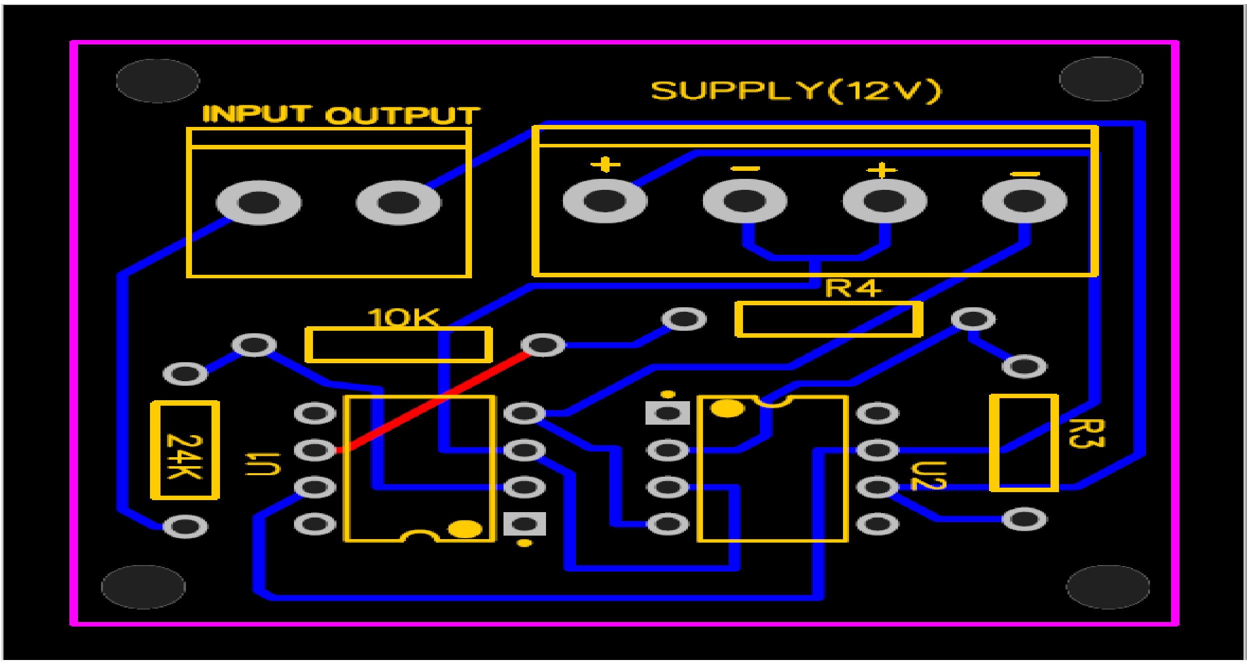


Figure 9-2- 7: PCB of Circuit three

4- **Buffer circuit:**

We using buffer circuit to overcome the voltage drop.

- **Components:**

3* Op-amp (lm741CN).

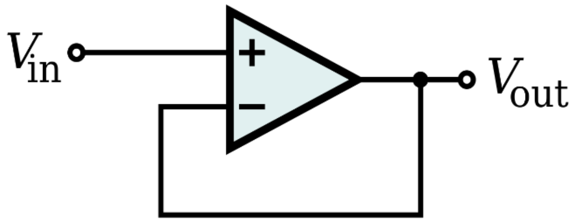


Figure 9-2- 8: Buffer Circuit

- **Circuit in Multisim:**

(3) Input (3) Output

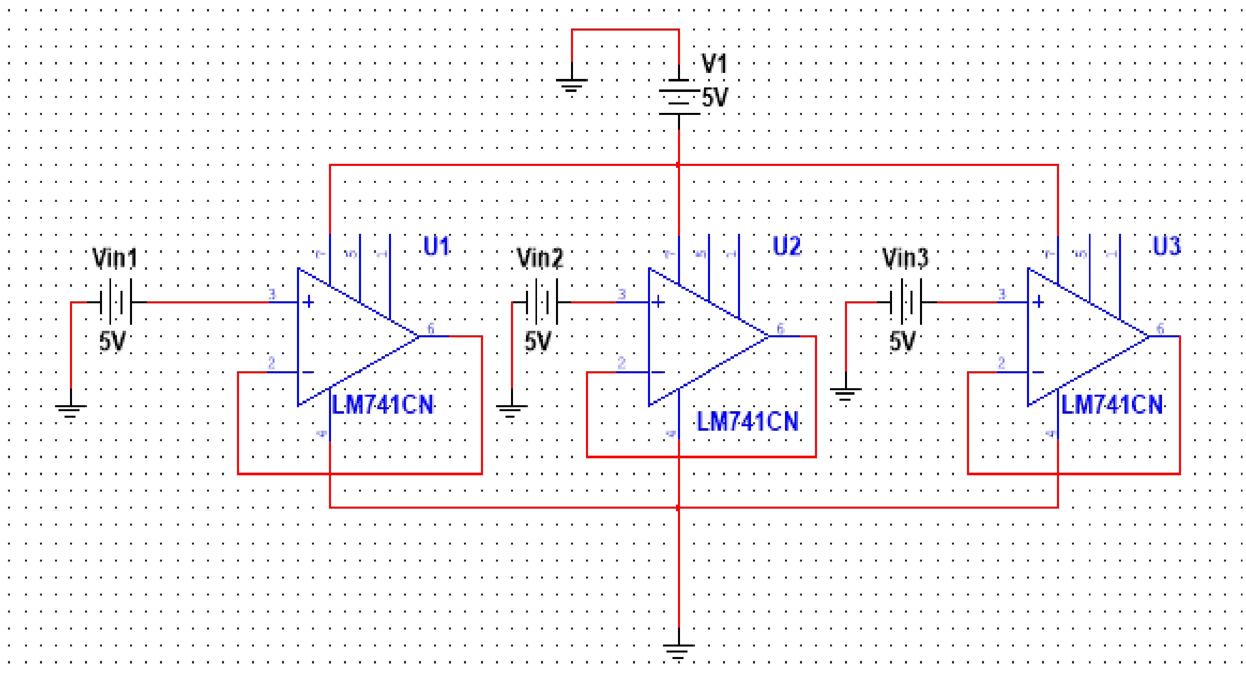


Figure 9-2- 9: Multisim of Circuit Four

- **Circuit in PCB:** (1) Input (1) Output

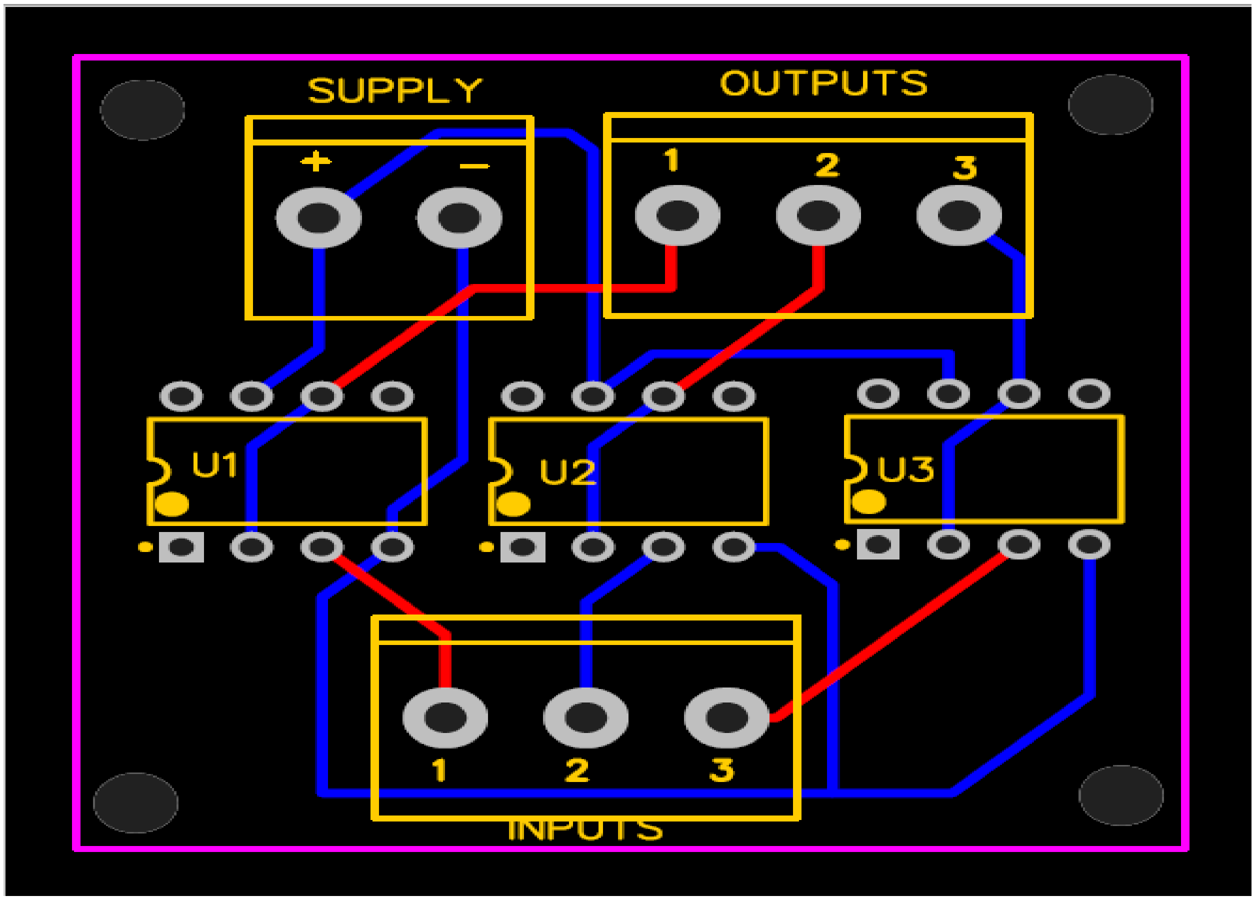


Figure 9-2- 10: PCB of Circuit Four

9-3: Actuators Control:

9-3-1: DC motor:

To control the motor, we need to make parameter estimation for the motor, for the control to be more accurate.

For estimating the model, we need to change the real motor into a model which can be simplified into mathematical equation to help in parameter estimation and control.

Modeling Of System definition:

A system model represents aspects of a system and its environment. A model is a mathematical representation of a physical behavior, or information system and is the process of developing abstract models of a system, with each model presenting a different view or perspective of that system.

Modeling Of System:

There are two different models in the machine

- **i.** Modeling of DC motor.
- **ii.** Modeling of DC motor with conveyer chain.

1- Modeling of DC motor

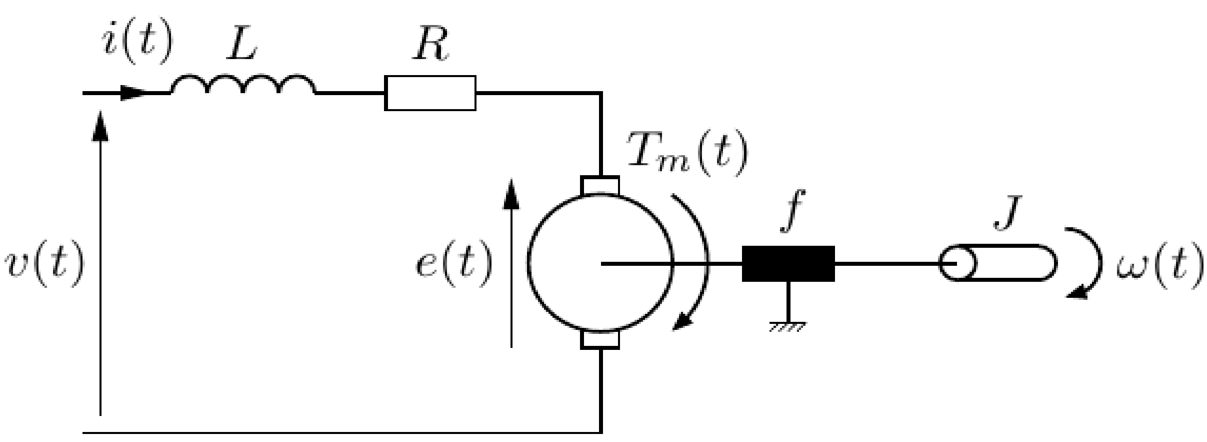


Figure 9-3-1- 1: Modeling of DC motor

$$Ei(s) = Ia * (RA + L) + Eb(s)$$

$$where\ Eb(s) = \ kb * Wm$$

$$Ia = \ Ei(s) - \frac{Eb(s)}{RA} + L \qquad (9\text{-}3\text{-}1\text{-}1)$$

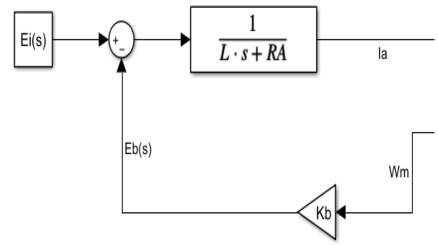


Figure 9-3-1- 2: Relation Between Current and The Input Voltage

..

$$Since,\ \ \Sigma T \ = J\alpha$$

$$Therefore, Tm = \ Jm * S\, Wm(s) + Bm \ * Wm(s) \qquad (9\text{-}3\text{-}1\text{-}2)$$

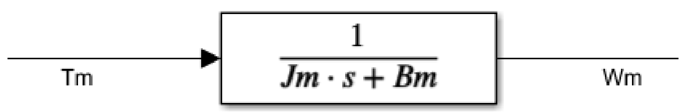


Figure 9-3-1- 3: Relation Between Torque and Motor Speed

$$Tm = Kt * Ia \qquad (9\text{-}3\text{-}1\text{-}3)$$

$$From\ equation\ 9-3-1$$

$$Tm = Kt \ * \left(Ei(s) - \frac{Eb(s)}{RA} + L \right) \qquad (9\text{-}3\text{-}1\text{-}4)$$

$$From\ equation\ 9-3-1-1{,}2{,}3$$

The block diagram of DC motor

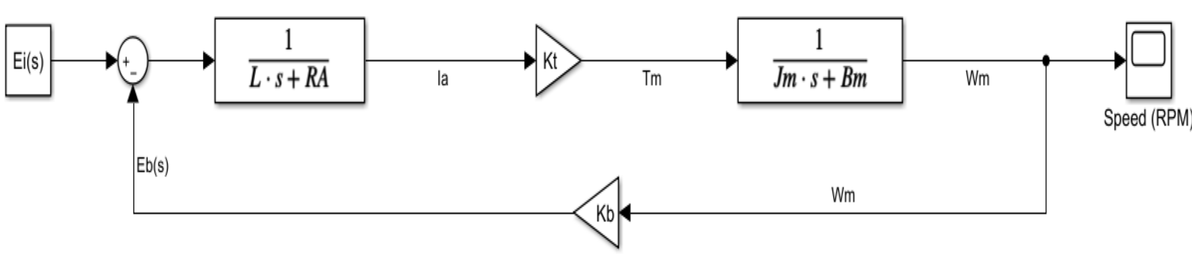


Figure 9-3-1- 4: Block Diagram of DC Motor

For Parameter Estimation of DC Motor:

Assume the input power equal output power so $Kt = Kb = Km$.

Due to the inductance value (L) is very low so it neglected.

This Is Final Model for DC Motor

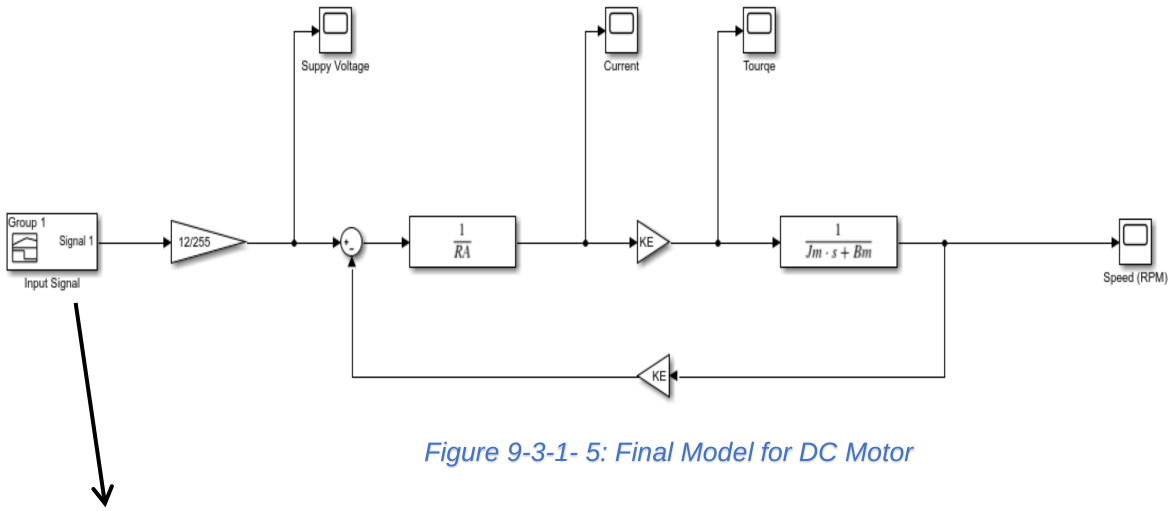


Figure 9-3-1- 5: Final Model for DC Motor

The Input Voltage That Is Selected to DC Motor Excitation

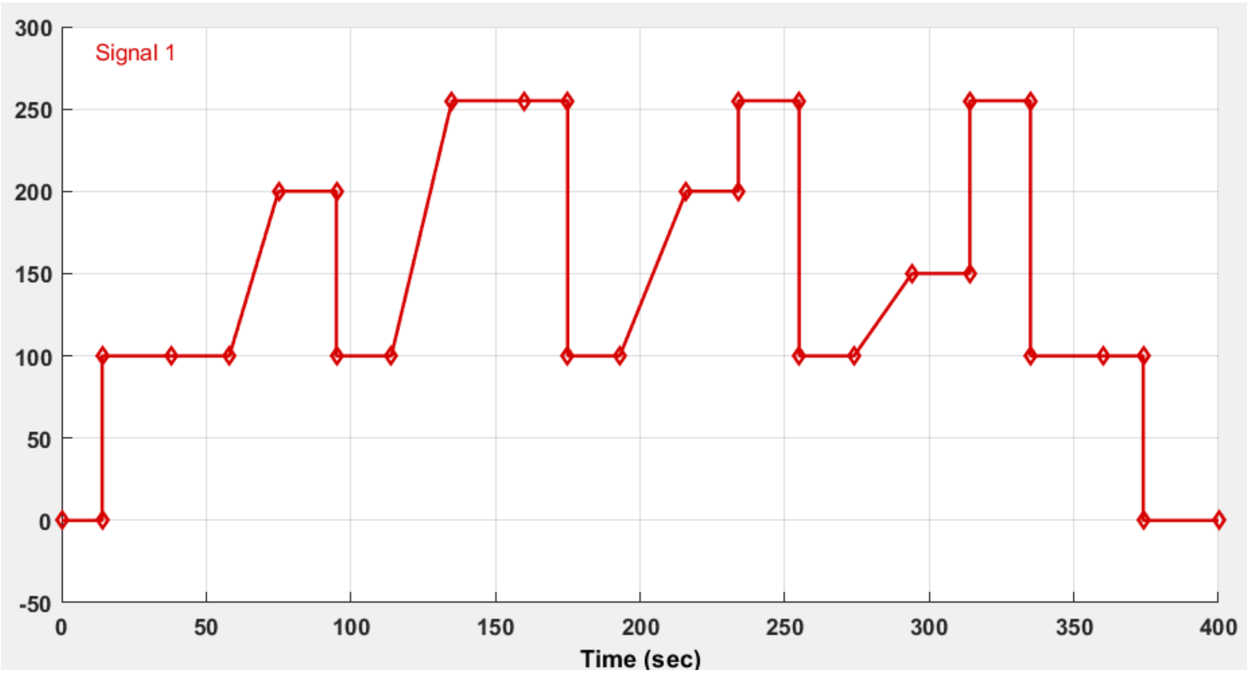


Figure 9-3-1- 6: Input Voltage for Motor Excitation

By using two Arduino uno one connected to MATLAB (Simulink) to get the input signal and give it to the DC motor and other to read the speed of DC motor in RPM.

