B.E. PROJECT

ON

AUTOMATED CLASSIFICATION OF FASTENERS FOR APPLICATION IN SELECTIVE ASSEMBLY USING DIGITAL IMAGE PROCESSING

Submitted in partial fulfilment of the requirements for the Award of the degree of

BACHELOR OF ENGINEERING (B.E)

IN

Manufacturing Process And Automation Engineering
Batch (2010-2014)

Submitted by

Abhishek Girotra	**605/MP/10**
Anurag Gandhi	**613/MP/10**
Atul Sanghi	**618/MP/10**
Ujjawal M. Srivastava	**669/MP/10**

Guided By

Mr. Pradeep Khanna
Mr. Sanjay Gupta

Division of Manufacturing Processes and Automation
Netaji Subhas Institute of Technology

(University of Delhi)

CERTIFICATE

This is to certify that the project entitled: "Automated Classification of Fasteners for Selective Assembly using Digital Image Processing" is a record of bonafide work carried out by:

Abhishek Girotra	605/MP/10
Anurag Gandhi	613/MP/10
Atul Sanghi	618/MP/10
Ujjawal Mayank Srivastava	669/MP/10

In the Division of Manufacturing Process and Automation Engineering, Netaji Subhas Institute of Technology (NSIT), New Delhi, under my supervision and guidance, in partial fulfilment for the award of the degree of Bachelor of Engineering (BE) in Manufacturing Process and Automation in the academic year 2013-2014.

Pradeep Khanna
Assistant Professor

Sanjay Gupta
Assistant Professor

Division of Manufacturing Process and Automation Engineering
Netaji Subhas Institute of Technology (NSIT)

(University of Delhi)

Acknowledgement

The satisfaction that accompanies the successful completion of any task would be incomplete without the mention of the people who made it possible and whose constant guidance and encouragement crown all the efforts with success.

First and Foremost, we would hereby like to express our gratitude towards Assistant Professor Pradeep Khanna and Sanjay Gupta, Department of Manufacturing Process and Automation Engineering (MPAE) for being an erudite project guide. We are thankful to them for providing us the right directions for the conduct of the project and also their enlightening guidance that was vital for the success of our project. We are also very grateful to them as they exuded in us tremendous faith and confidence which inspired us to conquer all our challenges that we faced during our project.

Lastly, we are also thankful to Mr Pawan K Shukla, lab in charge, Manufacturing Process and Automation Department and the entire staff of the welding, fitting and sheet metal workshop for their timely cooperation and assistance throughout the tenure of the project.

ABSTRACT

Our Project of Automated Classification of Fasteners for Selective Assembly using Digital Image Processing aims to ensure that fasteners of similar dimensions are sorted and placed as a mated pair in a single bin, thus, implementing the principle of Selective Assembly. The system essentially measures the features of fasteners using image processing techniques and performs a two-step classification, one to identify the type of fastener based on the roundness ratio and other to classify them as Small, Medium or Large by measuring nominal diameter using Minimal Bounding Rectangle method. The complete automation of the process aims to reduce monotony and effort experienced in human inspection. The system can be adapted to a larger number of classifications if high accuracy is ensured. Same hardware setup can also be extended to a wide variety of applications with minor/major modifications in the software module.

Table of Contents

List of Figures

List of Tables

CHAPTER - 1

Detailed Problem Statement

Selective assembly is a cost-effective approach for reducing the overall variation and thus improving the quality of an assembled product. In this process, components of a mating pair are measured and grouped into several classes (bins) as they are manufactured. The final product is assembled by selecting the components of each pair from appropriate bins to meet the required specifications as closely as possible.[14]

Our project of automated classification of fasteners is to ensure that both nuts and bolts of appropriate size are sorted as a single set and placed in a single bin. Thus a single set represent mated pair of nuts and bolts.

Thus this system segregates the mixture of nuts and bolts into sets of three different sizes on the basis of their dimensions and categorizes them into three sets namely: Small, Medium and Large pairs of Nuts & Bolts.

The complete automation of the project ensures steady flow of fasteners as well as efficient control of signals and removes the scope of human error and effort. Thus this system enables us to successfully perform selective assembly of Nuts & Bolts using Digital Image Processing.

1.1 PROBLEM FORMULATION & OBJECTIVE

a) To design and fabricate a 3D prototype of the system consisting of frame, conveyor belt system, sensors, Controller and Sorting System.

b) To build the individual components based on the design.

c) To develop a working algorithm using software framework and integrate it with hardware for selective assembly of fasteners.

d) To fabricate rotary sorting disk and its assembly upon stepper motor and interfacing with controller.

1.2 LITERATURE SURVEY

The project mainly deals with two main areas of research - Selective Assembly and Image Processing. Selective assembly principle is in widespread use over all industries particularly manufacturing and nanotechnology. And image processing is definitely a growing field as shown by the king of research undergoing in this highly specialised area of research.

Some research projects in the pasts include:

a) Size Selective Assembly of Colloidal Particles on a Template by Directed Self-Assembly Technique.

[*Authors: Binni Varghese, Fook Chiong Cheong, Swaminathan Sindhu, Ting Yu, Chwee-Teck Lim, Suresh Valiyaveettil and Chorng-Haur Sow*]

Ordered arrays of micron and submicron particles have attracted much scientific attraction because of their applications in the field of Nanotechnology. Physical Properties of these particles are dependent on their size and dimensions. Therefore, it is of utmost importance to combine them according to their size and thus creating array of micron and submicron particles.

This research talks about the template assisted size positioning of the colloidal particles. This approach utilizes the template assisted directed self-assembly technique. A topographically patterned photo resist surface is fabricated and used to create an ordered array of colloidal particles from their aqueous suspensions. Assembly of particles on this template is then achieved by using a conventional spin coating technique.

b) An object pass filter by Image Processing Technique

[Authors: J. Steven Mott ; James A. Roskind]

An object-pass filter for image processing is defined as a filter that passes or enhances objects in an image that are larger than a minimum threshold and smaller than a maximum threshold. Objects outside the pass band, i.e. too large or too small, are suppressed by replacing the pixel gray scale level with zero. An object-pass filter that is realizable in today's technology is presented. It is shown that an object-pass filter can be realized with cascaded sort-selection filters, which select the Nth largest element in a neighbourhood of elements. The object-pass filter's pass region can be determined by selecting the appropriate sort-selection filter window sizes.

c) Image Processing Technique to sort differently coloured objects

(Authors: Ross Johnson; Mark Bonze)

An object sorter was created to sort differently coloured Cans for the food & Packaging Industry. Algorithm was developed that uses Image Processing as well as Colour detection theme to classify objects on the basis of their colours and help to sort as well as remove unwanted materials during mass production.

1.2.1 Existing Systems

Nuts and bolts are kept in the fasteners section in the product line. The classification of different sized nuts and bolts is done using manual inspection for most applications. This might simply be visual inspection or measurement using gauges and/or measuring tapes. A matching pair of nut and bolt is also simply found by either mating, visual inspection or measurement. [13]

1.2.2 Problems with Existing Systems

a) At the instant of joining components through fasteners, wrong or variable size mating of fasteners could result in improper connections and thus lead to a faulty assembly of products.

b) Work of matching and thus selecting the mated pair of nut & bolt could result in monotony on the part of workers as the work becomes repetitive.

c) Pairing bolts and nuts of different sizes during checking could result in the wearing of the screw threads.

CHAPTER - 2

Detailed Component Analysis

2.1 CONVEYOR BELT SYSTEM

A conveyor system is a common piece of mechanical handling equipment that moves materials from one location to another. We have used conveyor system to transport our test specimens (Threaded Fasteners) from the starting position to the sorting system.

Conveyor systems are used widespread across a range of industries due to the numerous benefits they provide.

- Conveyors are able to safely transport materials from one level to another, which when done by human labour would be strenuous and expensive.
- They can be installed almost anywhere, and are much safer than using a forklift or other machine to move materials.
- They can move loads of all shapes, sizes and weights. Also, many have advanced safety features that help prevent accidents.
- There are a variety of options available for running conveying systems, including the hydraulic, mechanical and fully automated systems, which are equipped to fit individual needs.

Factors considered for selecting belt for the conveyor belt system:

There are many factors that one needs to consider when purchasing belt conveyors. This is because they come in many different types with each type based on various needs. They are:

a) Type of goods to be moved

The type of goods to be moved from one point to another dictates what kind of a conveyor we should have. This is mostly based on the items temperature, as well as conditions within the working place. Hot items can only be moved with metal or mesh belt conveyors, while rubberized conveyors can be used to move oily products.

b) Weight of items to be moved

Weight will determine what sub-frame will be needed to transport items effectively without experiencing breakdowns. The conveyor's power, bearings to be used as well as belt size is determined by the payload's weight too.

c) Maintenance needs

Every machinery needs maintenance and we will need a belt conveyor with the least maintenance needs and easy to maintain too. This is the reason why we need to look out for conveyors that are highly durable, flexible and advanced technologically. Purchasing the latest conveyor belt conveyors in the market can save you much in maintenance costs.

d) Safety of use and durability

The conveyor you are about to buy should be safe to use even without any user intervention. Most manufacturers today install safety measures and chips that ensure the conveyors operation is safe and doesn't pose any danger to its operators or anyone close-by.

e) Directional transportation of the load

Belt conveyors move items in two directions; vertical axis and horizontal axis. One conveyer may be effective to move items up a building vertically without any ado, but cannot deliver items horizontally. The texture in these conveyor belts affects the loads direction; hence a reason why you should factor in what direction your items will be moved for efficiency.

Figure 2.1: Conveyor Belt

2.2 DC MOTOR

A DC motor is an electric motor that runs on Direct current. DC motors can operate from rechargeable batteries and are very useful in driving low loads. According to one classification, Motors can be classified as: [16]

1. DC Motors
2. Stepper Motors
3. Servo Motors

After a thorough market survey, a DC Motor was chosen, whose supply voltage can be varied from 24 V to 5 V and thus its angular speed (rotation per minute) can be adjusted according to our requirements. DC motor was selected as we require constant speed operation of our conveyor belt.

Stepper motors were rejected due to supply complications. Further, servo motor was not used in our system as its output is used for controlling the angle, which was not required in the present design.

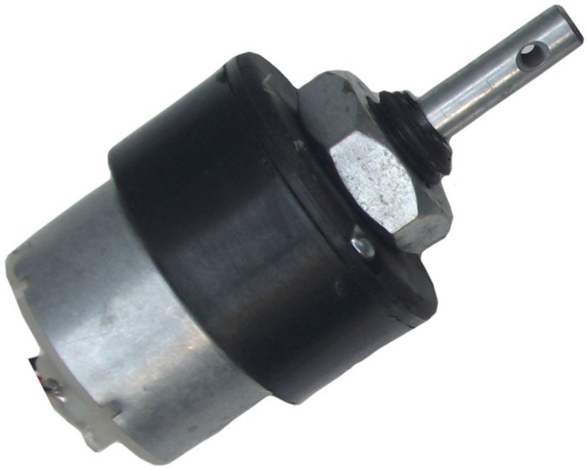


Figure 2.2: Geared DC Motor

2.3 CONTROLLER

Our system requires a controlled action to be performed on the part of the controller. It has to communicate the timing of sense obtained from Sensors to the Camera, so as to take the snap and pass on the signal to the MATLAB to do the appropriate action according to the algorithm.

After taking into considerations the requirements of the system, peer review and market availability, Arduino UNO was considered.

Arduino is an open source, prototyping platform based on flexible, easy to use hardware and software. It can sense the environment by receiving inputs from variety of sensors and can affect its surrounding by controlling motors, actuators and lights. Arduino Projects can also communicate with software running on computers.

Advantages of Arduino over other microcontrollers are:

- Debugging:-The Arduino Environment provide easiest debugging environment which is cross-platform and is accepted by every member of the family.

- No programmer or dumping flash by dirty ways, with most of the companies already providing on-board debugger still compared to a lot of microcontroller (8051) upload is a click away.
- The Input-Output pins of the microcontroller are typically already fed out to sockets/headers for easy access.
- Design of the board is very carefully crafted for beginners be it Moron Switch or ISP header to the polarity of power. The chances are steep that you would be blow it.
- Peripherals and Modular Design: Arduino Ecosystem has fantastic modular design, you can simply add the already designed shields to the board without any wire, just plug and play with peripherals like motor shield.
- Libraries: A lot of libraries and IC's have already been build for the same which is crucial a lot of times.

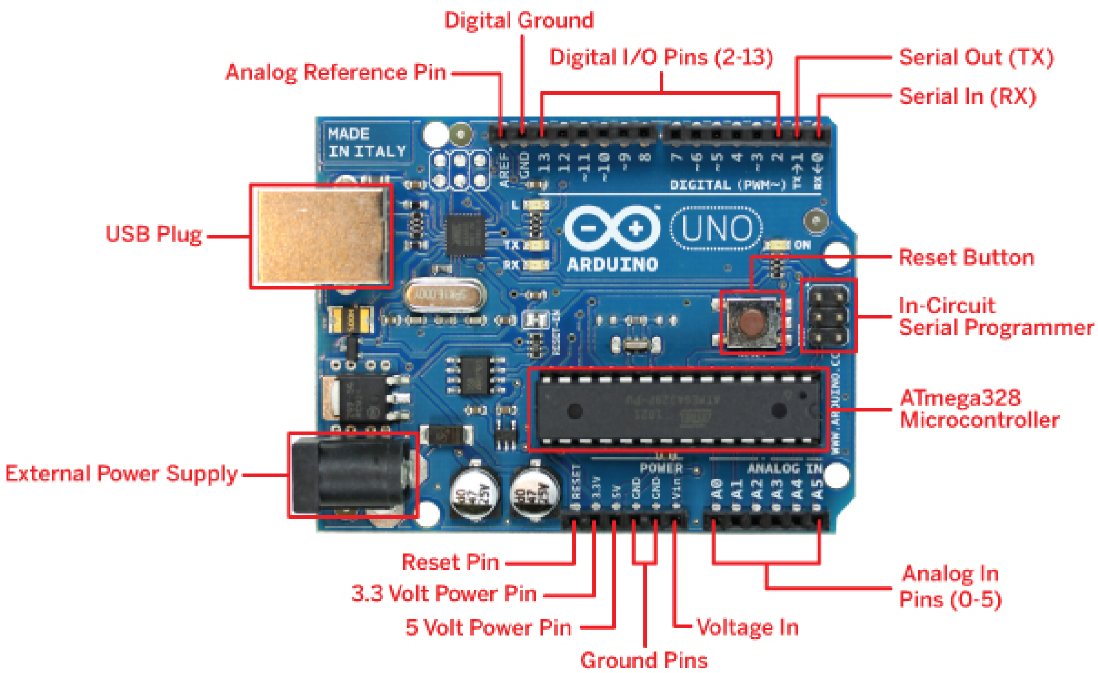


Figure 2.3: Arduino Uno Controller

2.4 SORTING SYSTEM

This is the sub-system in our project required for sorting and grading the components according to shape and size. It is positioned at the end of the path and collects the incoming work pieces which have been detected, identified and measured by previous installed systems (sensor and camera). It basically segregates the components in 3 different parts. The system moves according to the incoming work piece and aligns itself before the work piece reaches the end of conveyor path.

The system has following components:

1. **Stepper Motor:**

A Stepper Motor is a brushless, synchronous motor which divides a full rotation into a number of steps. Unlike a brushless DC motor which rotates continuously when a fixed DC voltage is applied to it, a step motor rotates in discrete step angles. The Stepper Motors therefore are manufactured with steps per revolution of 12, 24, 72, 144, 180, and 200, resulting in stepping angles of 30, 15, 5, 2.5, 2, and 1.8 degrees per step. The stepper motor can be controlled with or without feedback. [16]

Specifications

Manufacturer Part Number:	17HS16-2004S
Motor Type:	Bipolar Stepper
Step Angle:	1.8°
Holding Torque:	45Ncm(63.7oz.in)
Rated Current/phase:	2A
Phase Resistance:	1.1ohms
Recommended Voltage:	12-24V

Inductance: 2.6mH±20%(1KHz)

Figure 2.4: Stepper Motor

2. Rotary Disk

This is the custom made disc with 3 compartments (or bins) made out on a flat disc. The compartments are differentiated using walls which stand on the disc. Each compartment serves as a space for collection of the falling work pieces when the disc aligns itself with the conveyor belt.

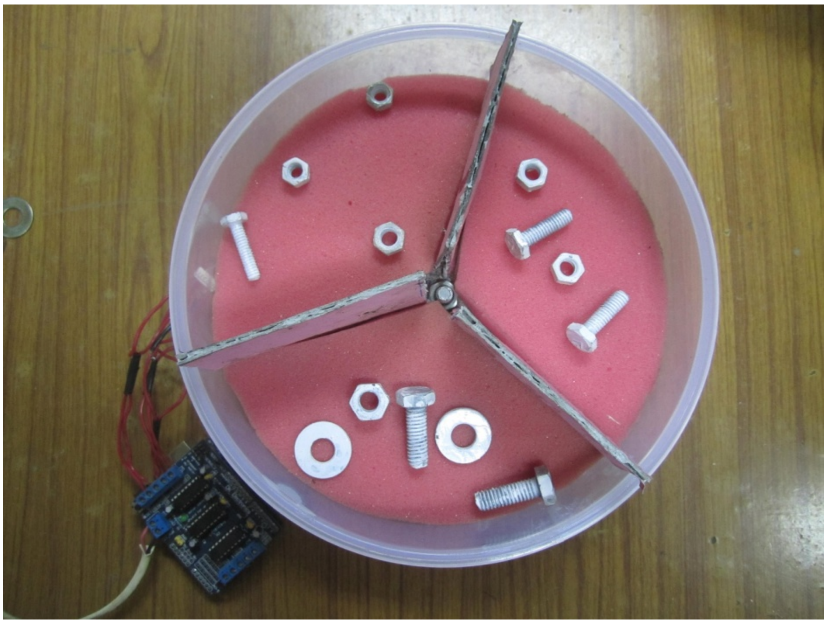


Figure 2.5: Rotary Disk

2.5 IMAGE ACQUISITION MODULE

Image acquisition in image processing can be broadly defined as the action of retrieving an image from some source, usually a hardware-based source, so it can be passed through whatever processes need to occur afterward. Performing image acquisition in image processing is always the first step in the workflow sequence because, without an image, no processing is possible.

The technology for image sensors has changed dramatically over the past 50 years, and sensors have shifted from vacuum tubes to solid-state devices, notably based on CCDs (charge-coupled devices) and CMOS (complementary metal oxide semiconductor) technologies.

In general, the better the acquisition device, the better would be the performance of an image processing system. For our system, we have selected a low-end USB web camera to ensure that the focus is on software framework and efficiency of processing algorithm rather than the quality of acquisition device.

Figure 2.6 Camera

The specifications of the web camera are -

- Name - Logitech HD Webcam C270
- Frame Rate - 30 fps
- Connectivity - USB
- Video Capture Resolution - 640 x 480
- Still Image Sensor Resolution - 3 megapixel
- Focus Range – 30mm minimum

2.6 SENSOR

The sensor is used in our work to detect the incoming objects on the belt. This generates a signal which is further used to time the rest of the system. Since our object are fasteners and are made up of metal only, so we require a metal detector or sensor to sense them over the belt. Metal detectors work on the principle of transmitting a magnetic field and analyzing a return signal from the target and environment. The transmitted magnetic field varies in time, usually at rates of fairly high-pitched audio signals.