For Simulink

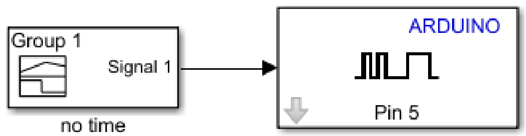


Figure 9-3-1- 7: Model for Getting the Input Signal

For Reading the Speed

encoder_data_for_matlab | Arduino 1.8.8

File Edit Sketch Tools Help

encoder_data_for_matlab §

```
unsigned long int no_of_pulses;//measuring the rising and falling edges of the signal
byte encoder_sensor_chA = 2;//The pin location of the channel A of sensor
int RE = 600;//encoder resolution in pulse/rev
float Ts = 1.0;//take sampling time Ts sec

void NOP ()//This is the function that the interupt calls
{  no_of_pulses++;//This function measures the rising edge of the encoder sensors signal
}

// The setup() method runs once, when the sketch starts
void setup()//
{
  pinMode(encoder_sensor_chA, INPUT_PULLUP);//initializes digital pin 2 as an input
  //pinMode(6, INPUT);
  Serial.begin(9600);//This is the setup function where the serial port is initialised,
  attachInterrupt(digitalPinToInterrupt(encoder_sensor_chA), NOP, RISING);//and the interrupt is attached}

}

// the loop() method runs over and over again,
// as long as the Arduino has power
void loop(){
  float Calc_RPM = 0;

  no_of_pulses =0;//Set number of pulses to 0 ready for calculations
  sei();//Enables interrupts
  delay(Ts*1000);//Wait TS millisecond
  cli();//Disable interrupts
  Calc_RPM = float((no_of_pulses * 60)/(RE * Ts));//(Pulse frequency x 60) / (encoder resolution x sampling time) = speed in RPM
  Serial.println(Calc_RPM, DEC);//Prints the number calculated above
}
```

Figure 9-3-1- 8: Arduino Code for Reading the Speed

Measured Output Speed from Motor In RPM

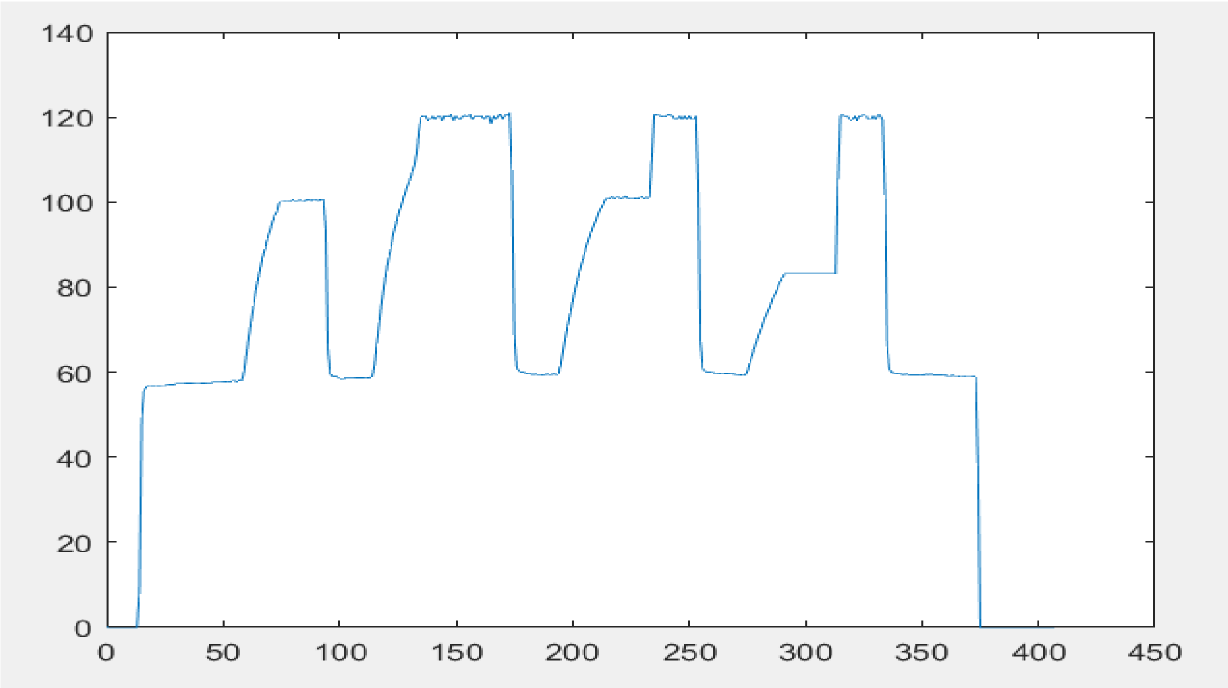
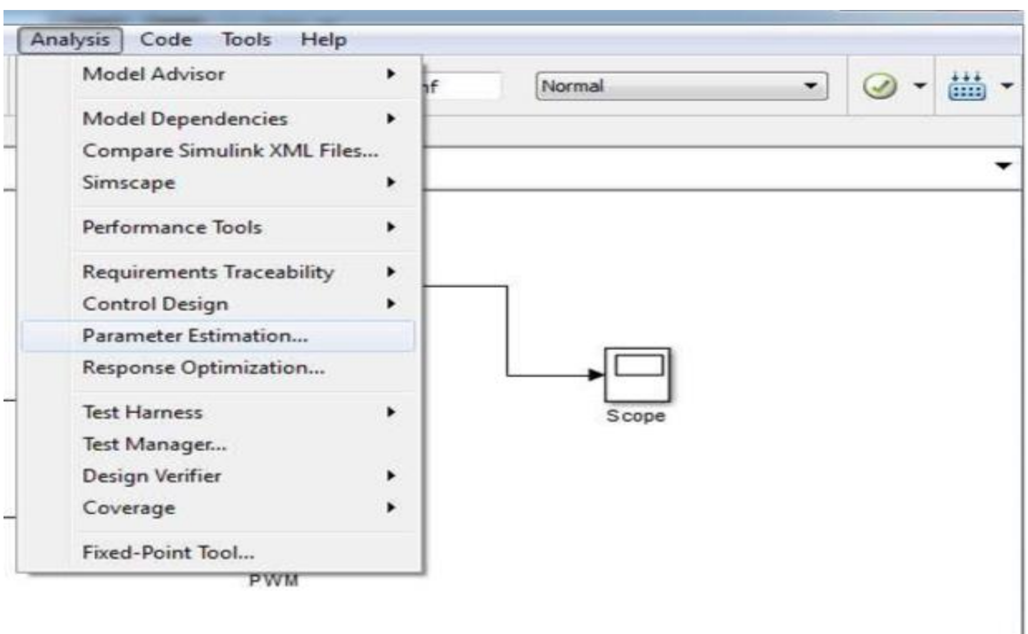
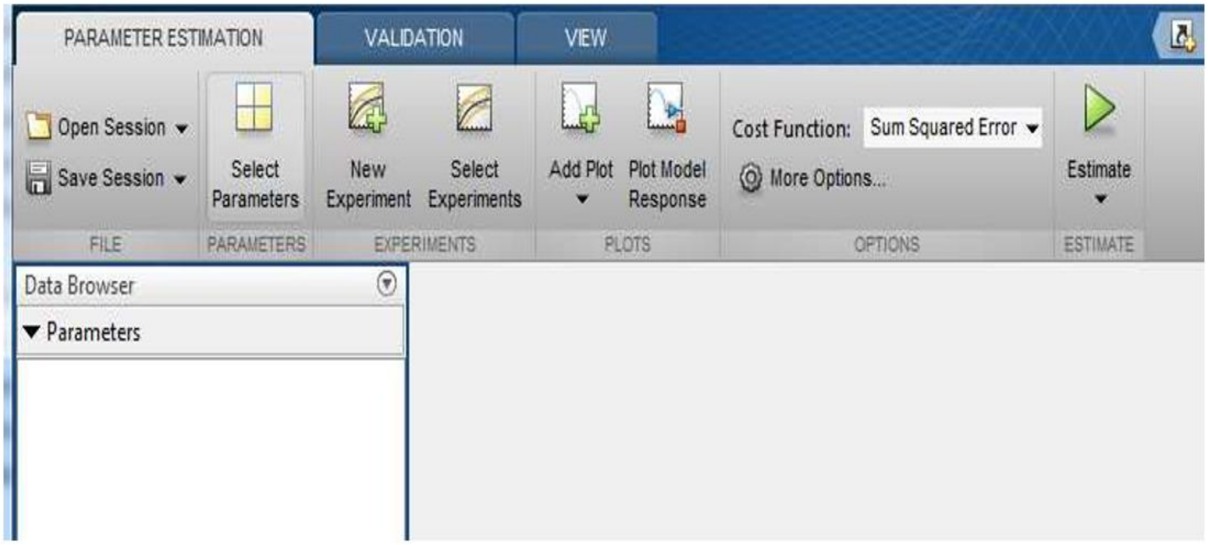


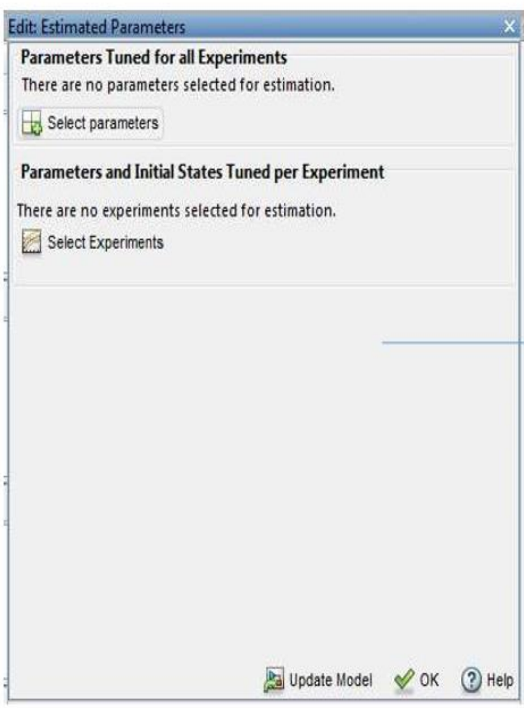
Figure 9-3-1- 9: Measured Output Speed

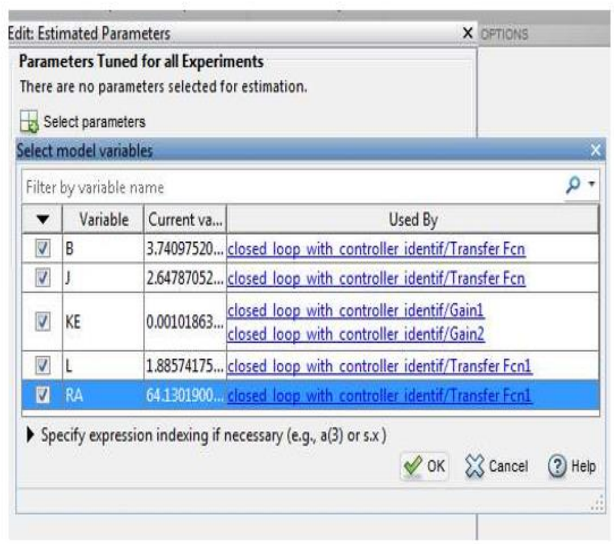
For getting the simulated output speed Excited the model with the same input signal in the Simulink then …In the Simulink model window, select Analysis > Parameter Estimation



Then click on select parameters

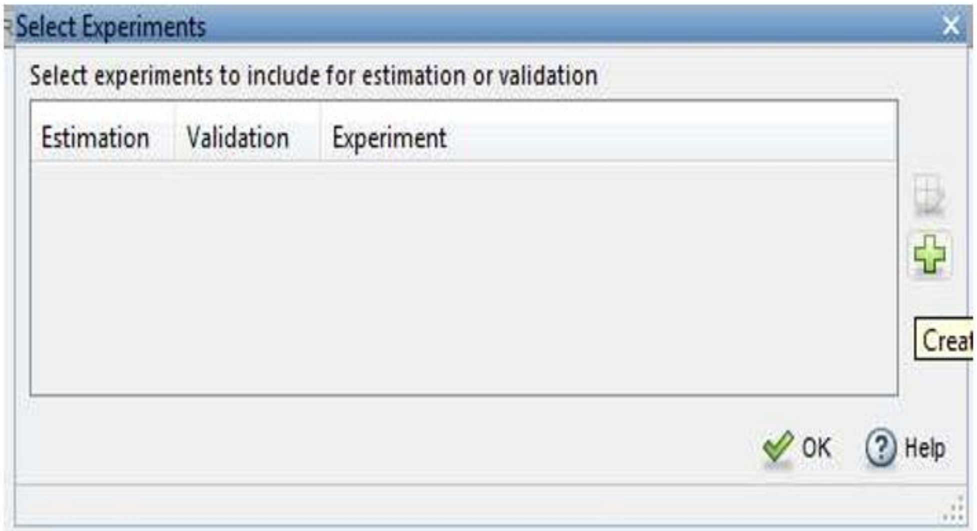




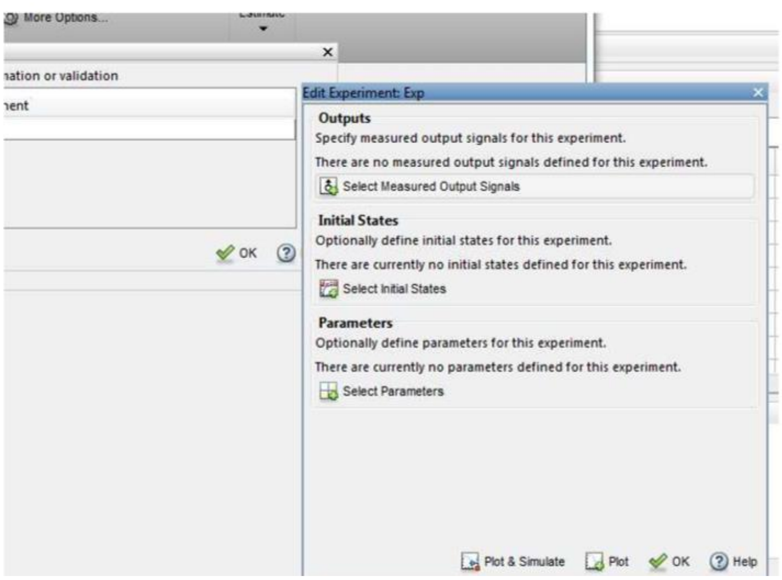


In the Parameter Estimation tool on the Parameter Estimation tab, click the New Experiment button. This will create an experiment with the name Exp in the Experiments list on the left pane.