The magnetic transmitter is in the form of a transmit coil with a varying electric current flowing through it produced by transmit electronics. The receiver is in the form of a receive coil connected to receive and signal processing electronics. The transmit coil and receive coil are sometimes the same coil. The coils are within coil housing. This changing transmitted magnetic field causes electric currents to flow in metal targets. These electric currents are called eddy currents, which in turn generate a weak magnetic field, but their generated magnetic field is different from the transmitted magnetic field in shape and strength. It is the altered shape of this regenerated magnetic field that metal detectors use to detect metal targets. [17]

The regenerated magnetic field from the eddy currents causes an alternating voltage signal at the receive coil. This is amplified by the electronics because relatively deeply buried targets produce signals in the receive coil which can be millions of times weaker than the signal in the transmit coil, and thus need to be amplified to a reasonable level for the electronics to be able to process. The metal sensor has been installed below the belt as close as possible to decrease the failure rate in sensing of the objects.

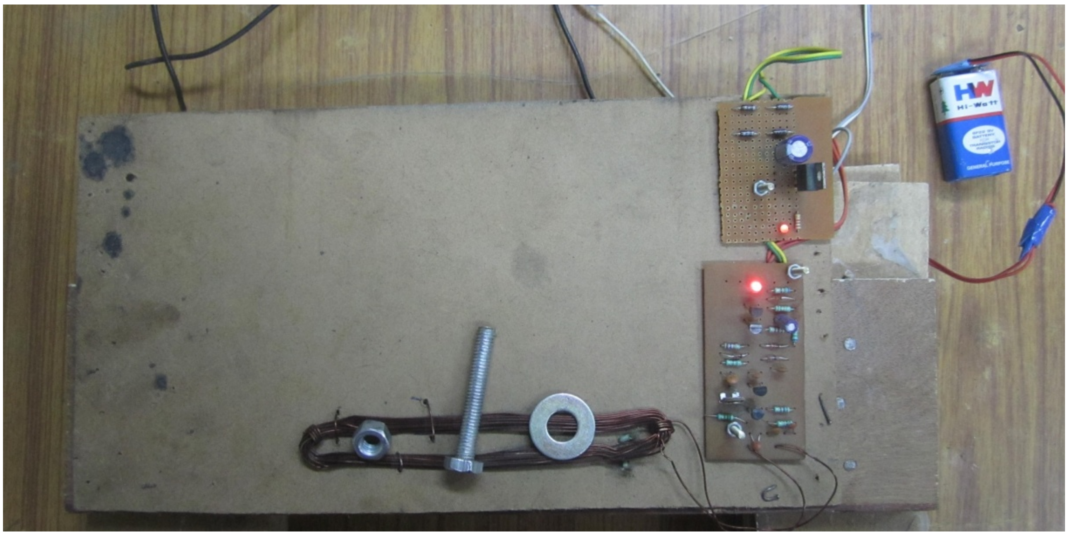


Figure 2.7 Metal Sensor

2.7 TEST SPECIMENS

Threaded fasteners are discrete hardware components that have external or internal threads for assembly of parts. Threaded fasteners are components that have external or internal threads for assembly of parts. The common threaded fastener types are screws, bolts, studs and nuts. [5]

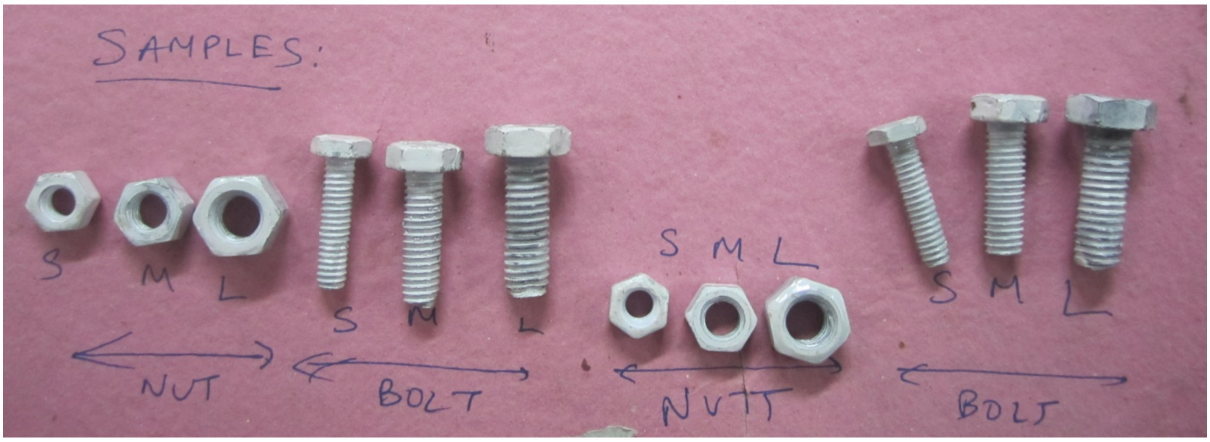


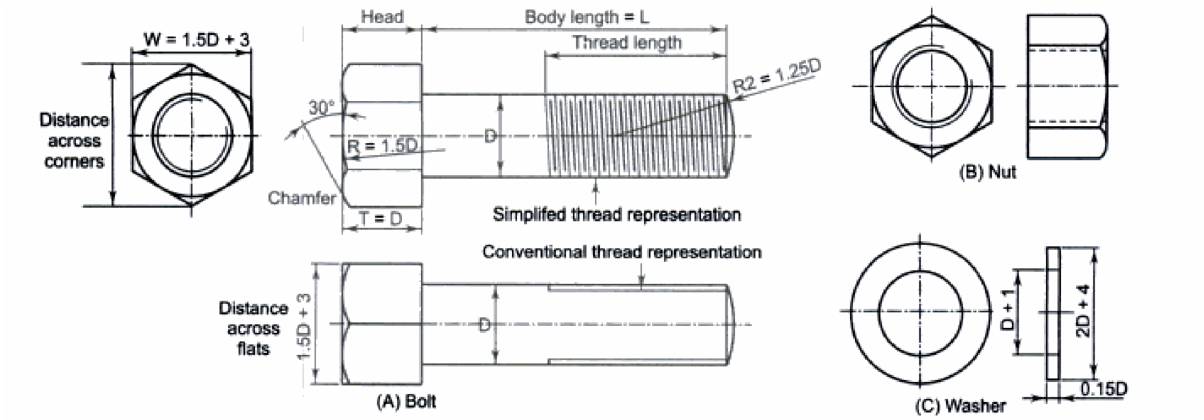
Figure 2.8: Test Specimens

- **bolt** is an externally threaded fastener that is inserted through holes in the parts and screwed into a nut on the opposite side;
- **screw** is an externally threaded fastener that is generally assembled into a blind threaded hole and no nut is required;

- **stud** is an externally threaded fastener, but without the usual head possessed by a bolt. Studs can also be used to assemble two parts using a nut. They are available with threads on one end or both;
- **nut** is an internally threaded fastener having standard threads. [5]

For our project, we have selected the most commonly used threaded fasteners - **hexagonal nuts and bolts.**

Hexagonal Nut - Bolt Assembly [5]



Hexagonal Nut

As the name indicates a hexagonal nut has six sides and forms the shape of a regular hexagon. The width across flats indicates the size of spanner used to tighten it. To ensure safety to the users, the corners of the nuts are chamfered.

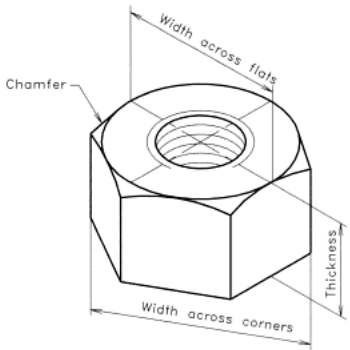


Figure 2.9 Hexagonal Nut

For our project we have chosen 3 different sizes of nuts classified as "small", "medium" and "large".

Small - M6

Medium - M8

Large - M10

Hexagonal Bolt

This is the most common and widely used bolt in machines and engineering woks to fasten two or more parts together. Like in the hex nut, the hexagonal head is chamfered at its upper end at an angle of 30° to its base to avoid injury to operator.

Proportions of Nuts and Bolts [5]

Dimensions of bolt head or nut can be expressed in terms of nominal diameter of the bolt. A set of such proportions are given in Table

Width across corners	2d
Width across flats	1.732d
Thickness of bolt head	0.8d
Thickness of nut	d
Angle of chamfer	30°
Core diameter of bolt	0.8d
Washer, outer diameter	2d + 3 mm
Washer, inner diameter	d + 1 mm
Washer thickness	0.12 d

Table 1 Dimensions of bolt head, nut in terms of nominal diameter

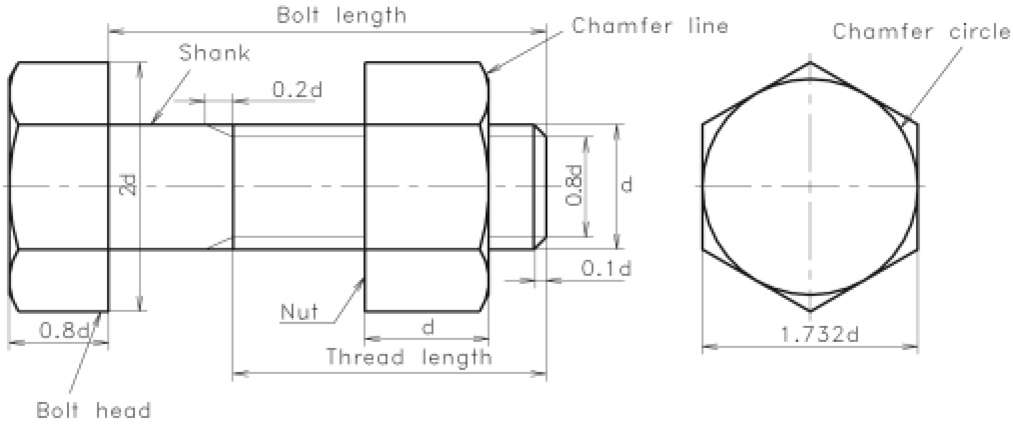
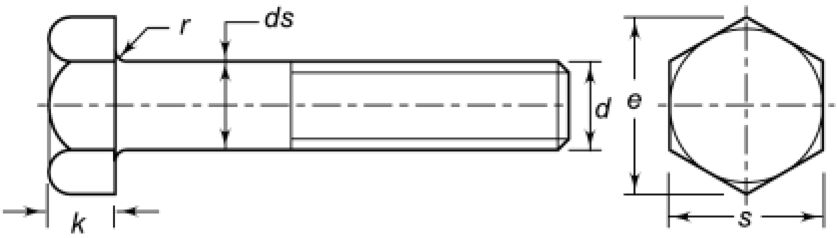


Figure 2.10 Hexagonal Bolt

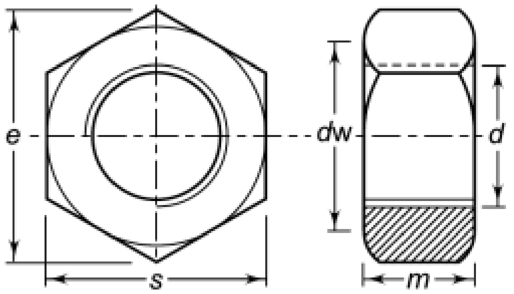
ISO Standards for dimensions of nuts and bolts [4]

Bolts - M6, M8, M10



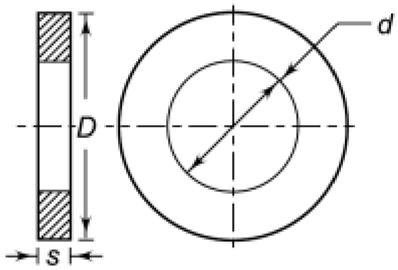
Thread size, d		M6	M8	M10
Pitch, p		1	1.25	1.5
ds	Max	6.48	8.58	10.58
	Min	5.52	7.42	9.42
e	Min	10.89	14.20	17.59
k	Nom.	4	5.3	6.4
	Min.	3.62	4.92	5.95
	Max.	4.38	5.68	6.85
r	Min.	0.25	0.4	0.4
s	Max.	10	13	16
	Min.	9.64	12.57	15.57

Nuts - M6, M8, M10 [4]



Thread size, d		M6	M8	M10
Pitch, p		1	1.25	1.5
dw	Min.	8.7	11.5	14.5
m	Max.	6.1	7.9	9.5
	Min.	4.9	6.4	8
s	Max.	10	13	16
	Min.	9.64	12.57	15.57
e	Max.	10.89	14.20	17.59

Washers [4]



Size, d	D	s	For Bolt or Screw Size
6.6	12.5	1.6	M6
9	17	1.6	M8
11	21	2	M10

2.8 SOFTWARE PLATFORM

MATLAB - Image Acquisition Toolbox Version 4.5

Image Acquisition Toolbox™ enables us to acquire images and video from cameras and frame grabbers directly into MATLAB® and Simulink®. We can detect hardware automatically and configure hardware properties.

In our project we have used this toolbox to interface with the webcam to acquire live images of test specimens as they traverse the conveyor.

MATLAB - Image Processing Toolbox Version 8.2

Image Processing Toolbox™ provides a comprehensive set of reference-standard algorithms, functions, and apps for image processing, analysis, visualization, and algorithm development. We can perform image analysis, image segmentation, image enhancement, noise reduction, geometric transformations, and image registration.

In this project we used this toolbox along with common MATLAB functions to analyse and draw conclusions from the acquired images of the test specimens.

MATLAB Support Package for Arduino

MATLAB Support Package for Arduino enables you to use MATLAB® or Simulink® to communicate with the Arduino® board over a USB cable. This package is based on a server program running on the board, which listens to commands arriving via serial port, executes the commands, and, if needed, returns a result.

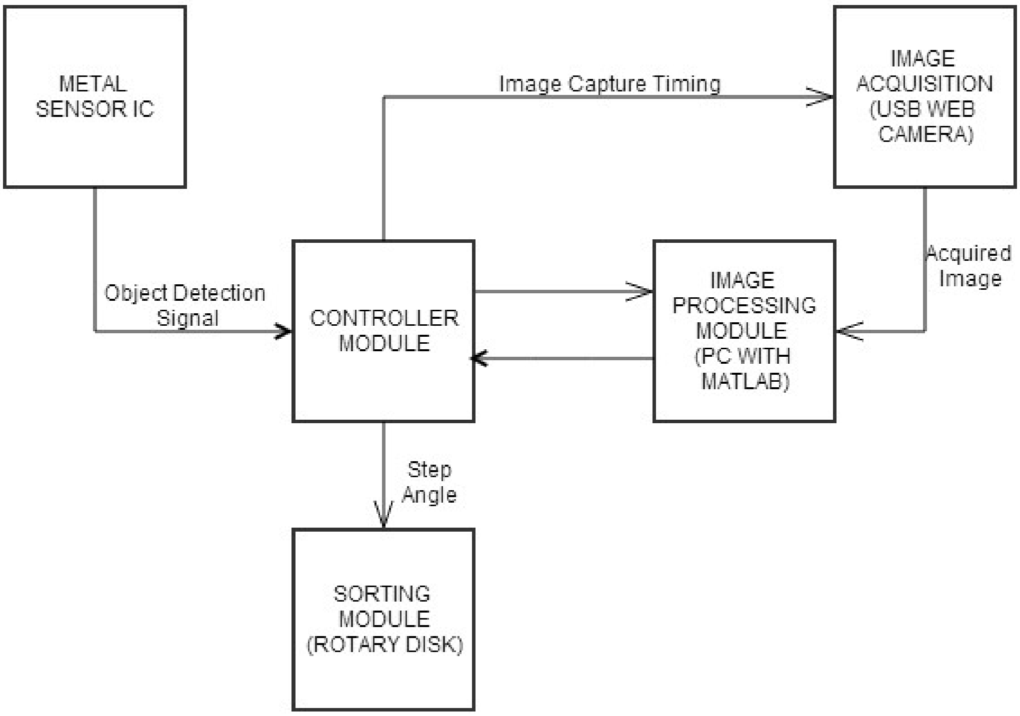
We have used this support package to directly control and time the sensor and stepper motor connected to Arduino Board.

CHAPTER - 3

Conceptualized Problem Solution

This system aims to classify the nuts and bolts according to their nominal size according to the image acquired by a web camera. The metal sensor placed under the conveyor belt detects the object when it passes over it and sends the output to Arduino controller board (Atmega8), which then signals the camera to acquire the top-view image of the test specimen. This image is analysed in real time using the image processing algorithm (MATLAB platform) which extracts selected features of the object required for classification as a nut or a bolt. Once it is known that object is a nut or bolt, corresponding pixel measurement of the nominal diameter is done. This pixel dimension is converted to real world dimensions using a pre-calculated calibration standard. On the basis of this dimension, the nut/bolt is classified as "small", "medium" and "large", and a corresponding signal is sent to the stepper motor to rotate the sorting disk which ensures that the object falls into the right bin.