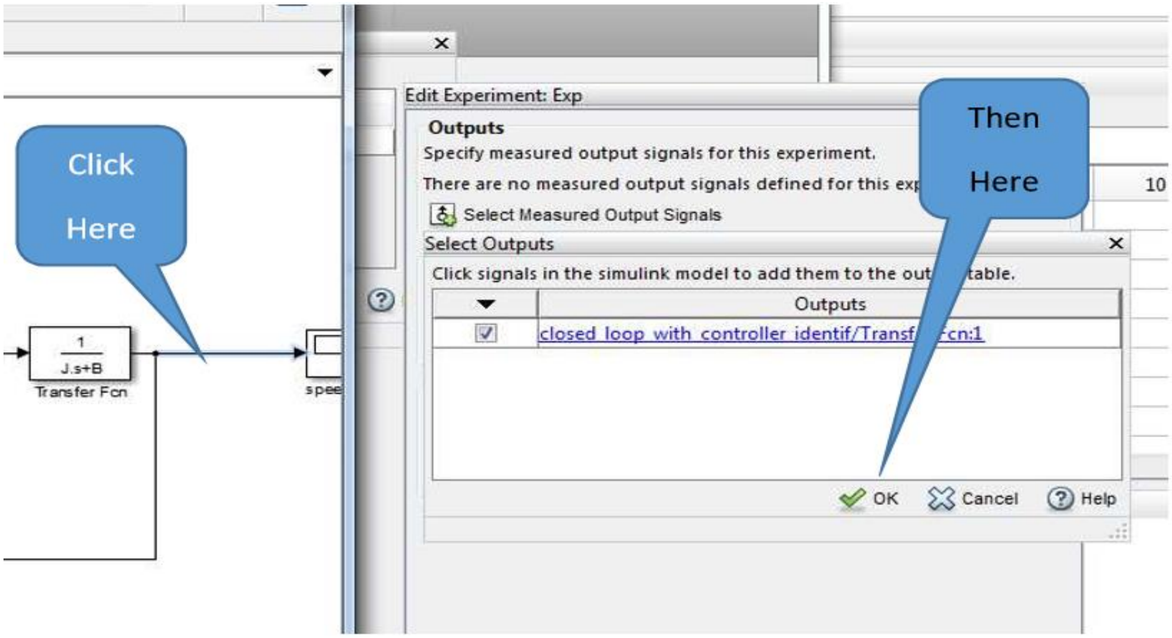
Then click on create



Click on select measured output signal and then to Simulink and click on the output signal



After that have to select from Simulink the output signal of the model



Write the variables of measured data in the following windows then click on plot and simulation

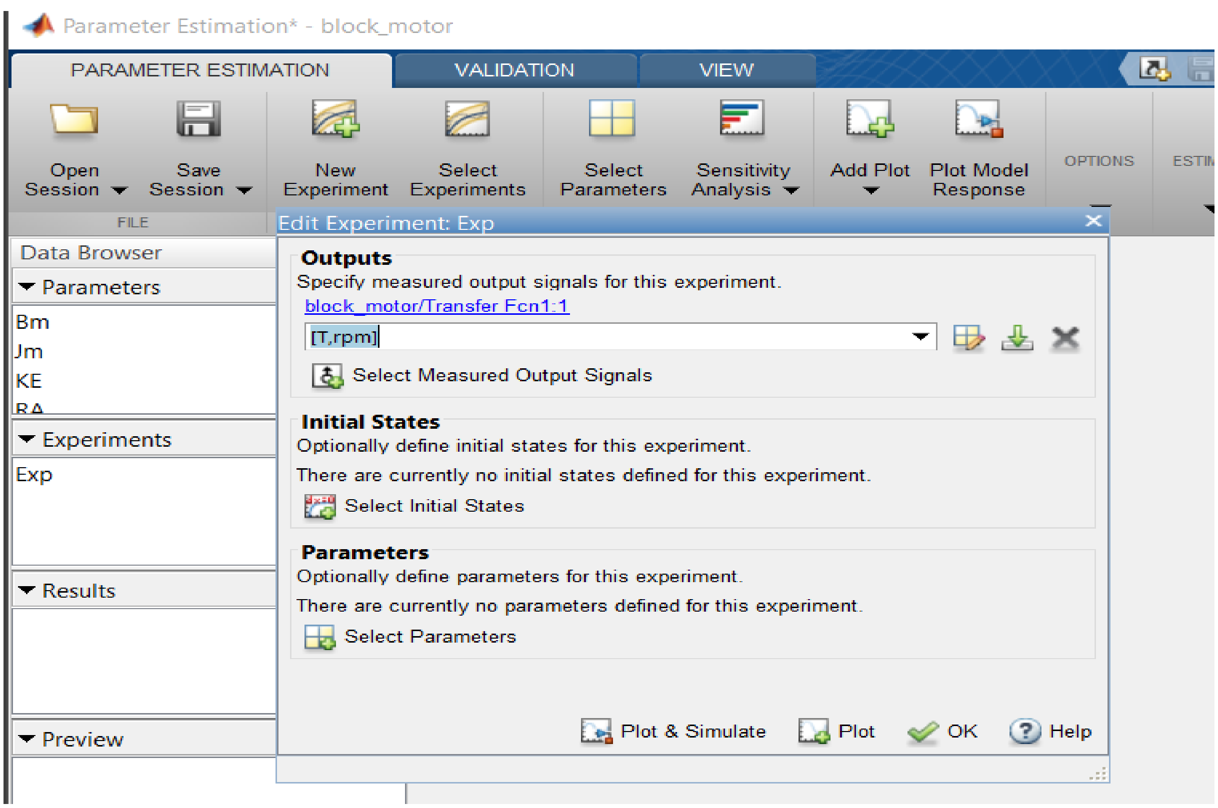


Figure 9-3-1- 10: Steps for parameter estimation on Simulink

Simulation Result VS Actual Response

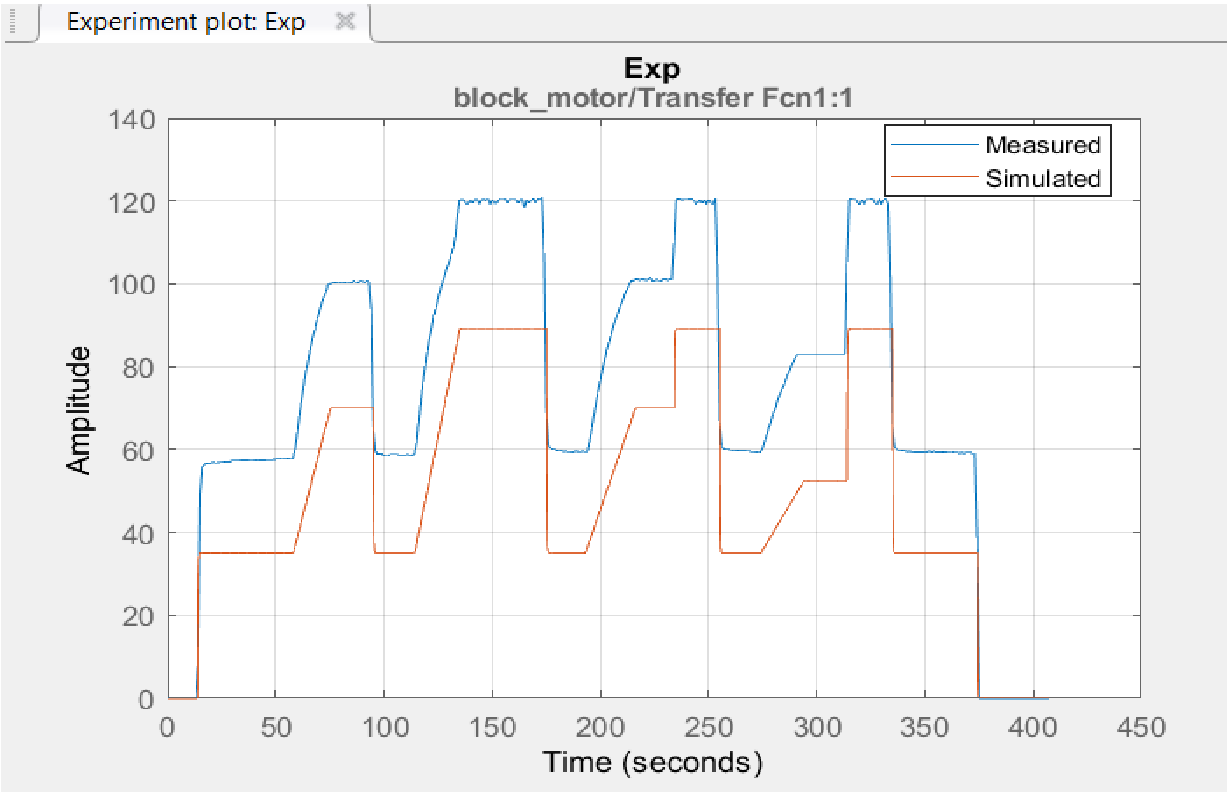


Figure 9-3-1- 11: Simulation Result VS Actual Response

Response Of the Simulation Model After Parameter Estimation

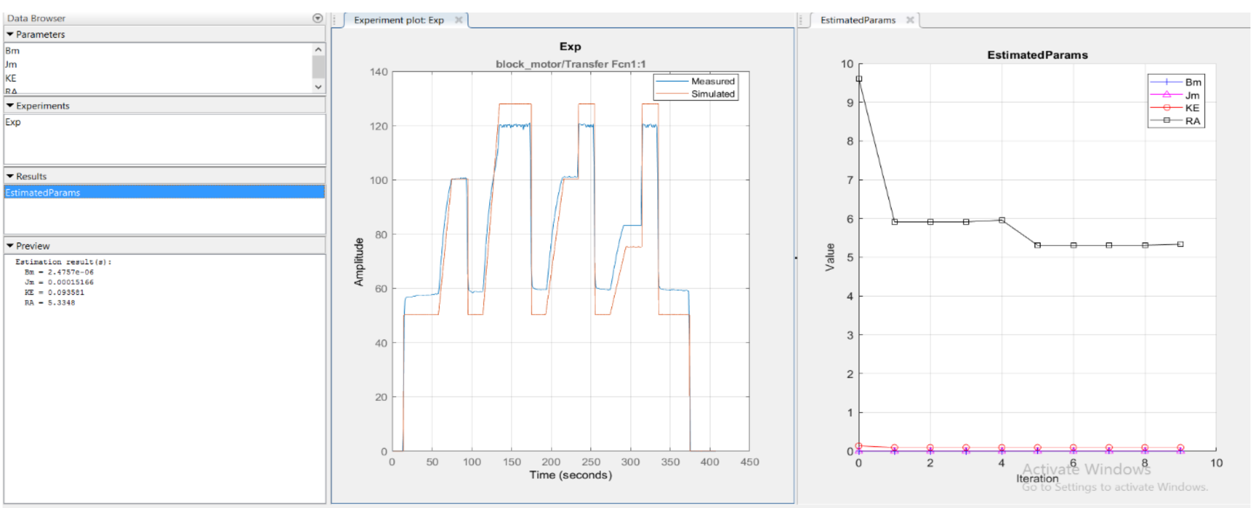


Figure 9-3-1- 12: Response of The Simulation Model After Parameter Estimation

2- **Modeling of DC motor with conveyer chain.**

The conveyer chain effected with more inertial and more damping on the DC motor.

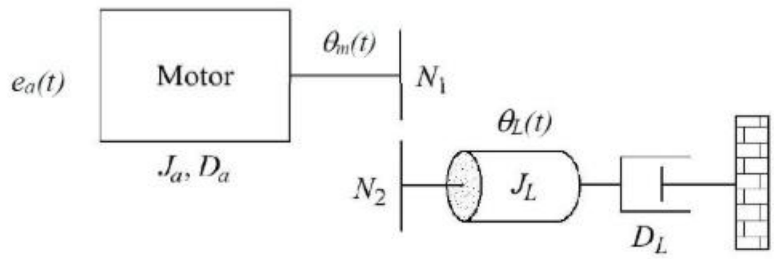


Figure 9-3-1- 13: DC Motor with Conveyer chain

$$Since\ \Sigma T = J\alpha\ ,Therefore,$$

$$Tm = Jm * S\,Wm(s) + Bm * Wm(s) + \frac{Tl(s)}{Ng} \qquad (9\text{-}3\text{-}1\text{-}5)$$

$$where\ Ng = \frac{N2}{N1} = \frac{76}{24}$$

$$Tl(s) = Jl * S\,Wl(s) + Bl * Wl(s) = \left(Jl * S\frac{Wm(s)}{Ng}\right) + \left(Bl * \frac{Wm(s)}{Ng}\right)$$

$$So, Tm = Jm * S\,Wm(s) + Bm * Wm(s) + \left(Jl * S\frac{Wm(s)}{Ng^2}\right) + \left(Bl * \frac{Wm(s)}{Ng^2}\right) \qquad (9\text{-}3\text{-}1\text{-}6)$$

By

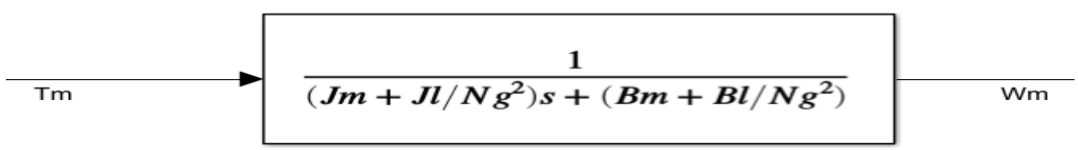


Figure 9-3-1- 14: Torque Related to Motor Speed with The Conveyer Chain

combination the conveyer chain with DC motor model

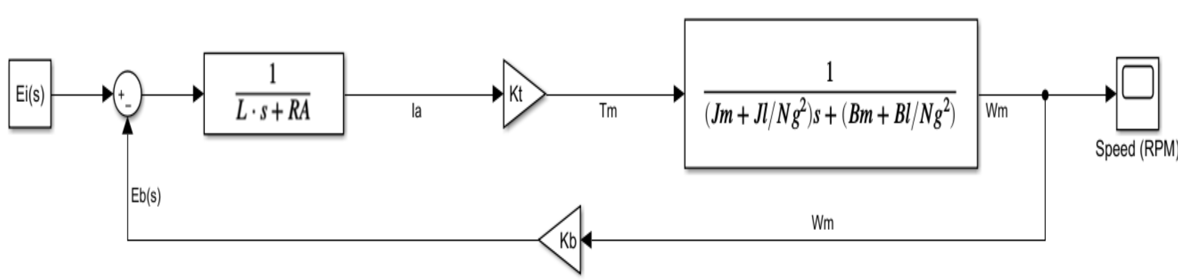


Figure 9-3-1- 15: DC Motor with Conveyer Chain Model

By apply the same technique for parameter estimation, so can estimate the Jl and Bl parameters.