3.1 BLOCK DIAGRAM



3.2 SETUP

Cad Model

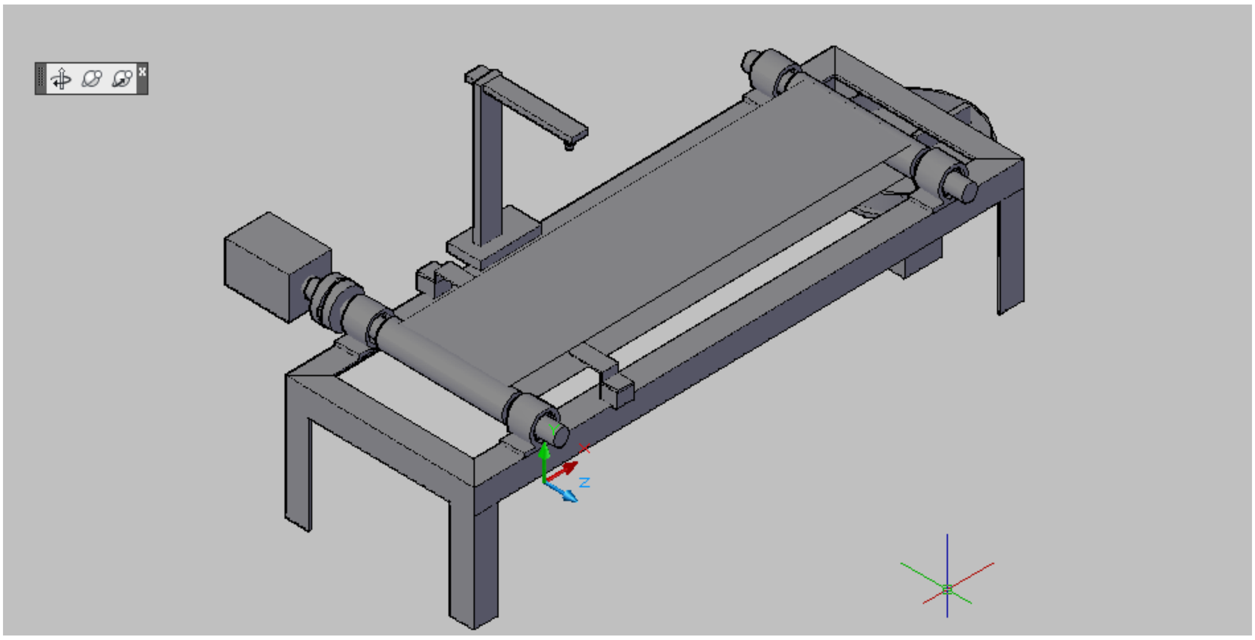


Figure 3.1 Isometric View of the System

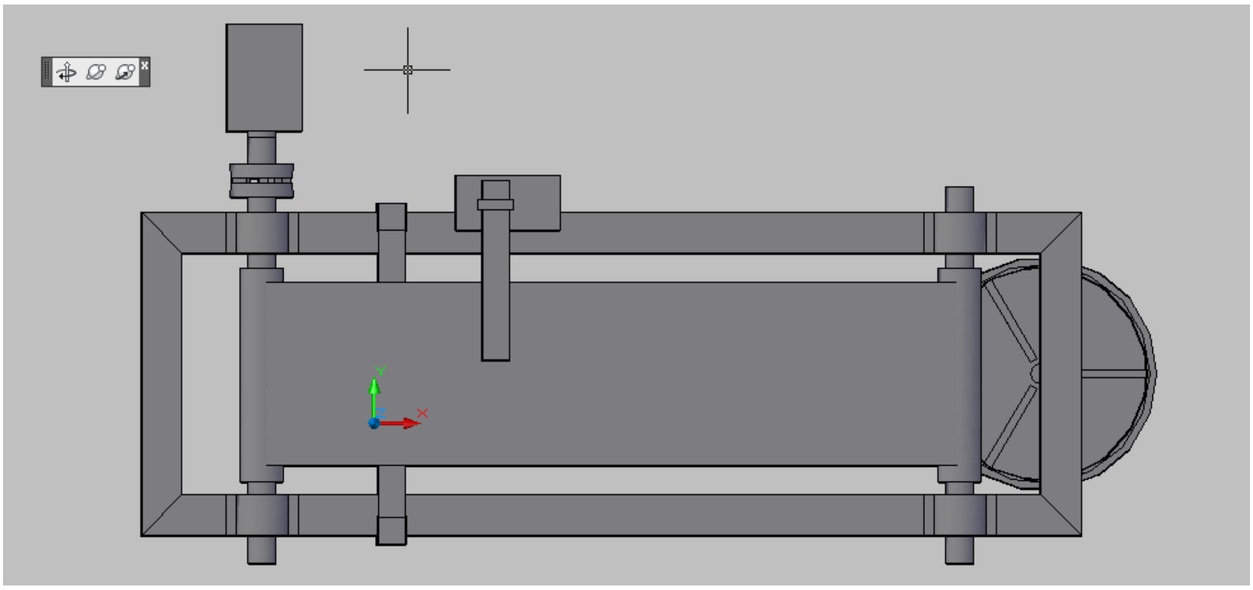


Figure 3.2 Top View of the system

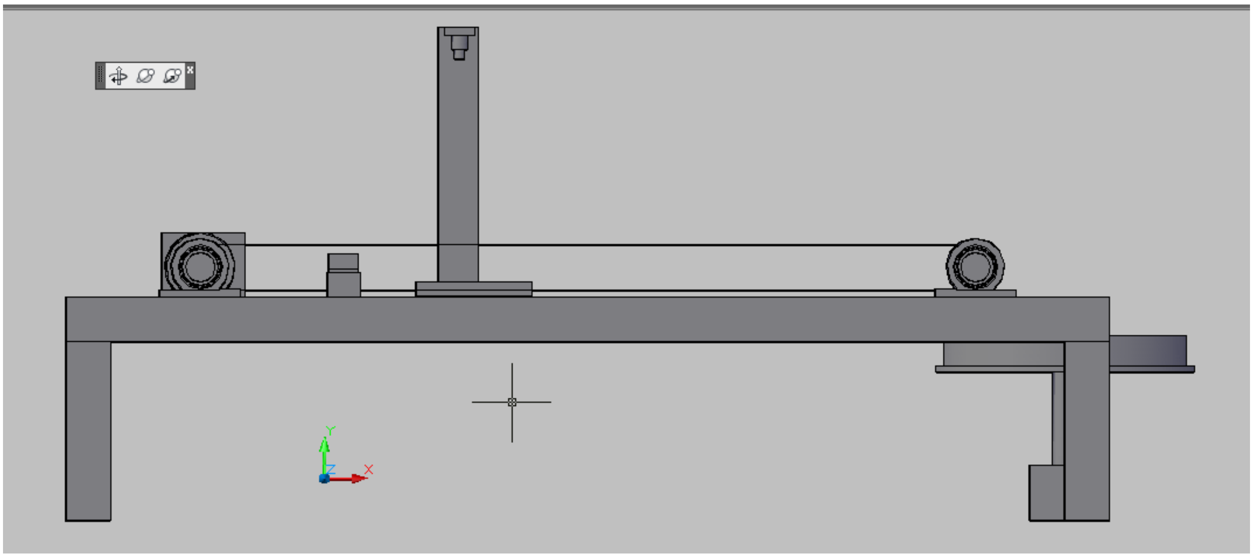


Figure 3.3 Front View of the system

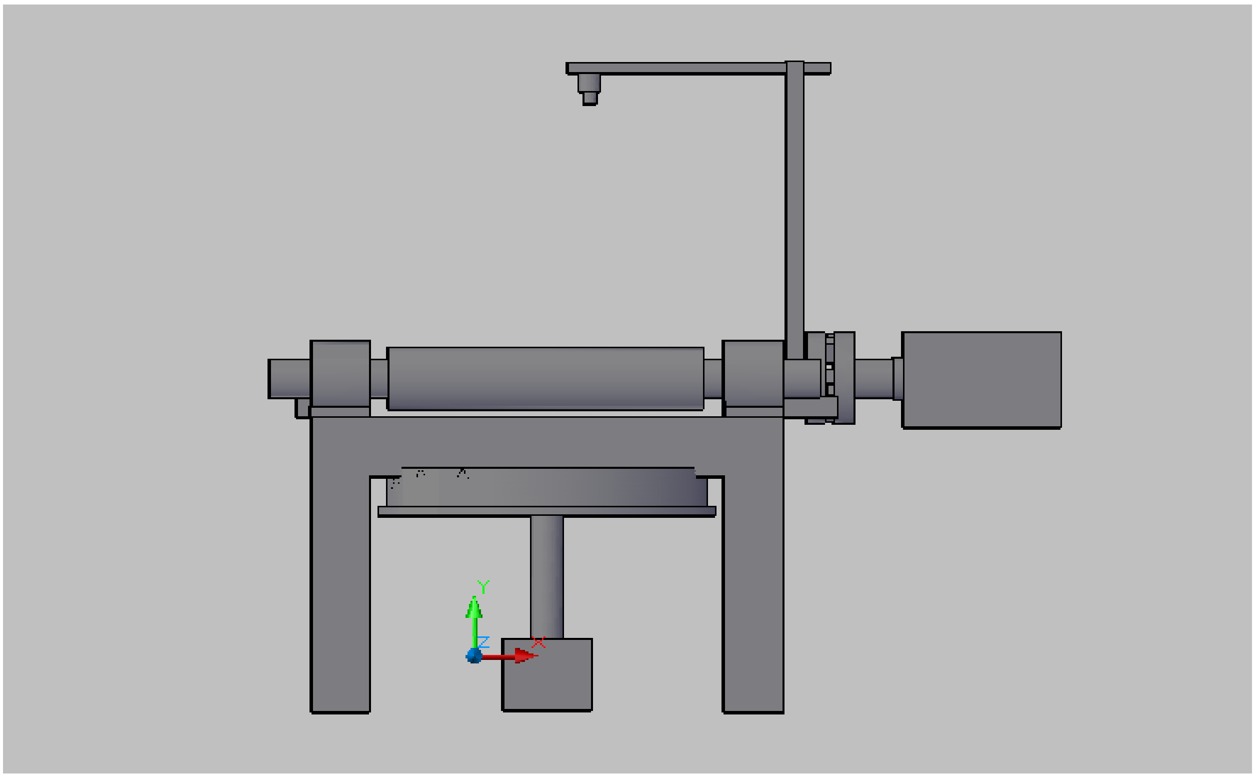


Figure 3.4 Side View of the system

CHAPTER - 4

Problem Analysis and Sequence of Approach

4.1 BUILDING THE BASIC FRAME

A thorough study was carried out to determine the basic dimensions of the frame. Materials to be used for the frame were decided too. Many factors went into deciding the material for the base of the metallic frame, including workability, weight, strength, and toughness.

The material was then procured and welded to required size and shape. Attachments including conveyor belt system were mounted on the frame along with Camera stand and sensors.

In our project, the frame construction was done through welding of angle iron pieces at both their ends. The angle iron used was made of steel. The weld was machined subsequently to achieve a smooth finish at the end joints. The stands used to provide height to the frames are also angle irons which have been secured to the frame through welding.

Therefore, the basic frame supports and maintains the alignments of the idlers and pulleys and supports the driving machinery.

The frame was constructed using angle irons which have been welded together at the ends to create a rectangular frame of dimensions 35 x 12 inches.

The frames were welded using the SMAW welding which gave sufficient strengths to the end joints.