The Final Model for The System

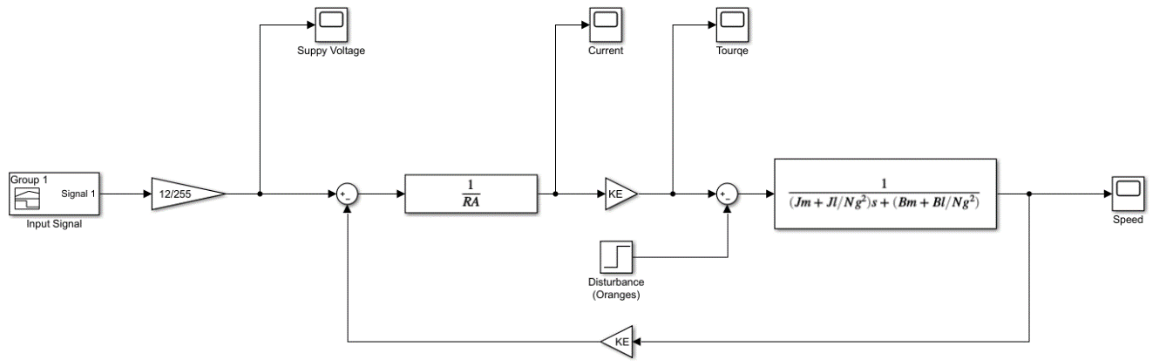


Figure 9-3-1- 16: The Model of System

Note: the disturbance is the impact of oranges on the conveyer chain

The Input Voltage That Is Selected to System Excitation

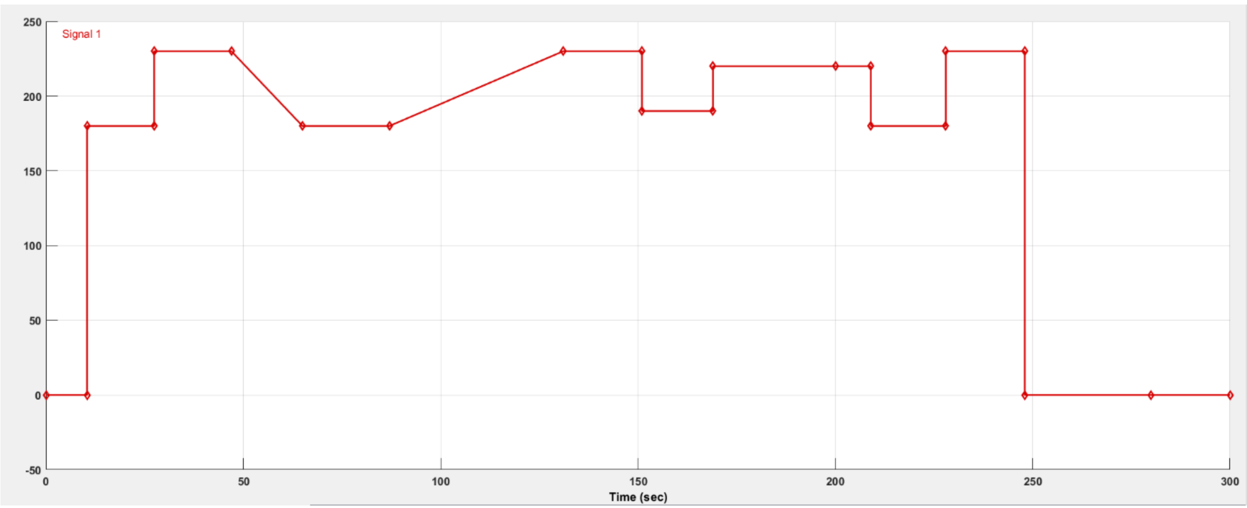


Figure 9-3-1- 17: The Input Voltage for The System

By applying the all-previous steps so,

Measured The System Output Speed In RPM

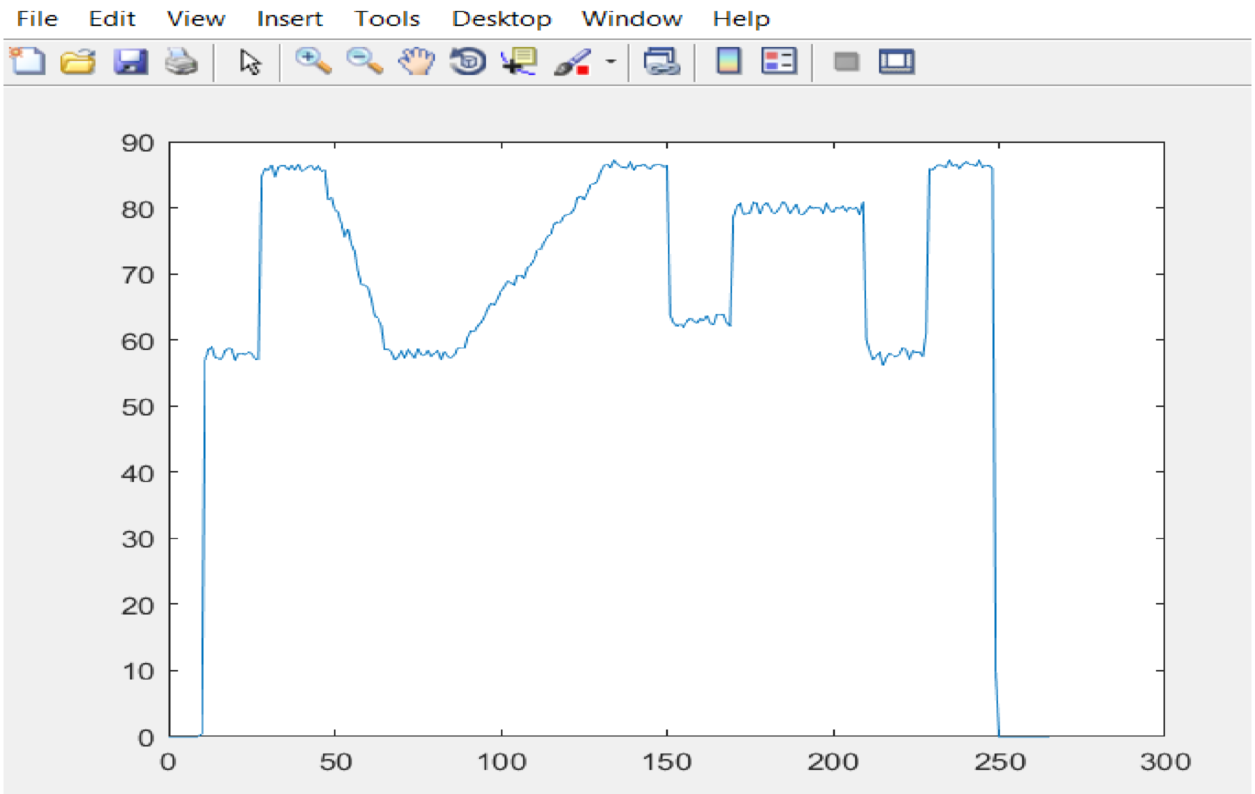


Figure 9-3-1- 18: Measured Speed of System

Simulation Result VS Actual Response

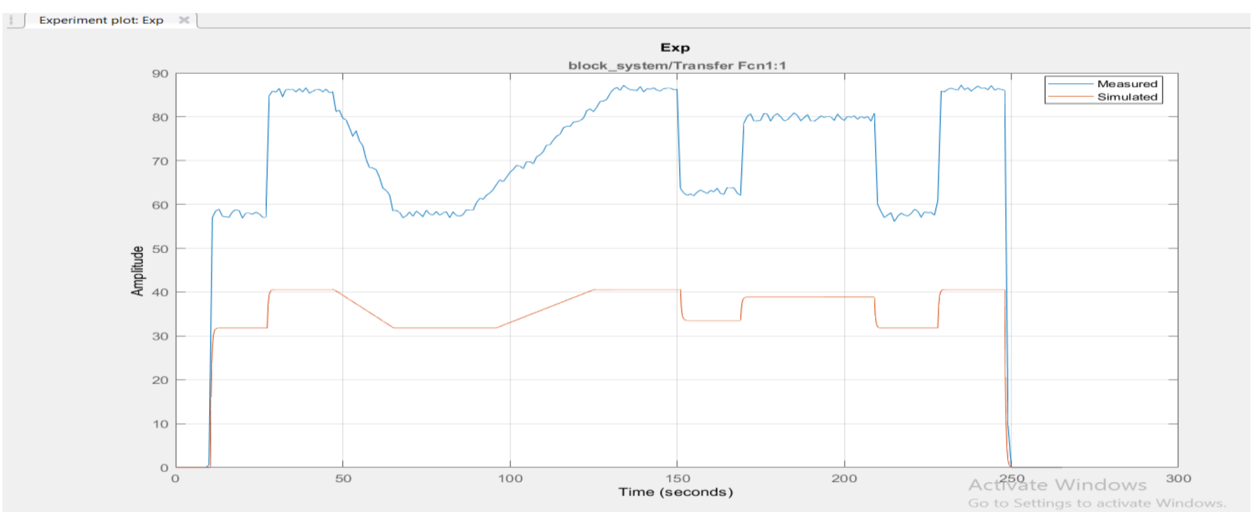


Figure 9-3-1- 19: Simulation Result VS Actual Response

Response Of the Simulation Model System After Parameter Estimation

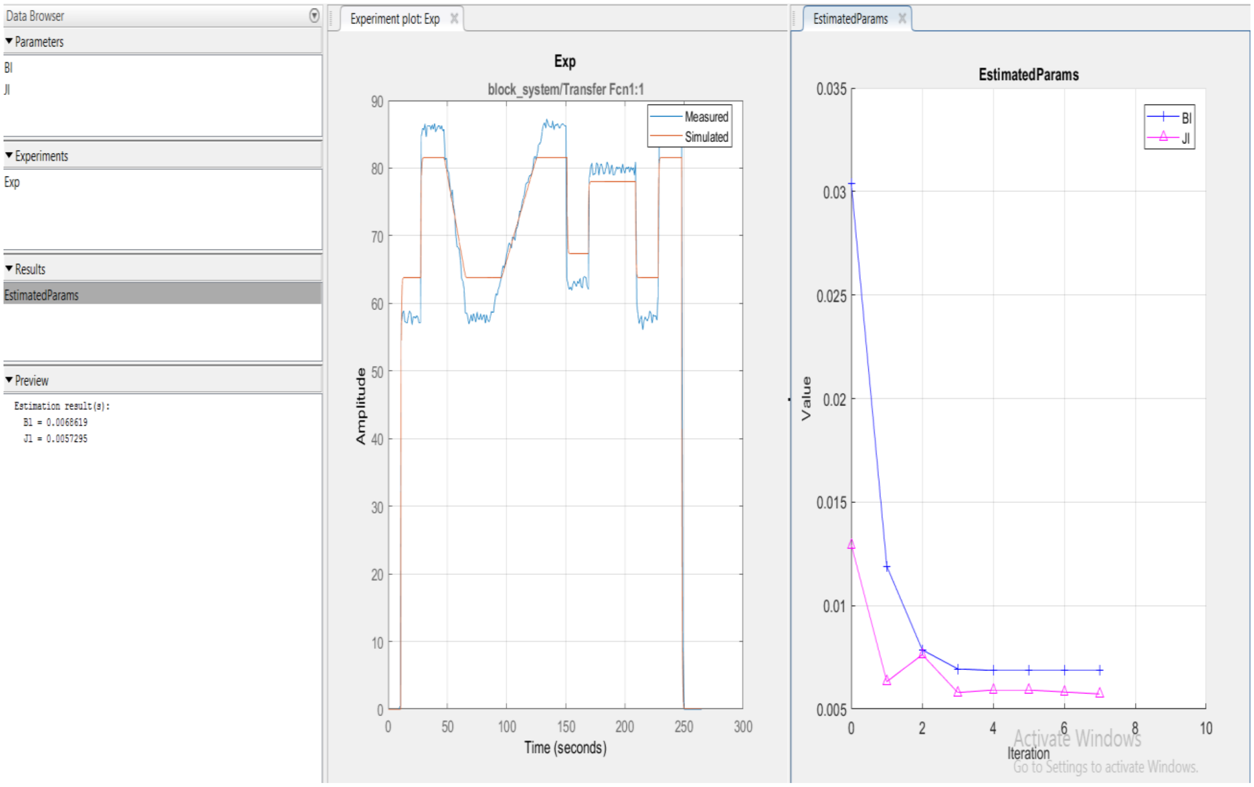


Figure 9-3-1- 20: Response of The Simulation Model System After Parameter Estimation

Finally, the parameter estimation for system as known

Model initialization function:

```
RA=5.3348;
KE=0.093581;
Jm=0.00015166;
Bm=2.4757*10^-6;
Jl=0.0057295;
Bl=0.00686619;
Ng=76/24;
```

Figure 9-3-1- 21: Motor Parameters

Where,

$\boldsymbol{Jm}$: the inertial of motor.

$\boldsymbol{Jl}$: the inertial of conveyer.

$\boldsymbol{KE}$: the constant gain.

$\boldsymbol{Ng}$: the sprocket ratio.

$\boldsymbol{Bl}$: the damping coefficient of conveyer.

$\boldsymbol{Bm}$: the damping coefficient of DC motor.

$\boldsymbol{RA}$: the resistance of DC motor.

$\boldsymbol{Eb}(\boldsymbol{s})$: the back EMF of motor.

$\boldsymbol{Ia}(\boldsymbol{s})$: the armature current.

$\boldsymbol{Wm}(\boldsymbol{s})$: the speed of motor.

$\boldsymbol{Wl}(\boldsymbol{s})$: the speed of conveyer.

$\boldsymbol{Tm}$: the torque of motor.

$\boldsymbol{Tl}$: the torque of conveyer transferred to motor.

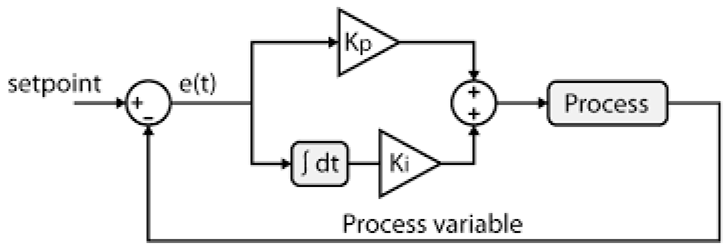
$\boldsymbol{\alpha}$: the angular acceleration.

Control of dc motor:

Because we need to keep the output of the motor at the fixed value, the PID controller is used.

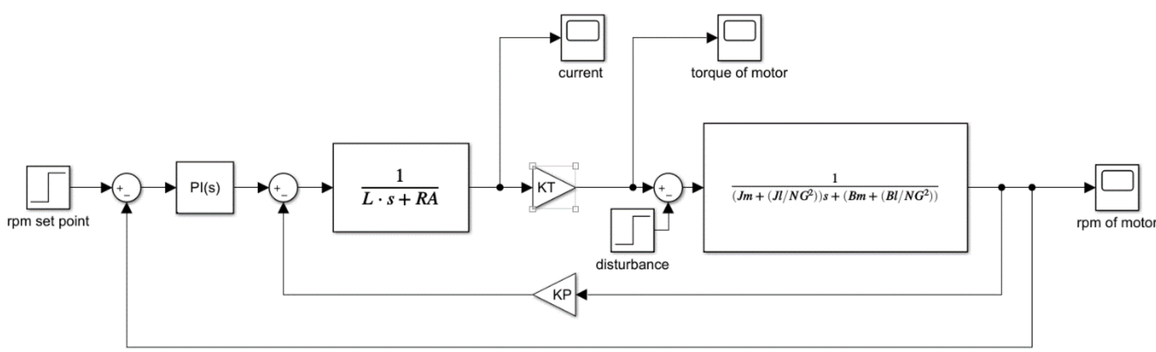
PID control uses closed-loop control feedback to keep the actual output from a process as close to the target or setpoint output as possible.

Because we need to control the speed of the motor, the only PI controller is used.



$$u = \underbrace{K_p e}_{\text{Proportional Term}} + \underbrace{K_i \int_0^t e\,dt}_{\text{Integral Term}}$$

The MATLAB Simulink program is used to get the value of P and I by using the auto tune in the PID block:

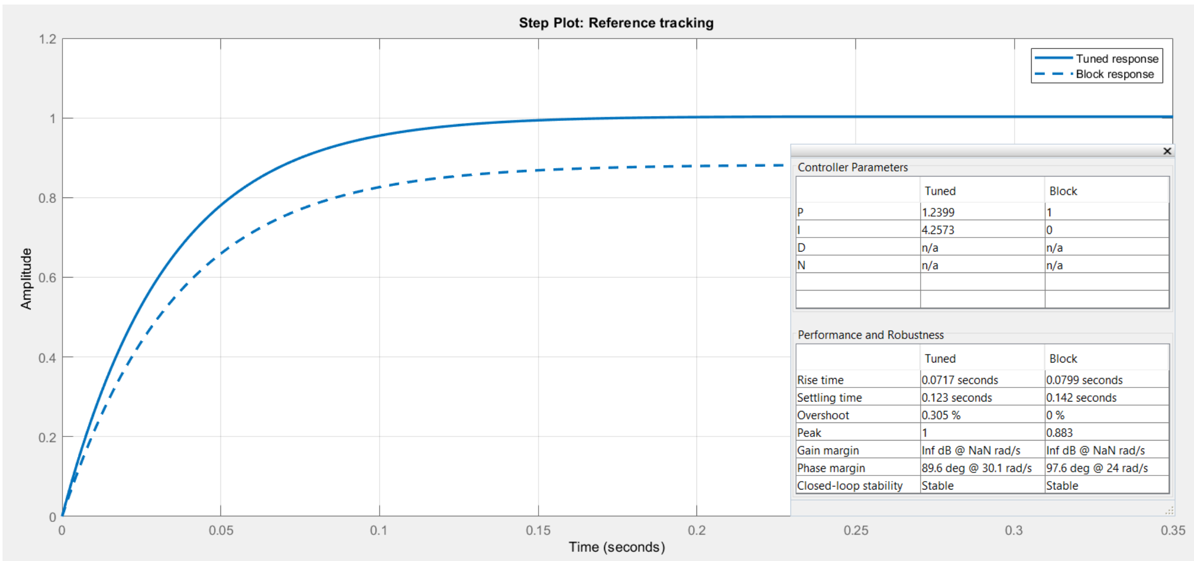


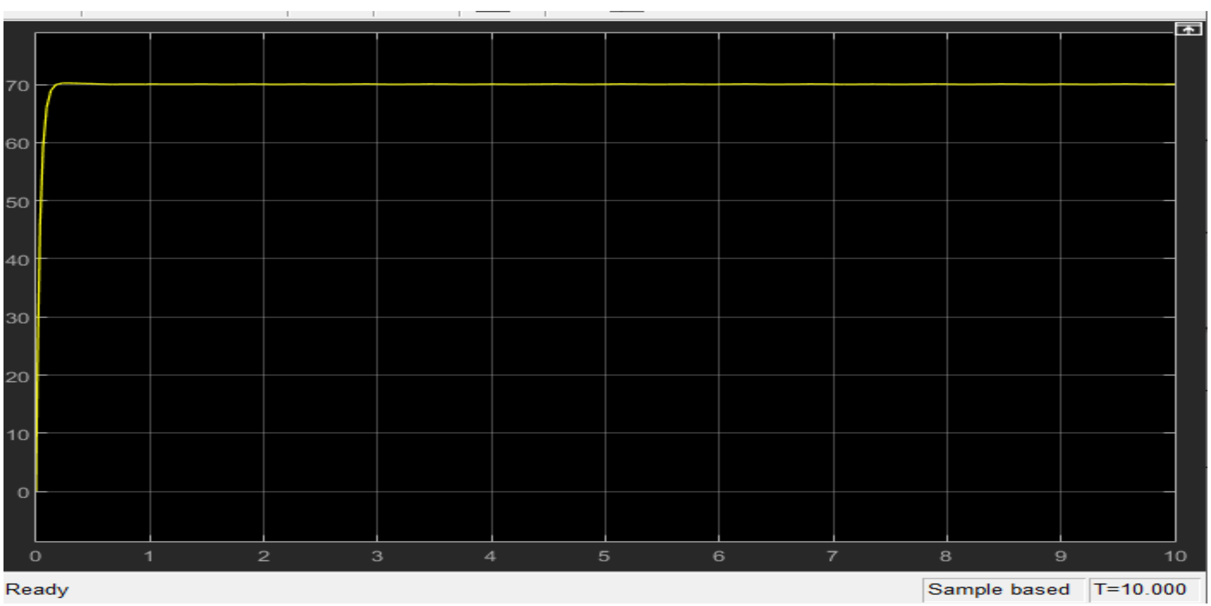
$$The\ result\ from\ auto\ tune\ is$$

$$P = 1.2339, I = 4.2573\ these\ values\ make\ the:$$

$$rising\ time = 0.0717\ sec, settling\ time = 0.123\ sec$$

$$max.overshot\ Percentage = 0.305\%$$





9-3-2: Stepper motor:

In rejection phase, we're using stepper motor for position control we have three phases at start of machine home position with the plate will be horizontal, then for two decision that came from camera, if decision came that camera is good then the plate will move clockwise with angle of less than 10 degrees, while if the decision came that the camera is rotten then the plate will move around 90 degrees approximately in the opposite direction (counter clockwise).

We need to an interface between the controller which is PLC and Stepper motor, so motor driver is used which is tb6600, that can work with different stepper motor with different current and steps/rev depend on the motor, for current up to 4A and up to 6400 steps/rev, the suitable current and steps/rev can be selected manually through six switches, three for steps/rev and the other three for current.

The selected motor is 57HZ76-13, which work with current range from 2.12A to 4.2A depend on the selected connection of motor either unipolar or bipolar series or parallel, with step angle of 1.8 degrees per step, which means each step the rotor move it moves 1.8 degrees, so for one complete revelation, $\frac{\mathbf{360}}{\mathbf{1.8}} = \mathbf{200}\ \frac{\boldsymbol{steps}}{\boldsymbol{rev}}$.

The suitable selection of motor connection, depend on the holding torque since when the orange will be projected on the rejection plate, so we need higher holding torque, from the datasheet of stepper motor we can choose the suitable connection to be bipolar with holding torque of $200\ N.cm$, as shown in Table 9-3-2-1 below.