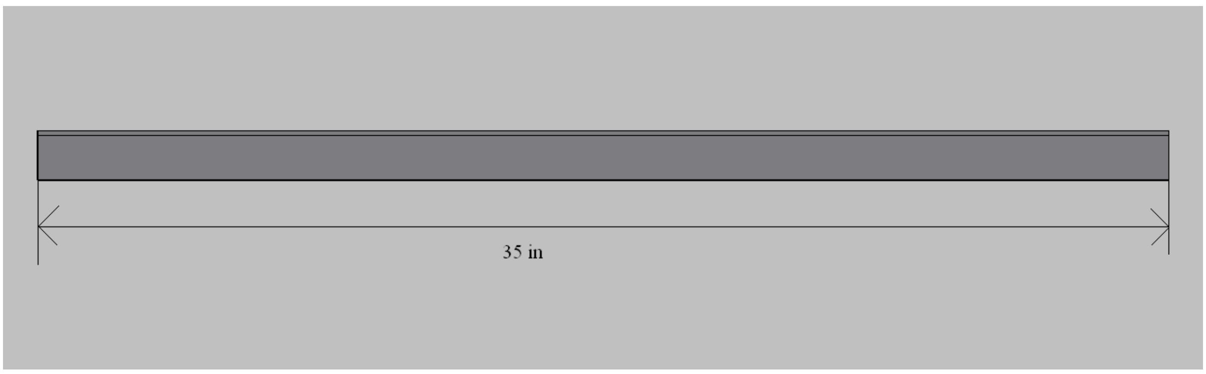


Figure 4.1: Angle used in length of frame (in inches)

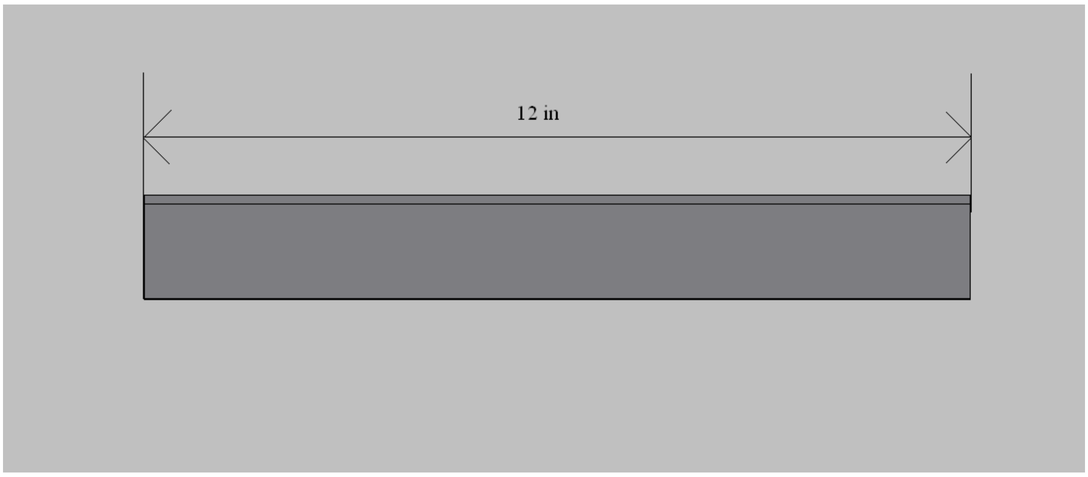


Figure 4.2: Angle used for breadth of the frame (in inches)

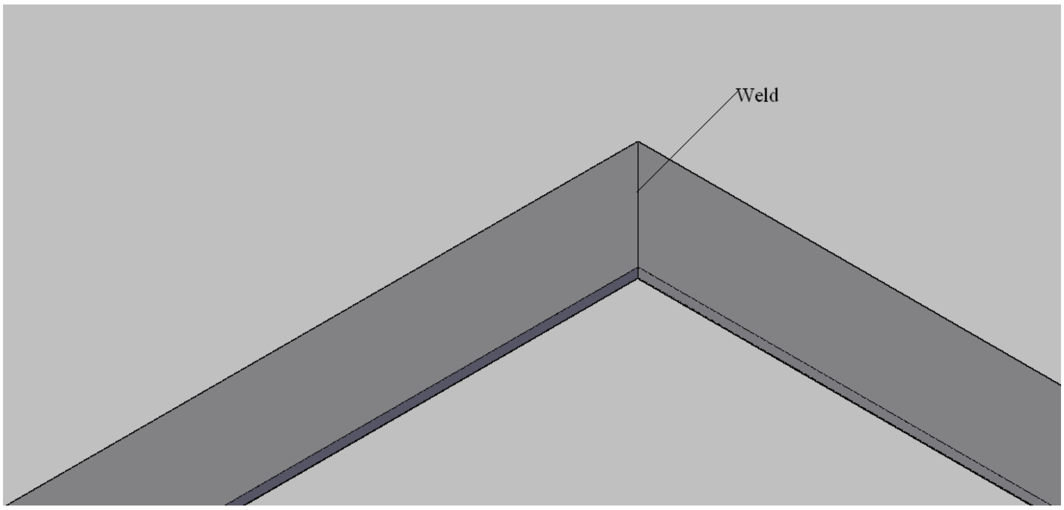


Figure 4.3: Joining of two angles to create a joint for frame

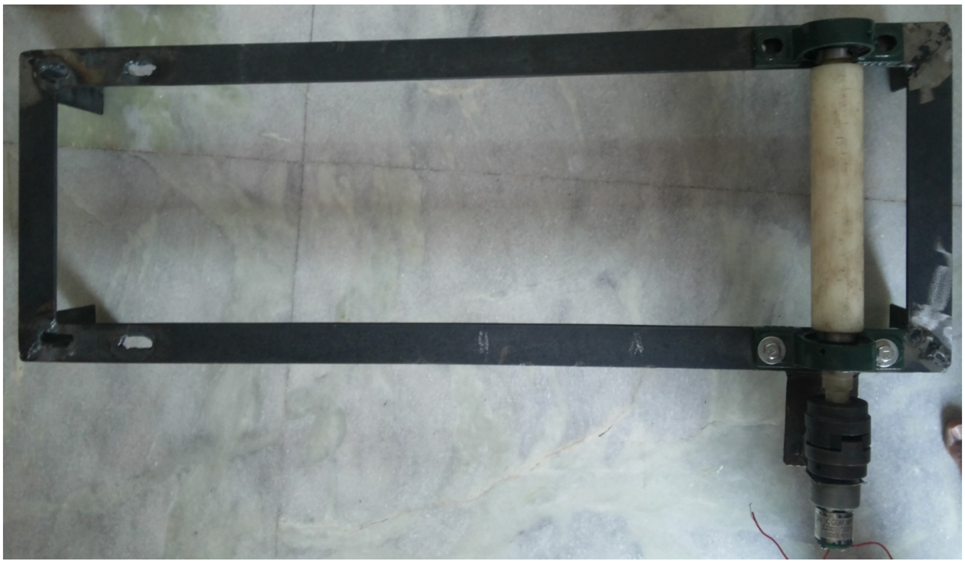


Figure 4.4 Basic Frame

4.2 DESIGNING THE CONVEYOR BELT SYSTEM

Many factors went into deciding the material for the rollers like surface finish, workability, strength, friction and machinability and finally Nylon Rollers were selected to meet the purpose. They were mounted on the frame using suitable bearing along with bearing clamps.

The conveyor belt width and circumferential length were calculated on the basis of the dimensions of the base frame and a time belt was chosen to get a precise and smooth drive.

Material selected for the conveyor belt depending upon the weights of the parts to be transported, is PVC. Since it have considerable amount of friction which help our parts (Threaded Fasteners) to be transferred with ease.

4.3 DESIGNING THE ELECTRONIC CIRCUIT

Various microcontrollers were studied which could be programmed suitably according to the requirements of the system. Arduino Board was chosen due to its compatibility with computers and various electronic devices.

The digital sensing signals from the Sensors can easily be detected by the controller in the form of Binary Logic which states:

1 is equivalent to object being detected by the sensor.

0 is equivalent to No Object State.

These signals initiate the image acquisition process through Camera according to the signal from the Arduino.

4.4 ASSEMBLING AND INTEGRATING THE SYSTEM

In the last stage of development of the project, various individual components consisting of Sensors, Camera, Arduino and Sorting System were integrated with the system.

Conveyor System is fixed to the metallic frame which was fixed on the table. Sensory device was required to carry out the conveyor movement and the sorting process is achieved through the sorting disk mounted on the stepper motor.

The parts/min and accuracy was calculated on the basis of 3 desired outcomes and final results were obtained.

The belt was used in continuous or automated fashion and parts are fed randomly through hand

CHAPTER - 5

Frame and Conveyor Design

5.1 FRAME DESIGN

The frame is the structure which carries the other systems installed in our project. The frame construction was done through welding of angle iron pieces at both their ends. The angle iron used was made of steel. The weld was machined subsequently to achieve a smooth finish at the end joints. The stands used to provide height to the frames are also angle irons which have been secured to the frame through welding.