PHASE	2 PHASE		
STEP ANGLE	1.8±5% °/STEP		
DETENT TORQUE	6 N.cm Max		
INSULATION CLASS	B		
LEAD STYLE	AWG22 UL1007		
	UNIPOLAR RESP.ONE WINDING	BIPOLAR RESP.BIPOLAR SERIAL	BIPOLAR ONLY PARALLEL
CURRENT	3.0 A/PHASE	2.12 A/PHASE	4.2 A/PHASE
RESISTANCE	1.0 ±10% Ω/PHASE	2.0 ±10% Ω/PHASE	0.5 ±10% Ω/PHASE
INDUCTANCE	1.8 ±20% mH/PHASE	7.2 ±20% mH/PHASE	1.8 ±20% mH/PHASE
HOLDING TOGQUE	142 N.cm Min	200 N.cm Min	200 N.cm Min

Table 9-3-2- 1: Holding torque of different stepper connection

We choose the bipolar serial connection for higher holding torque and less consume of current, the connection as shown in Figure 9-3-2-1.

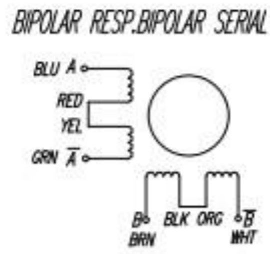


Figure 9-3-2- 1: Bipolar serial connection

So, the switches in driver will be manually adjusted to give 200 steps/rev and current range 2 to 2.2 A.

The driver contain 12 pins, two for power supply from 9V to 40V, then 4 pins for motor connection since the driver work with 2 phase, with bipolar connection A+,A- for phase one and B+,B- for phase two, then the last 6 pins for control, two for enable to enable the motor the work without this the motor will not rotate even by given the right pulses, two for direction to move the motor clockwise or counter clockwise, the last two pines for PWM each complete pulse period will let the motor move 1.8 degrees, for example if 90 degrees is needed then the pulse given with be 50 pulses $\frac{90}{1.8} = 50\ pulses$, also the speed of motor will depend on the period of high pulse.

In the driver I have two modes either active low or active high, if the pins of ENA+, DIR+, PUL+ are connected to 5 volts then the control will be done on ENA-, DIR-, PUL-, the other mode will be ENA-, DIR-, PUL- are connected to Ground, then the control will be done on ENA+, DIR+, PUL+.

From the Table 9-3-2-2 shown we can understand how to control the drivers by controller,

Pins	**Mode 1**		**Mode 2**	
ENA+	HIGH		LOW(ON)	HIGH(OFF)
DIR+	HIGH		LOW(CW)	HIGH(CCW)
PUL+	HIGH		FALLING EDGE	
ENA-	HIGH(ON)	LOW(OFF)	GND	
DIR-	HIGH(CW)	LOW(CCW)	GND	
PUL-	RISING EDGE		GND	

Table 9-3-2- 2: Different mode of operation for stepper

We’re going to work with Mode1, but with the connection of Mode two since the PLC is active high.

PLC Algorism Control:

As we discussed above, we need to control 3 pins which is, enable, direction, pulse.

The plate contains three states:

- State one the rejection plate is on good orange state
- State two the rejection plate is on rejected state
- State three in between as the plate go between one state to other state.

1. Enable Pin Control:

The enable pin must be high for letting the stepper motor to rotate so there are some conditions.

- Project must be running which means the start button must be “ON”.

2. Direction Pin Control:

The direction pin responsible for moving the rotor in Clockwise direction or Counter Clockwise.

- The action depends on camera state either good or rotten orange.

Good Camera (A)	Rotten Camera (B)	Stepper Direction Pin (O)
0	0	1
0	1	0
1	0	1
1	1	1

Table 9-3-2- 3: Direction pin control

So, as shown in Table 9-3-2-3 the plate will be in state one unless the camera send signal that the orange is rotten so the plate will move to state two (rotor will move CCW).

$$O = \bar{A}\bar{B} + A\bar{B} + AB$$

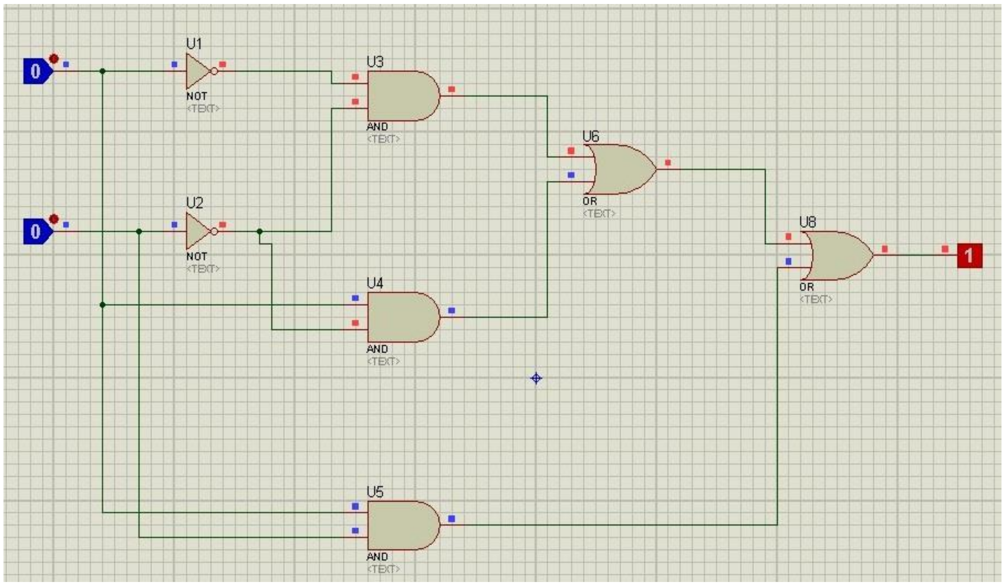


Figure 9-3-2- 2: Logic gates of Direction pin

3- **Pulse Pin Control:**

For pulse control it needs simple closed loop for more accuracy and precise.

The feedback came from two limit switches at the end of each state of the plate as either state one and state two.

The feedback control depends on some conditions.

- Limit Switch One (The one at the end of state one).
- Limit Switch Two (The one at the end of state two).
- Camera signal as either good or rotten

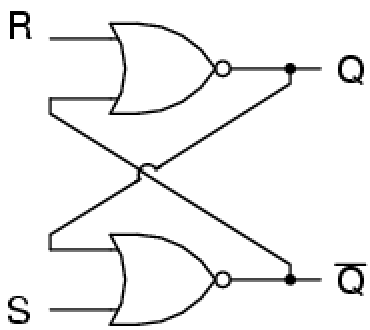
The signal that came from camera is pulse, the signal gives only one pulse high then back to low so we have to control both two signal that came from camera and state of limit switch.

So, we will control each state independent, when signal came from camera it will see the state from the limit, if good camera signal and limit one is zero then let the rotor move, and if rotten camera signal and the limit two is zero then let rotor rotate.

Good Camera Signal	Limit one	Output
0	0	No change
0	1	0
1	0	1
1	1	0

Table 9-3-2- 4: Feedback control

We can say that it like SR latch, also it’s the same from the rotten camera signal with limit two.



S	R	Q	$\overline{Q}$
0	0	latch	latch
0	1	0	1
1	0	1	0
1	1	0	0

Figure 9-3-2- 3: SR latch for feedback control on stepper

Figure 9-3-2- 4: SR latch for feedback control on stepper

The pulse control is responsible for moving the 1.8 degrees as given pulse.

It depends on,

- Enable pin is on.
- Feedback control signal.

The pulse given is controlled by timer as on for specific time and off for the rest of period.

We need the signal to be high as soon as the enable and feedback is high for specific time and to be off after this time for specific time and so on the cycle repeat itself until one of the two pins are low (enable, feedback).

As we said the pulse is given by timer, for as soon as given high the pulse will be high until time is done the monostable timer (TMON) is good for this case, while to cut off the signal after the period is done, we can use normal ON timer (TON), after the whole period is completed, the timer needs to be reset, the output of TON is used for resting the timers.

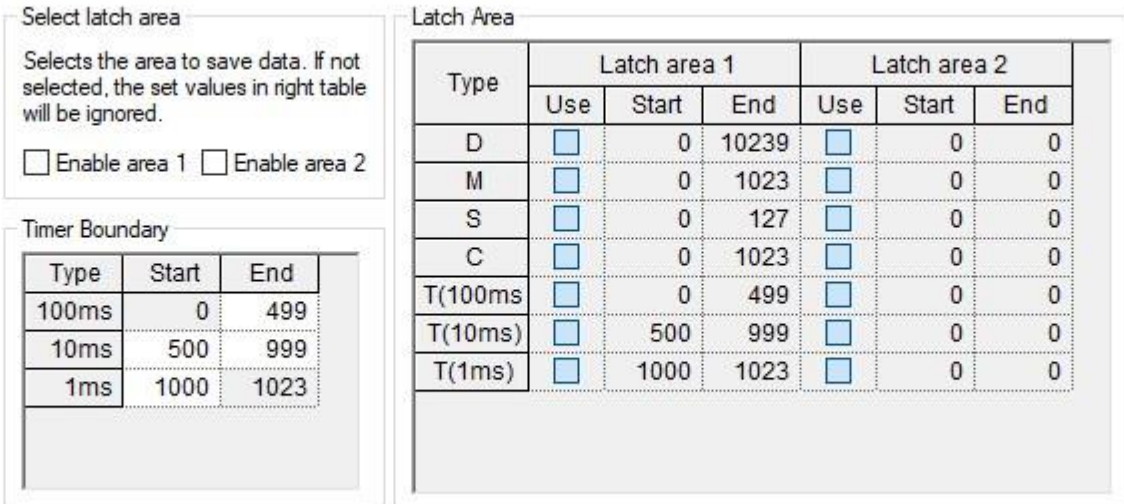
In XBC DN20SU PLC, it contains three types of timers with different addresses, the different between the timers is the time period as 100ms, 10ms, 1ms, as shown in Table 9-3-2-7.

For 100ms, timer address is from 0 to 499.

For 10ms, timer address is from 500 to 999.

For 1ms, timer address is from 1000 to 1023.

The choose of the timer depend on speed needed since for stepper motor the pulse duration is related to speed, as the pulse period is less the speed will increase since speed is frequency of pulse.


Select latch area

Selects the area to save data. If not selected, the set values in right table will be ignored.

☐ Enable area 1 ☐ Enable area 2

Timer Boundary

Type	Start	End
100ms	0	499
10ms	500	999
1ms	1000	1023

Latch Area

Type	Latch area 1			Latch area 2		
	Use	Start	End	Use	Start	End
D	☐	0	10239	☐	0	0
M	☐	0	1023	☐	0	0
S	☐	0	127	☐	0	0
C	☐	0	1023	☐	0	0
T(100ms	☐	0	499	☐	0	0
T(10ms)	☐	500	999	☐	0	0
T(1ms)	☐	1000	1023	☐	0	0

3. **HMI data:**

The data that will be shown in HMI to be monitored will be the state of the plate and the number of good and rotten orange.

- For counting the orange, counter up will be used as either signal from good orange or rotten orange will be counted.
- The other reading is state of plate, the state one, two, and three.
  State one depends on limit 1 “green lamp”.
  State two depends on limit 2 “red lamp”.
  State three depends on both limit 1 and 2 “yellow lamp”.

9-4: Display and Recording:

In display and recording is eXP40-TTA/DC, as discussed in **Chapter 4**, we will discuss about the ways of communication between PLC and HMI and the design of HMI.

9-4-1: Communication between HMI and PLC:

Communication is the act of giving, receiving, and sharing information, to make communication among PLC and HMI it's far had to recognize why the HMI is being used.

The Human Machine Interface (HMI) manner the tool that communicates among the operator and the equipment. Strictly speaking, any manner an individual **"communicates"** with a gadget through an interface display is an HMI.

HMI video display units are actually so acquainted to humans, particularly in industry, it performs an exceptionally crucial function within side the communicate among humans and machines.

HMI is the working interface among individual and gadget through PLC, they're related with every different via way of means of sign cable. When the operator pushes the button at the display or units the parameters, the request can be dispatched to the PLC, PLC controlling the machine.

The requirements0for data exchanges between a PLC and an HMI station are basically:

1. The first part is a physical connection that is available to both, such as an Ethernet cable, a RS-485 Rs-232, Ethernet, or USB connection,0along with the adequate ports on both, a common protocol that can exist on the selected physical connection(hardware). protocol drivers that will bind the communication interface to the protocol (software).
2. The second part is exchanging data between the PLC and the HMI.
   When you program the PLC, you use registers in the CPU to control the process and collect the system status. This is part of the basis of the PLC program.
   When the HMI program is0developed, in each screen the graphic interfaces is created which reflect and send commands to the PLC program through the configured protocol. because every input/output field, alarm display, status icon it is linked to a tag, linked to an address of a register in the PLC.
   So, when the value in an input field that created to change the set-point of a PID loop, it is0transferred to the address specified (in the tag definition) in the PLC program. When the PID output value changes in the PLC, the HMI receives0the value to display it in the output field you have generated in the active field.

So basically, the HMI prepares a list of tags it needs to write to the PLC tag addresses, and values it has to read in the CPU memory every time it becomes active (when it has control of the communication link), using the tag addresses configured in both PLC and HMI programs to connect the two.

Types of communication between the PLC and HMI as shown in Table 9-4-1-1:

Properties\ Types	RS-485	RS-232c	Ethernet	Rs-422
Data transmission rate	60-9600 baud/s	50-19200 baud/s	10000 baud/s	1200 baud/s
Transmission length	Up to 3000m	15m	250-2500m	Up to 1200m
No of transceiver	It is up to 128	only 1	Up to 65,535 devices	It is up to 128
Speed of transmission	10Mbps	20kbps	100-1000 Mbps	19kbps
Duplex mode	Half-duplex	Full-duplex	Full-Duplex	Full-duplex

Table 9-4-1- 1: Types of communication between PLC and HMI

The communication that being used between HMI (exp 40-TTA/DC) and XBC-DN20SU

It is RS-485 because it is the fastest type of communication between the two devices while this type of plc does not support Ethernet communication.

9-4-2: HMI Design:

- **HMI Screen show**
  - This is the human interface control which allow the user to comminicate with the machine and give it order and know their response.

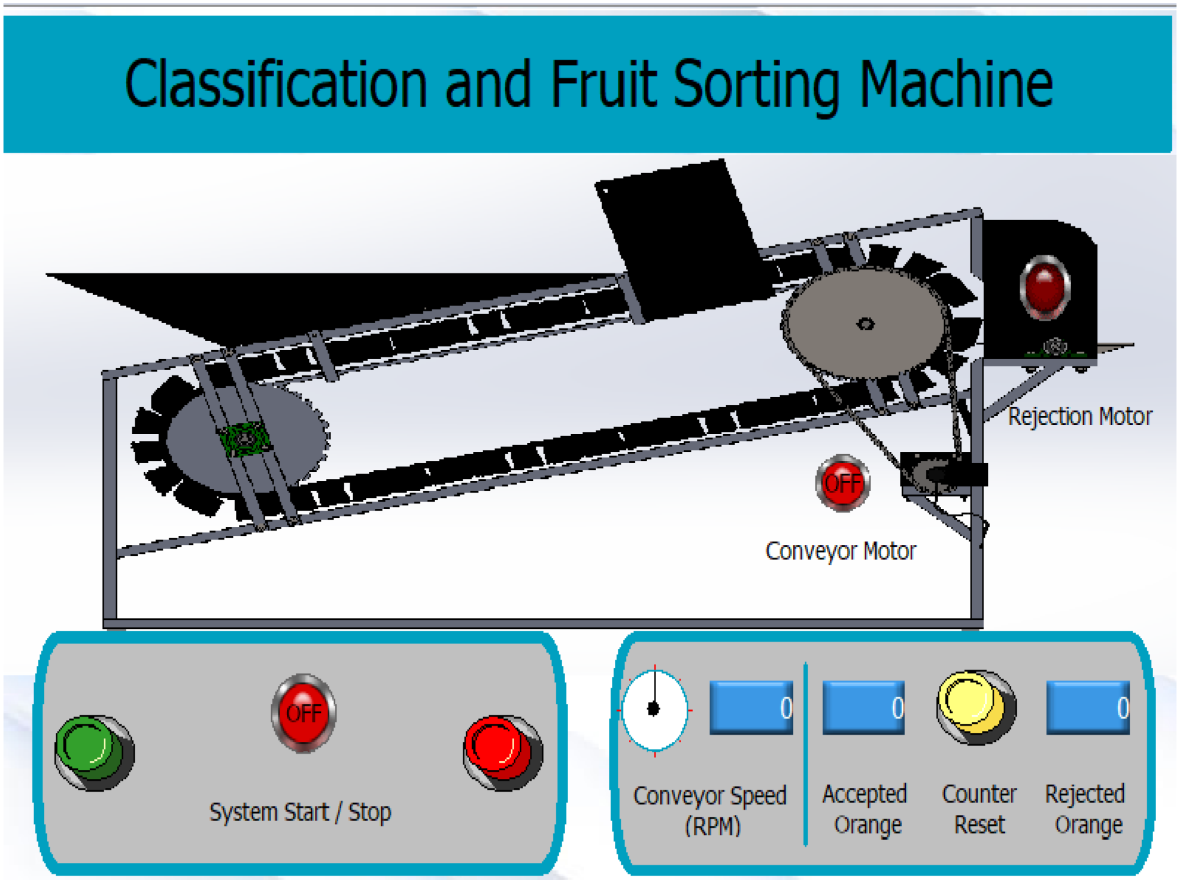


Figure 9-4-2- 1: HMI screen show

Figure 9-4-2- 2: HMI screen show

➢ Start Stop corner

- There are two push button one for starting the machine and one for Stop the machine.
- LED for indication whether the machine is on or off.