Dimensions of Angle Iron:

Thickness: .25 inch

Width: 1.5 inch on both perpendicular sides

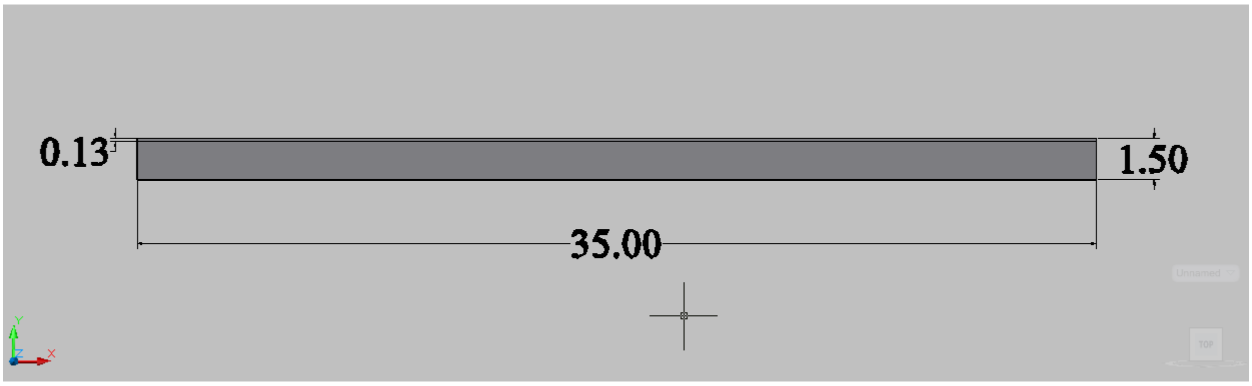


Figure 5.1: Front View of Angle Iron (all dimensions are in inches)

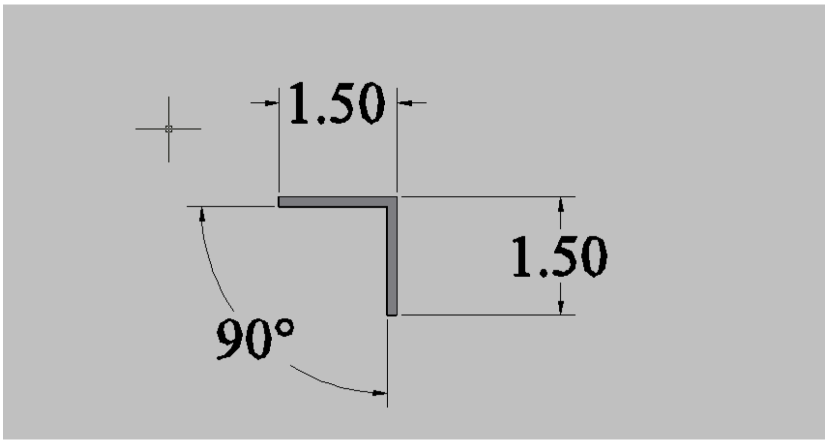


Figure 5.2 Side View of the Angle Iron (all dimensions are in inches)

Dimensions of the frame:

Length: 35 inches

Width: 12 inches

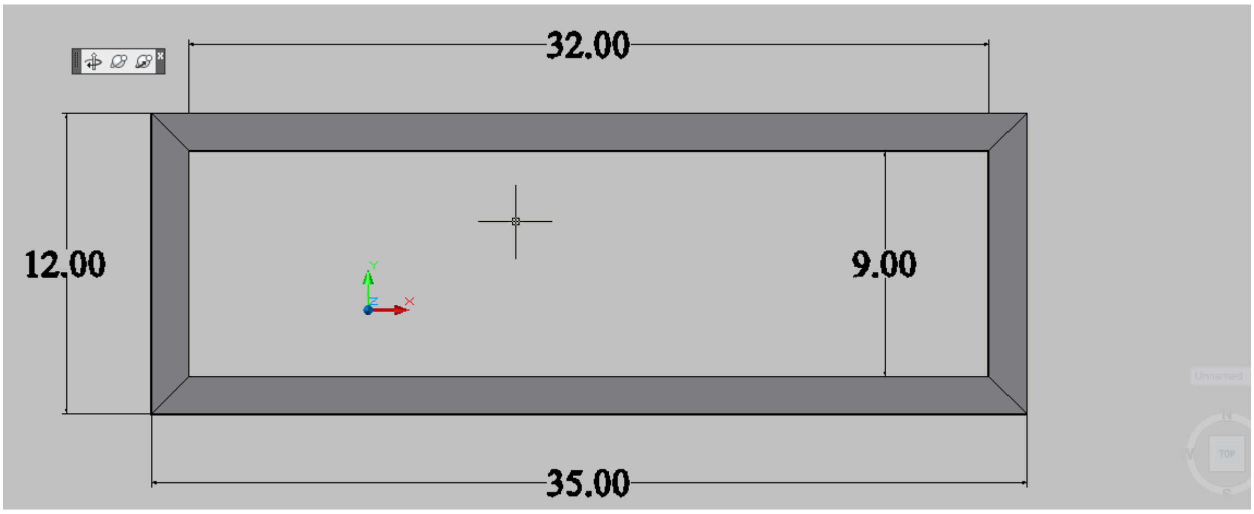


Figure 5.3 Top View of the Frame (all dimensions are in inches)

5.2 BEARINGS

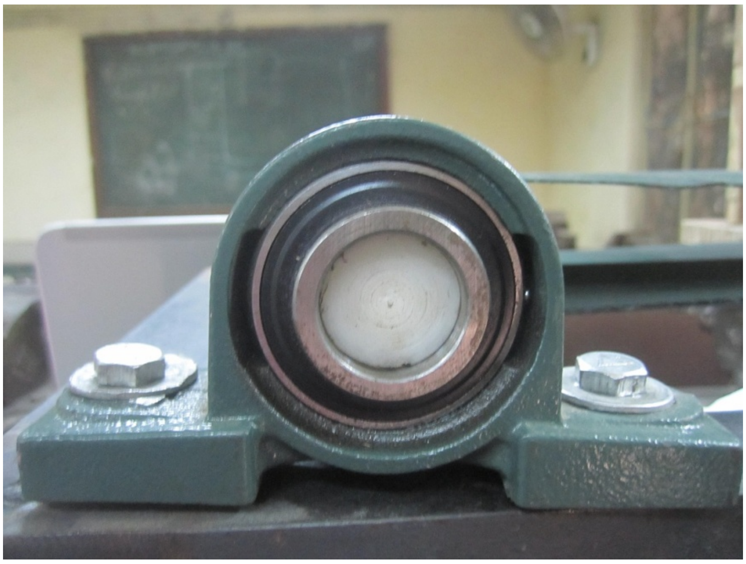


Figure 5.4 Bearing

To support the rotary motion of the shaft during the runtime we have utilized the single groove ball bearings that support the shaft as well as reduce friction to decrease power loss due to friction. Four bearings were used to support the four ends of the shaft.

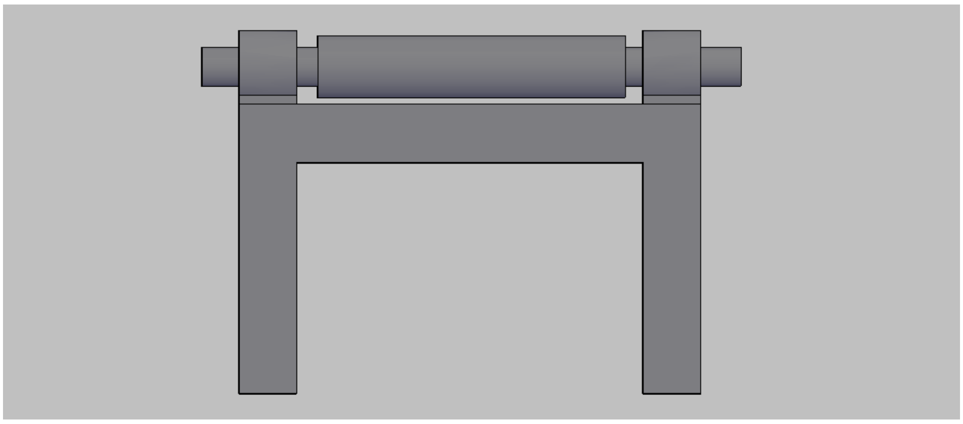


Figure 5.5 Frame Side View with Bearings mounted

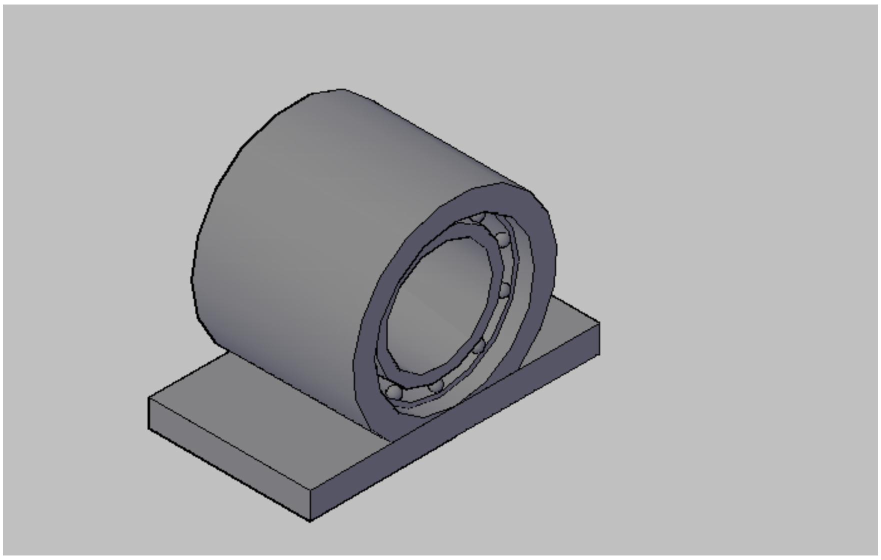


Figure 5.6 Bearing with a Bracket

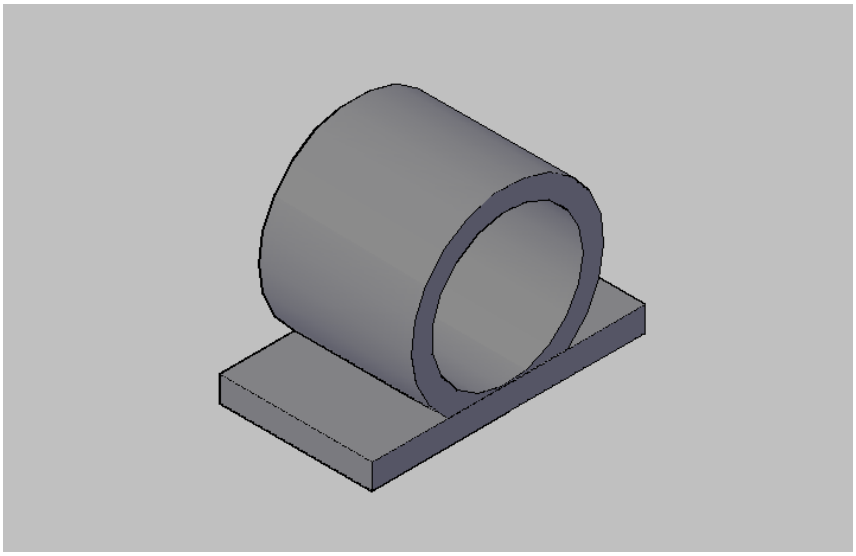


Figure 5.7 Bearing Bracket

Specification of the bearings:

SKF 6B105

Radius of the Bore: 25 mm or .504 inches

5.3 SHAFT

The shaft is the component which rotates with the motor to provide motion to the belt and the fasteners. The material used for the shaft if nylon because it renders our system with low inertia due to its low weight. It weighs almost .33 times that of steel for same volume. The shaft was machined through step turning in order to create space for the drum for the belt and also for the ends to be fitted inside the bearings.