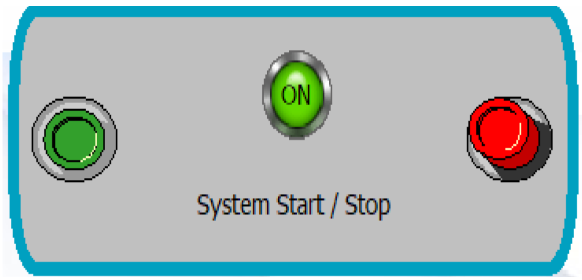


Figure 9-4-2- 3: Start/ Stop corner

Figure 9-4-2- 4: Start/ Stop corner

➢ Counter corner

- There are counter for calculation Conveyor speed and shown it as RPM and indicate it on the Graph meter.
- Second counter calculate the number of Accepted fruit.
- Third counter calculate the number of rejected Fruit.
- Yellow button used to reset the two counter.

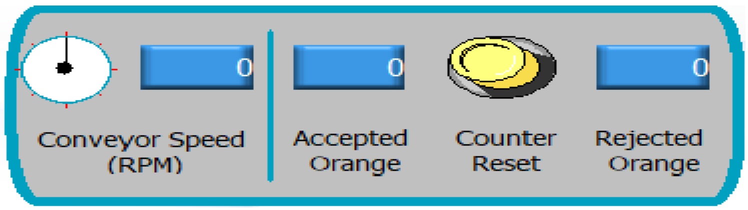
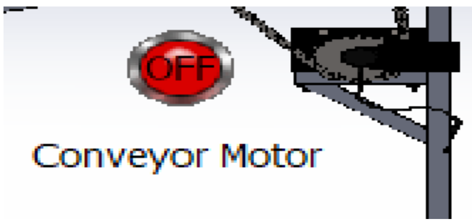


Figure 9-4-2- 5: Counter corner

Figure 9-4-2- 6: Counter corner

- **Conveyor Motor LED**

  This LED indicate Whether th Conveyor Motor ON or OFF.



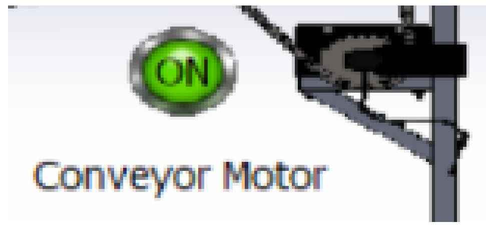


Figure 9-4-2- 7: Conveyor Motor Led

Figure 9-4-2- 8: Conveyor Motor Led

- **Rejection Motor LED**

  There are Three Position in this Motor

  1. Accepted Fruit Position, LED Will light with **green** light.
  2. Rejected Fruit Position, LED will light with **red** light.
  3. Moving plate Position, while plate moving from Accepted Position to Rejection Position or otherwise, LED will light with **yellow** light.

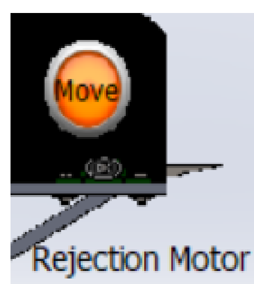


Figure 9-4-2- 9: Rejection Motor Led

Figure 9-4-2- 10: Rejection Motor Led

Chapter 10
Engineering Design Process

Name of part	**Material / dimension**	**Criteria selection**				**Result**
		Surface Smoothness	**Material Availability**	**Weight**	**Cost**	**Out of 20**
Rollers on second stage	Steel	5	5	2	5	17
	Artellon	4	2	3	3	12
	Wood	2	5	5	2	14
So, the selected rollers are steel.						
Bar Metal on second stage		**Suitable to Screw Holes**	**Material Availability**	**Weight**	**Cost**	**Out of 20**
	20*20 mm	5	5	5	5	20
	25*25 mm	5	5	4	3	17
	30 *30 mm	5	5	3	2	15
So, the selected bar metal is 20*20 mm.						
Sheet Metal		**In Case, There Are No Loads**	**Material Availability**	**Weight**	**Cost**	**Out of 20**
	1 mm	5	5	5	5	20
	2 mm	4	5	3	3	15
	2.5 mm	3	3	2	2	10
So, the selected sheet metal with thickness 1mm						
Welding		**Quality**	**Material Availability**		**Cost**	**Out of 15**
	Arc welding	3	5		5	13
	Laser welding	5	2		1	8
	Fraction welding	4	3		2	9
So, Arc welding is selected						
Motor		**Less maintenance**	**Availability**	**Power to Weight ratio**	**cost**	**Out of 20**
	BLDC	5	2	5	2	14
	PMDC	3	5	5	5	18
	Induction	5	4	3	4	16
So, PMDC was selected						
Rejection motor		**Less maintenance**	**Availability**	**No need for Control ler**	**cost**	**Out of 20**
	PMDC	3	5	2	3	12
	Servo	5	5	5	2	17
	stepper	5	5	5	5	20
So, stepper motor was selected						

PLC unit		Free loop PID Availability	Availability	Software Fee	Cost	Out of 20
	Siemens	5	5	2	2	14
	LS	5	5	5	5	20
	GEMO	2	5	5	5	17

So, LS is selected

Bearing		Quality	Material Availability	Cost	Out of 15
	Ball Bearing	5	5	5	15
	Roller Bearing	5	3	4	12

So, Ball Bearing was selected

Conveyor Base		Load	Color	Stability	Weight	Availability	Cost	Out of 30
	Sheet Metal	5	5	5	3	5	3	26
	P.V.C	3	1	5	5	2	5	21
	Rubber	4	1	3	5	3	4	20

So, it is to better to select sheet metal

Camera Box		Color	Stability	Weight	Availability	Cost	Out of 25
	ECLIRC	4	3	3	4	4	18
	MDF wood	5	5	3	5	5	23
	Sheet metal	2	4	5	3	1	15

So, MDF was selected

Shafts		Shaping & Surface finish	Elongation	Weight	Strength	Cost	Out of 25
	Iron	2	3	3	2	5	15
	Steel	5	4	3	5	4	21
	Aluminum	3	2	4	1	3	13

So, the material of Shaft is steel

Sorting Roller		Withstand the mechanical operation on it	Ability to be painted/ Black color	Weight	Cost	Out of 20
	Steel	1	4	1	5	11
	Aluminum	2	2	3	1	8
	Artellon	5	5	5	4	19
	Teflon	5	1	4	2	12

So, the material of sorting roller is Artellon

Feeding box & Attachment chains link		Ability to be painted/ Black color	Rust	Weight	Cost	Out of 20
	Steel Sheet Metal	5	4	3	5	17
	Aluminum Sheet Metal	4	5	5	2	16

So, the material for Feeding box and Attachment chain link is Steel sheet metal

Rejection Motor Fixation & Main Motor Fixation		Withstand the mechanical operation on it	Rust	Weight	Cost	Out of 20
	Steel Sheet Metal	5	4	3	5	17
	Aluminum Sheet Metal	3	5	5	2	15

So, the material for Rejection and Main Motor Fixation is Steel sheet metal

Rejection Dropped, side, and gate plate		Withstand the mechanical operation on it	Rust	Weight	Cost	Out of 20
	Steel Sheet Metal	5	4	3	5	17
	Aluminum Sheet Metal	3	5	5	2	15

So, the material for Rejection dropped, side, and gate plate is Steel sheet metal

First stage base		Withstand the mechanical operation on it	Withstand load	Rust	Weight	Cost	Out of 25
	Steel square hollow bar	5	5	4	3	5	22
	Aluminum square hollow bar	4	5	5	5	1	20
	Steel circular hollow bar	3	3	4	2	4	16
	Aluminum circular hollow bar	1	3	5	4	1	14

So, the material for base of first stage is Steel square hollow bar

Conveyor system selection criteria:

Criteria / Types	Chain conveyor	Automotive conveyor	Bucket conveyor	Belt conveyor	Gravity conveyor	Vibrating conveyor
Usage with food industry	5	2	3	5	3	2
precision	5	5	2	4	2	0
Transmission efficiency	5	4	2	4	2	1
System size and weight	5	1	2	5	2	1
Components availability	5	1	3	4	2	3
Easy for maintenance	5	2	4	4	2	2
Noise reduction	4	2	2	5	1	0
Power consumption	5	1	2	5	2	0
Conveyor capacity	3	4	4	4	4	5
Cost	5	1	2	4	2	1
Total result	47	23	26	44	22	15

Pitch type of conveyor roller chain selection criteria:

Criteria / Types	Double pitch roller chain	Standard roller chain
Weight	5 (light)	3 (heavy)
Cost	4 (cheap)	2 (expensive)
Strength/m	5 (higher)	3 (lower)
Components/m	4 (less)	3 (more)
Speed	3 (moderate)	5 (higher)
Total result	21	16

Power transmission method selection criteria:

Criteria / Types	Belt drive	Chain drive	Shaft coupling	Gear drive
Transmission efficiency	4	5	4	5
Velocity ratio	3	5	1	5
Cost	5	4	2	4
Noise reduction	5	5	4	4
Maintenance	4	5	4	4
Life span	5	5	3	5
Installation	3	5	4	5
Impact load handling	4	5	5	3
Space occupation	5	5	2	2
Total result	38	44	29	37

Sensor Fixation Selection Criteria:

Type / Criteria	Weight	Color	Stability	Availability	Cost	Total
ECLIRC 6 m	4	5	3	5	5	22
MDF 6mm	5	3	3	2	4	17
Sheet Metal	2	4	5	3	1	15

The selection raspberry pi is: Raspberry Pi 4 B 4G ram:

Criteria / Types	Price	Core Type	CPU Clock	RAM	Overall rating
Raspberry Pi 4 B	$60.00 (3/5)	Cortex-A72 (ARM v8) 64-bit (5/5)	1.5 GHz (5/5)	1 GB, 2 GB, 4 GB,8GB (5/5)	18/20
Raspberry Pi 3 Model A+	$25.00 (5/5)	Cortex-A53 64-bit (4/5)	1.4 GHz (4/5)	512 MB (2/5)	16/20
Raspberry Pi 3 B+	$35.00 (4/5)	Cortex-A53 64-bit (4/5)	1.4 GHz (4/5)	1GB (3/5)	15/20

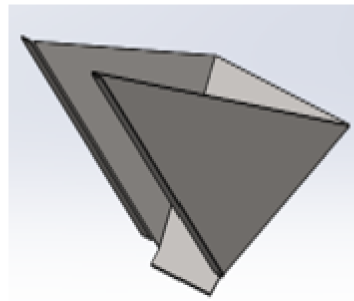
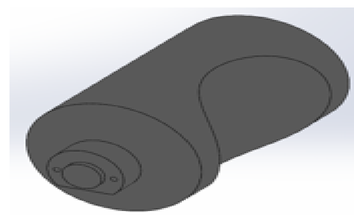
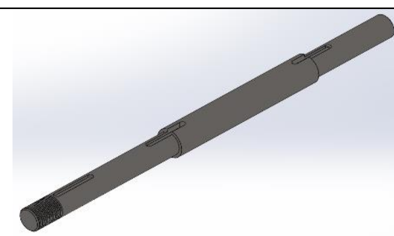
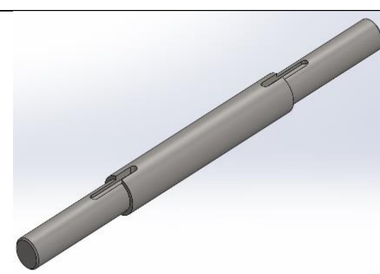
The selection camera is: Camera Module v2:

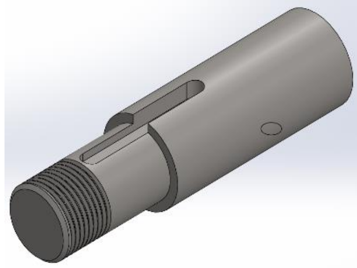
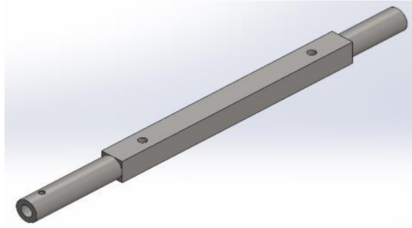
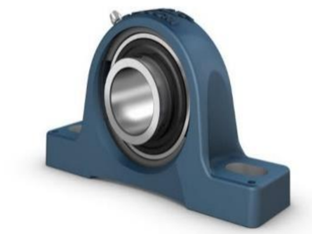
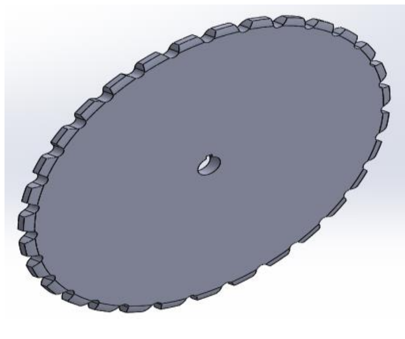
Criteria / Types	Still resolution	Sensor resolution	Net price	Available for purchase	Overall rating
Camera Module v1	5 Megapixels (3/5)	2592 × 1944 pixels (3/5)	$25 (5/5)	Available (5/5)	16/20
Camera Module v2	8 Megapixels (4/5)	3280 × 2464 pixels (4/5)	$25 (5/5)	Available (5/5)	18/20
HQ Camera	12.3 Megapixels (5/5)	4056 x 3040 pixels (5/5)	$50 (3/5)	Not available (0/5)	13/20

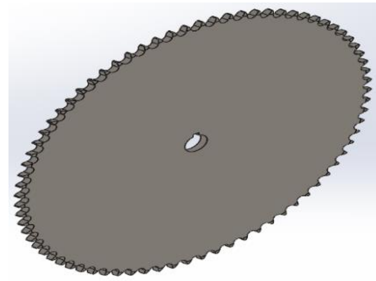
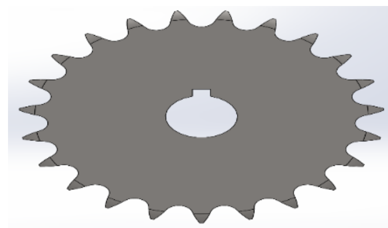
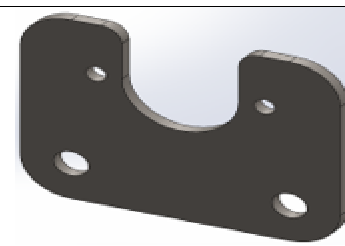
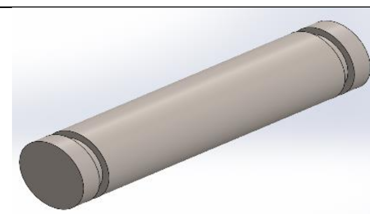
Chapter 11 Results and Discussion

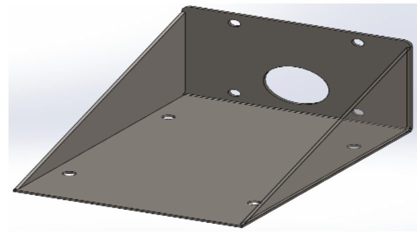
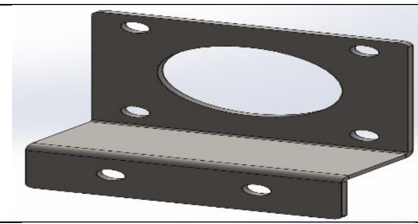
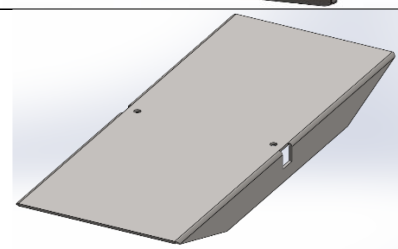
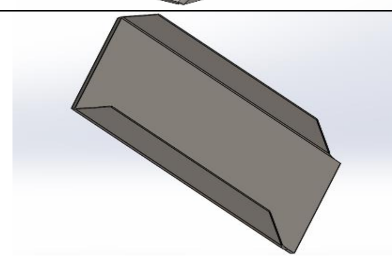
Chapter 11: Results and discussion

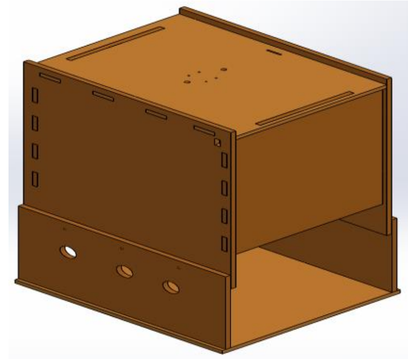
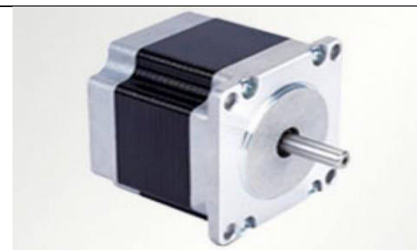
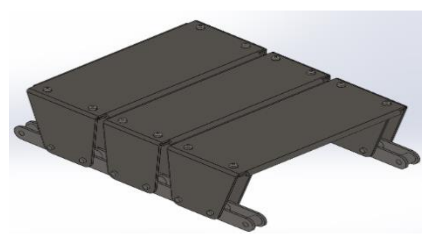
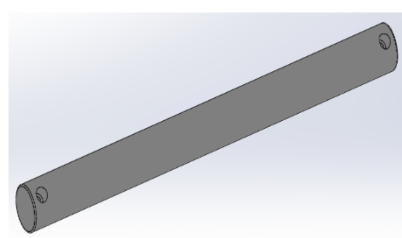
After the design has been done all the result of each part will be summarized below.

Part Name	Specification	Part image
Feeding Tank	Steel Sheet Metal with thickness of 2 mm	
Sorting Roller	Artellon with diameter of 75 mm	
Drive Shaft	Steel AISI 1020 with diameter of 30 mm	
Driven Shaft	Steel AISI 1020 with diameter of 30 mm	

Motor Shaft	Steel AISI 1020 with diameter of 30 mm	
Rejection Shaft	16*16 mm solid bar	
Drive and Driven Shaft Bearing	Ball bearing UCF 204	
Rejection Shaft Bearing	Ball bearing UCF 201	
Main Gears	Steel with thickness of 9 mm and 31 teeth Double Pitch of 1.25 in	

Driven Gear	Steel with thickness of 6 mm and 76 teeth Pitch of 0.5 in	
Drive Gear	Steel with thickness of 6 mm and 23 teeth Pitch of 0.5 in	
Chain Link	Steel Sheet Metal with thickness of 2 mm	
Sprocket Pin	Free steel with diameter of 5 mm	
E-Clips	Stainless Steel Star snap ring with Internal Diameter of 4 mm	

Main Motor Fixation	Steel Sheet Metal with thickness of 2 mm	
Rejection Motor Fixation	Steel Sheet Metal with thickness of 2 mm	
Rejection Gate Plate	Steel Sheet Metal with thickness of 2 mm	
Rejection Dropped Plate	Steel Sheet Metal with thickness of 2 mm	
Rejection Side Part	Steel Sheet Metal with thickness of 1 mm	

Camera Box	MDF wood	
Main Motor	Permanent magnet DC motor	
Rejection Motor	2 phase Stepper motor	
Parts between two sorting rollers	Steel Sheet metal with thickness of 2 mm	
Roll of second stage	Steel shaft with diameter of 30 mm	

Discussion:

The design was done to meet the standers for exporting the orange fruit to the outside world through sorting and classification of orange fruit, each phase was done to ensure that another phase can be added before the sorting stage, between two stages, or after the second stage.

All the parts and the implementation were done in oriental factories and workshop.

The image processing process was done by get the data from oriental farms and compare the oranges from this data to know if the orange is good or rotten.

Conclusion and Recommendation

Our design was categorized into two stages, one stage for sorting the orange from good and rotten and rejection phase the good will continue to second stage and rotten will be rejected, and the second stage for classification the fruit through the size by 5 phases from 53 mm to 106 mm.

Fruit sorting is done by image processing where the fruit is compared to save data to distinguish between the good and rotten one.

The main idea of design is making project to meet the requirements of markets with the use of advanced technology and minimize the error as possible, of course the implementation must be local, to help new generation that there is no such thing as impossible.

In the future there can be multiple stage added to these stages or making new machine for mass product with the same idea, keep in mind that this project is just prototype for what we hope to be in our factories, also the software can be change to meet another spherical fruit not just orange.

In the selection of motor, fortunately the selected motor meets our requirements, but it’s better to get higher horse power motor but in our local markets there are problem in new motors, we could get better motor but it will not meet the target for implementation must be local.

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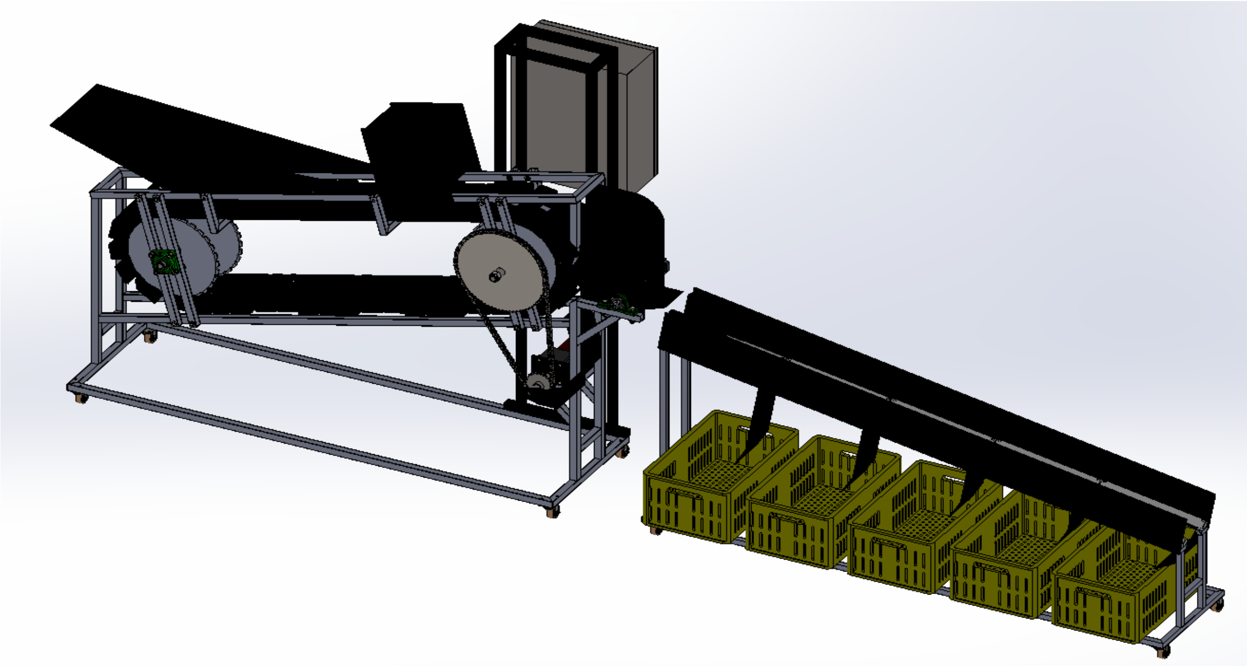
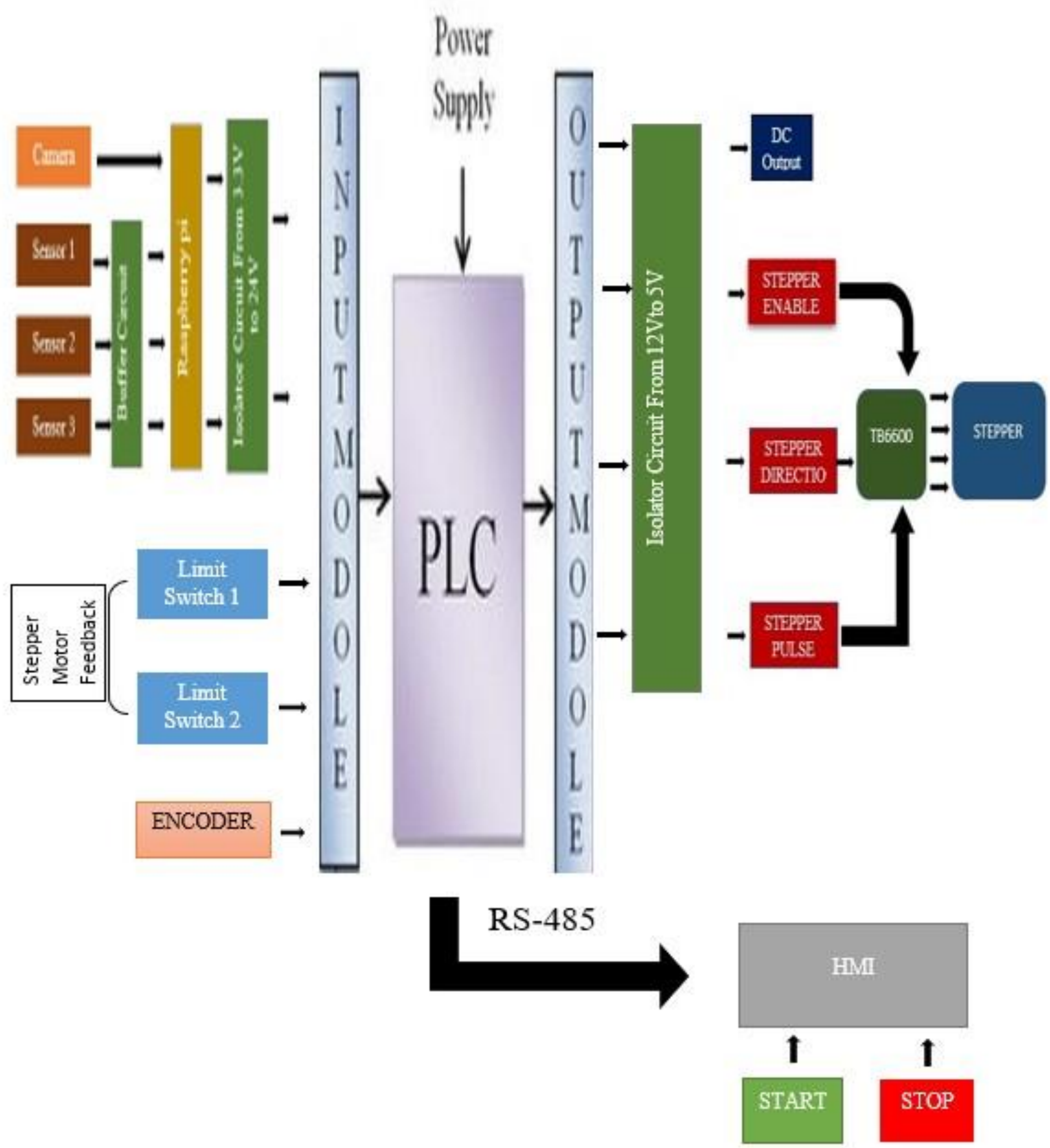
APPENDICES

Appendix A

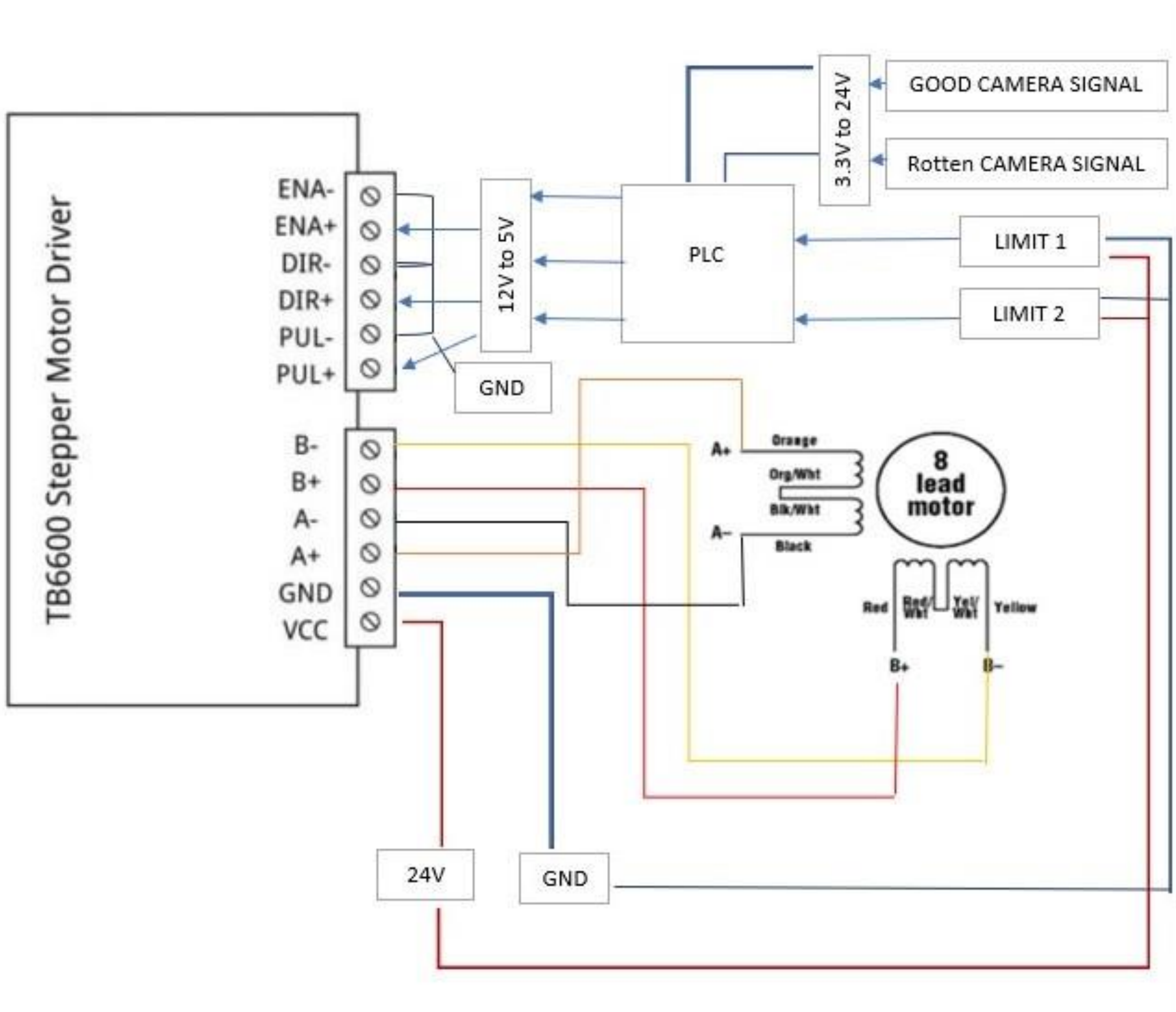
A.1: The whole system



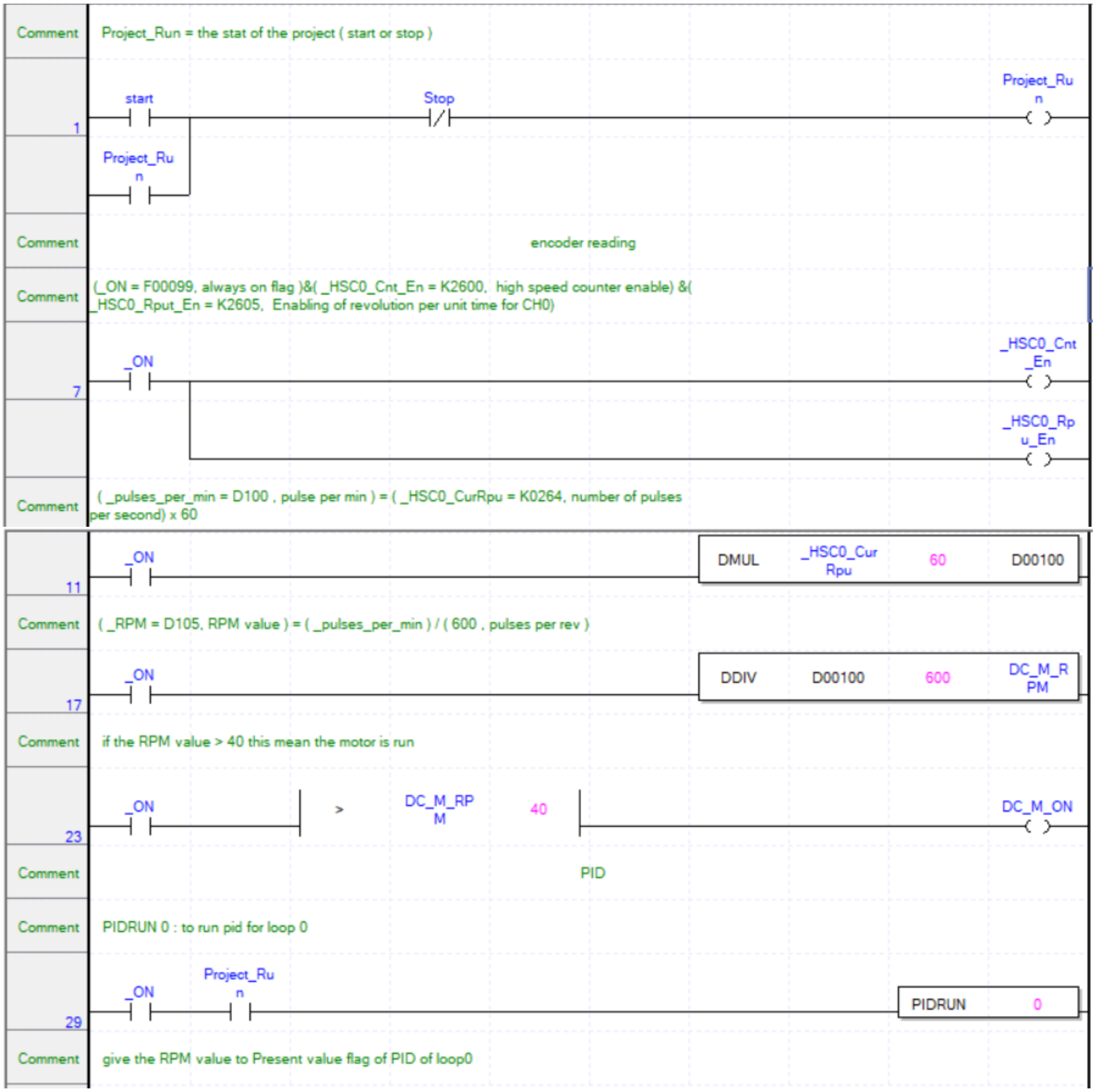
A.2: Block Diagram For system:

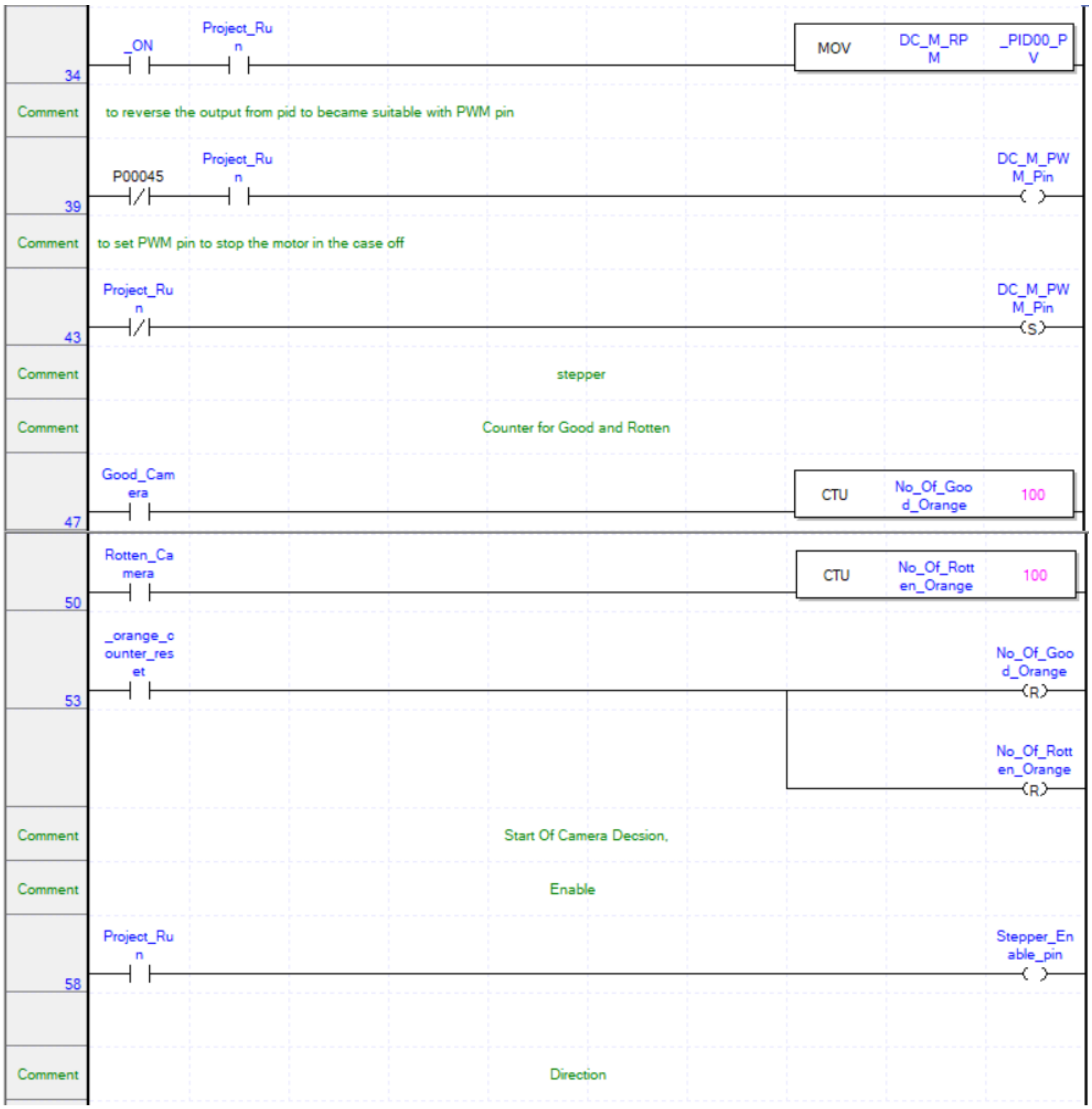


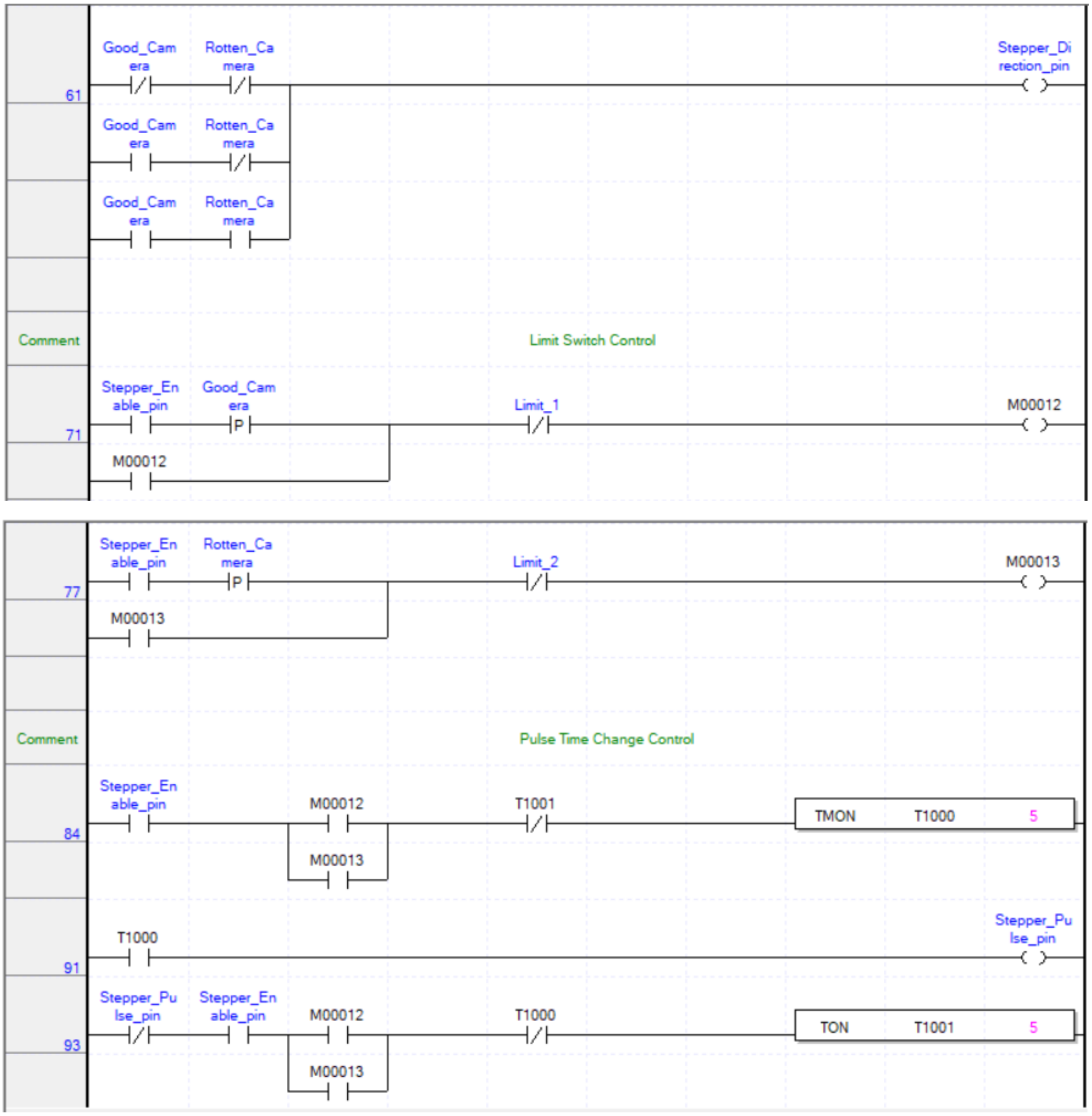
A.3: Wiring Diagram for Stepper:

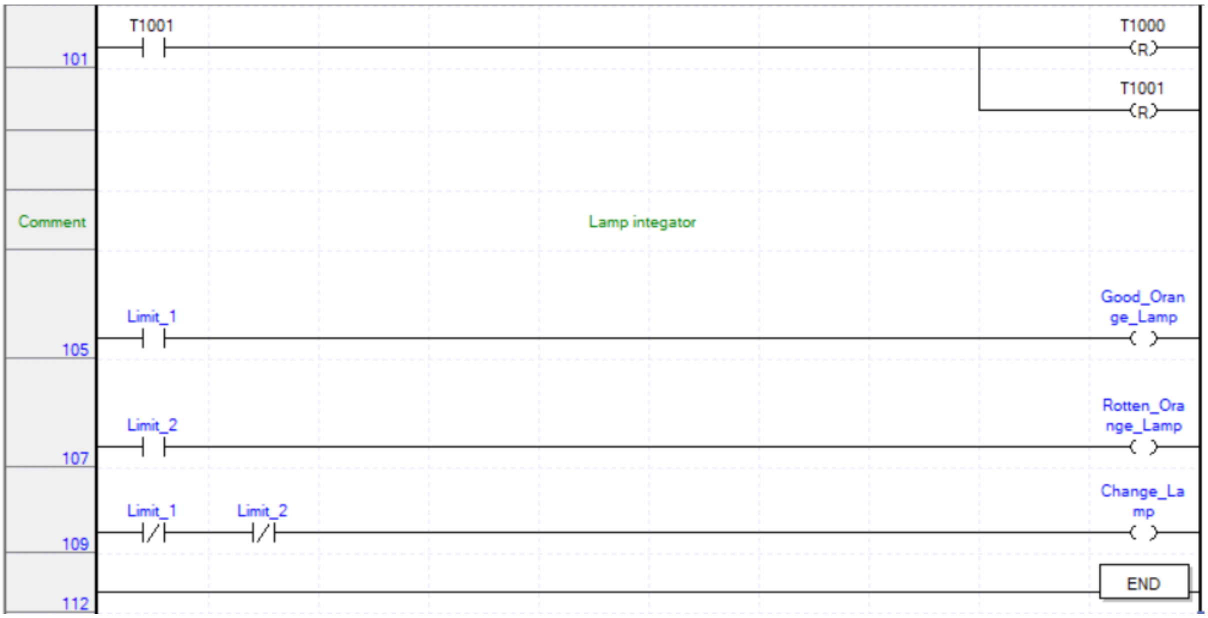


A.4: PLC program




34
_ON
Project_Run
MOV
DC_M_RPM
_PID00_PV
Comment
to reverse the output from pid to became suitable with PWM pin
39
P00045
Project_Run
DC_M_PWM_Pin
Comment
to set PWM pin to stop the motor in the case off
43
Project_Run
DC_M_PWM_Pin
S
Comment
stepper
Comment
Counter for Good and Rotten
47
Good_Camera
CTU
No_Of_Good_Orange
100
50
Rotten_Camera
CTU
No_Of_Rotten_Orange
100
53
_orange_counter_reset
No_Of_Good_Orange
R
No_Of_Rotten_Orange
R
Comment
Start Of Camera Decsion,
Comment
Enable
58
Project_Run
Stepper_Enable_pin
Comment
Direction


61
Good_Camera
Rotten_Camera
Stepper_Direction_pin
Good_Camera
Rotten_Camera
Good_Camera
Rotten_Camera
Comment
Limit Switch Control
71
Stepper_Enable_pin
Good_Camera
P
Limit_1
M00012
M00012
77
Stepper_Enable_pin
Rotten_Camera
P
Limit_2
M00013
M00013
Comment
Pulse Time Change Control
84
Stepper_Enable_pin
M00012
T1001
TMON
T1000
5
M00013
91
T1000
Stepper_Pulse_pin
93
Stepper_Pulse_pin
Stepper_Enable_pin
M00012
T1000
TON
T1001
5
M00013


T1001
T1000
101
T1001
Comment
Lamp integator
Limit_1
Good_Orange_Lamp
105
Limit_2
Rotten_Orange_Lamp
107
Limit_1
Limit_2
Change_Lamp
109
END
112

A.5: Raspberry Pi Code

```
#load the libraries
import numpy as np
import cv2
import pandas as pd
from picamera import PiCamera
from sklearn import neighbors
from sklearn import model_selection
import RPi.GPIO as GPIO
from skimage.feature import greycomatrix, greycoprops
from skimage import io, color, img_as_ubyte
```

```
#load dataset
df = pd.read_csv('/home/pi/new/testf.txt')
df.replace('?', -99999, inplace=True)
df.drop(['id'], 1, inplace=True)
# x is features of the dataset
x = np.array(df.drop(['class'], 1))
# Y is label of  fruit
y = np.array(df['class'])
```

```
#split the dataset into train and test
x_train, x_test, y_train, y_test = model_selection.train_test_split(x, y, test_size=0.1)
clf = neighbors.KNeighborsClassifier()
#train the KNN classifier
clf.fit(x_train, y_train)
```

```
#define the inputs and outputs pins
GPIO.setmode(GPIO.BOARD)
GPIO.setup(12,GPIO.OUT)
GPIO.setup(37,GPIO.OUT)
GPIO.setup(36,GPIO.IN)
GPIO.setup(15,GPIO.IN)
GPIO.setup(13,GPIO.IN)
```

```
#define the camera specification
camera = PiCamera()
camera.resolution = (500,500)
camera.shutter_speed = 10000
camera.iso = 800
camera.exposure_mode = 'snow'
```

```python
def tamtom (r):
#read on resize the image
  img=cv2.resize(r,(100,100))
  #segmentation by use otsu threshold
  ret2,th2 = cv2.threshold(img,0,255,cv2.THRESH_BINARY_INV+cv2.THRESH_OTSU)
  #extract statistial features
  b=round(np.mean(th2)/30,3)
  c=round(np.std(th2)/10,3)
```

```python
#extract texture features (GLCM)
gray = color.rgb2gray(th2)
image = img_as_ubyte(gray)
bins = np.array([0, 16, 32, 48, 64, 80, 96, 112, 128, 144, 160, 176, 192, 208, 224, 240, 255]) #16-bit
inds = np.digitize(image, bins)
max_value = inds.max()+1
matrix_coocurrence = greycomatrix(inds, [1], [0, np.pi/4, np.pi/2, 3*np.pi/4], levels=max_value, normed=False, symmetric=False)
contrast = greycoprops(matrix_coocurrence, 'contrast')
dissimilarity = greycoprops(matrix_coocurrence, 'dissimilarity')
energy = greycoprops(matrix_coocurrence, 'energy')
correlation = greycoprops(matrix_coocurrence, 'correlation')
asm = greycoprops(matrix_coocurrence, 'ASM')
aa=round(np.mean(contrast),3)
bb=round(np.mean(dissimilarity),3)
cc=round(np.mean(asm),3)
dd=round(np.mean(energy),3)
ff=round(np.mean(correlation),3)
mm=round(np.std(contrast),3)
nn=round(np.std(dissimilarity),3)
uu=round(np.std(correlation),3)
```

```
#make the features vector
y=np.array([aa,bb,cc,dd,ff,mm,nn,uu,b,c])
z1=(y.flatten())
yyy1= np.reshape(z1, (1, -1))
test_example=yyy1
#pass the feature vector to the classifier
n=clf.predict(test_example)
return n
```

```
#define three variable that will Organize the photographing process
T,R,O=1,0,0
while(1):
    #to receive signal from the first sensor to take first image
    a=GPIO.input(36)
    Y=1-a
    T=1
    if(Y==1 & T==1):
      camera.start_preview()
      camera.capture('/home/pi/Desktop/image11.jpg',use_video_port=True,quality=100)
      camera.stop_preview()
      T=0
      R=1
    B=GPIO.input(15)
    P=1-B
    if(P==1 &R==1 ):
        camera.start_preview()
        camera.capture('/home/pi/Desktop/image12.jpg',use_video_port=True,quality=100)
        camera.stop_preview()
        R=0
        O=1
    C=GPIO.input(13)
    i=1-C
    if(i==1 &O==1 ):
        camera.start_preview()
        camera.capture('/home/pi/Desktop/image13.jpg',use_video_port=True,quality=100)
        camera.stop_preview()
        T=1
        O=0
```

```
#call the function to classify the three images
r =cv2.imread('/home/pi/Desktop/image11.jpg',0)
#classify the first image
prediction=(tamtom(r))
r =cv2.imread('/home/pi/Desktop/image12.jpg',0)
#classify the second image
prediction2=(tamtom(r))
r =cv2.imread('/home/pi/Desktop/image13.jpg',0)
#classify the third image
prediction3=(tamtom(r))
```

```python
#send signal to plc by pin 12 when the fruit is healthy
if (prediction==2 & prediction2==2 & prediction3==2):
    print('healthy and bin 12 is activated now')
    GPIO.output(12,0)
    GPIO.output(12,1)
#send signal to plc by pin 37 when the fruit is healthy
else:
    print('non healthy and bin 37 is activated now')
    GPIO.output(37,0)
    GPIO.output(37,1)
```

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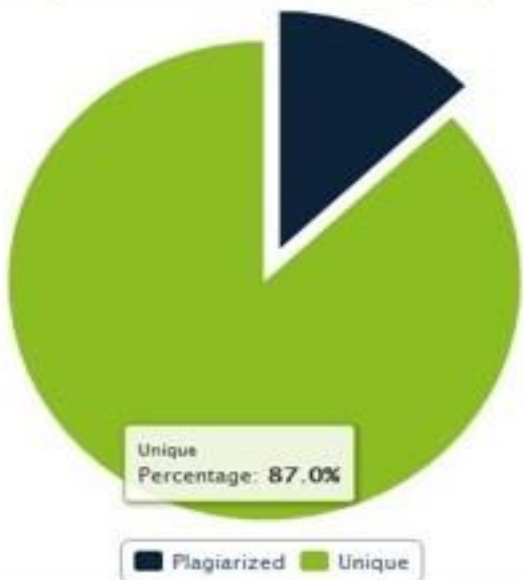

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شكر وتقدير

أولا وقبل كل شيء نود أن نشكر الله عز وجل خالقنا مصدر إلهامنا وحكمتنا وعلمنا وفهمنا. لقد كان الله مصدر قوتنا طوال هذا المشروع.

نود أيضا التعبير عن امتناننا و شكر وتقدير للدكتور أمين دانيال والدكتوره علا محمد على كل المساعدة والتوجيهات التي قدموها طوال فترة تعليمنا.

نود أن نشكر عائلتنا ، وخاصة والدينا ، على تشجيعهم وصبرهم ومساعدتهم على مر السنين.

" نحن مدينون إلى الأبد لوالدينا "

إخلاص

هذا المشروع مخصص لآبائنا وعائلاتنا الذين
إعطاءنا الفرصة للدراسة و ربونا لنصبح
من نحن الان،

لأصدقائنا الذين شاركنا معهم هذا العمل من خلال
هذا الطريق الطويل،

لموجهينا الذين قدموا لنا المعرفة الواضحة ووضعونا على
الطريق الصحيح.

بسم الله الرحمن الرحيم

الأكاديمية المصرية للهندسة والتكنولوجيا المتقدمة

قسم هندسة الميكاترونكس وقسم الاتصالات والإلكترونيات

مشروع تخرج (٢)

عنوان المشروع: آلة تصنيف وفرز الفاكهة بتقنية الذكاء الاصطناعي

يتم تقديم مشروع تخرج إلى قسم هندسة الميكاترونكس في الوفاء الجزئي بمتطلبات درجة البكالوريوس في الهندسة الميكانيكية وقسم هندسة الإلكترونيات في في الوفاء الجزئي لمتطلبات درجة البكالوريوس في الهندسة الكهربائية.

تقرير تقني

مقدم من

فريق ميكانيكا		فريق كهرباء	
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د. امين دانيال

د. علا محمد على

أغسطس ٢٠٢١