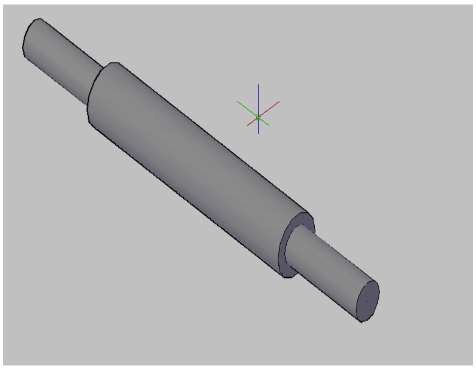


Figure 5.8 Turned Shaft

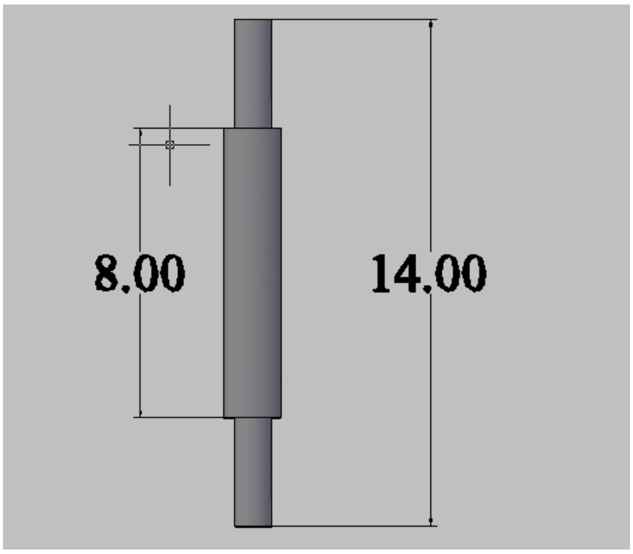


Figure 5.9 Top View of the shaft with drum (all dimensions are in inches)

Dimensions of Shaft:

Drum Diameter: 40mm or .79 inches

Drum Length: 8 inches

Shaft End Diameter: 25mm or .49 inches

Shaft Length: 14 inches

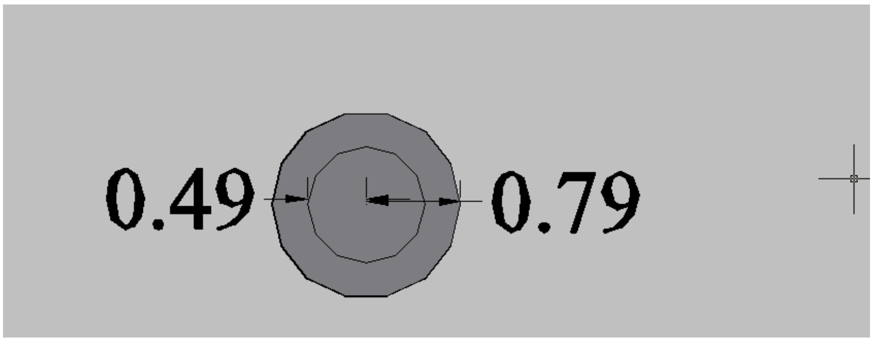


Figure 5.10 Side View of Shaft (all dimensions are in inches)

5.4 BELT

The belt is the flexible link which moves around and within the two drums. It is the component which carries the component from the point of start to the point where the sorting takes place. The belt used by us is made up of polyvinyl chloride which has been joined end to end to create an endless link.

Dimensions of the Belt:

Width: 6 inches

Length: 57 inches

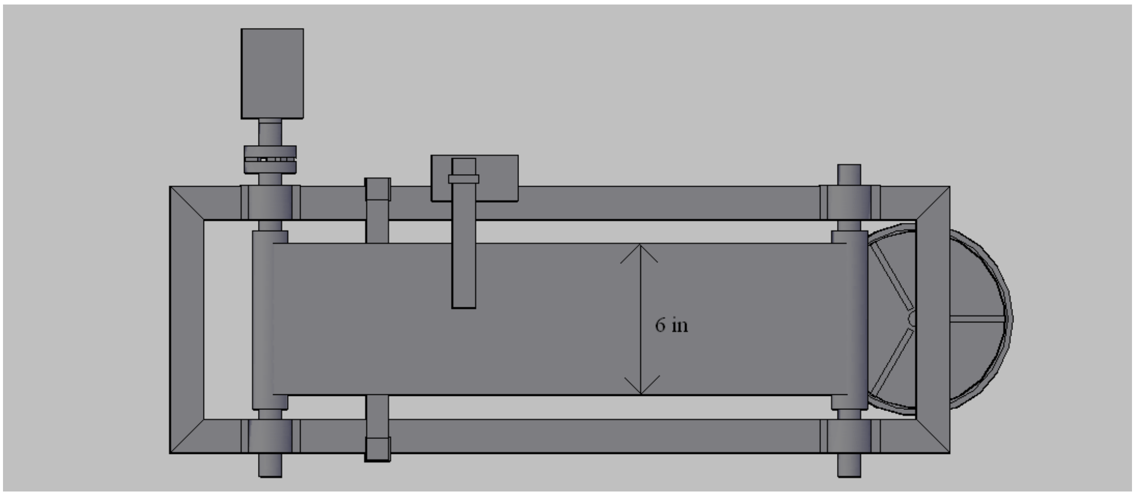
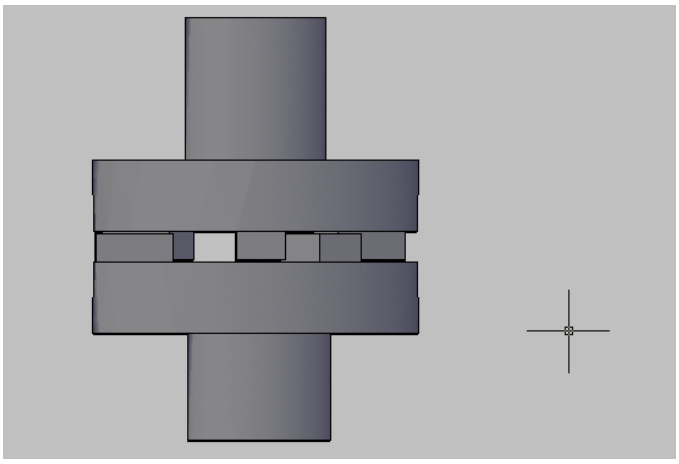


Figure 5.11 Belt in Top View of the setup (dimension is in inches)

5.5 COUPLING

The coupling main job is to transmit motion from the motor to the shaft. It consists of two pieces which are mounted separately through bolts. The coupling used is the claw coupling whose one piece is mounted on the motor spindle and other on the shaft end. The coupling also utilizes a plastic padding which fills the gap between the coupling pieces to take care of the lateral displacement in the shaft and the motor spindle. The coupling is made up of cast iron which has been bored to create a through hole of 6mm and 25mm for motor spindle and shaft end respectively.



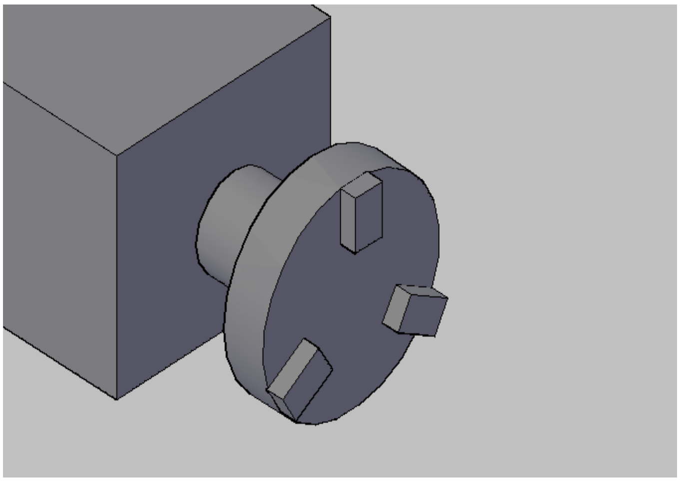


Figure 5.12 Top and Isometric View of the Claw (or Star) Coupling

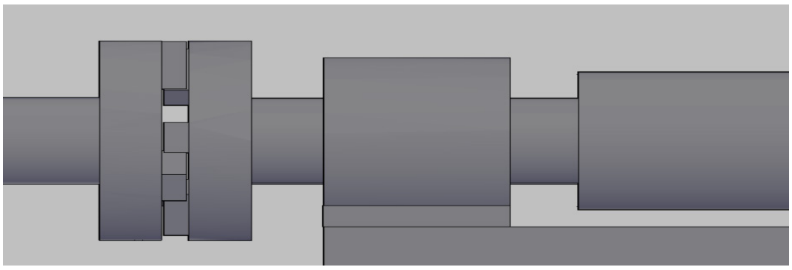


Figure 5.13 Shaft joining Coupling and Bearing

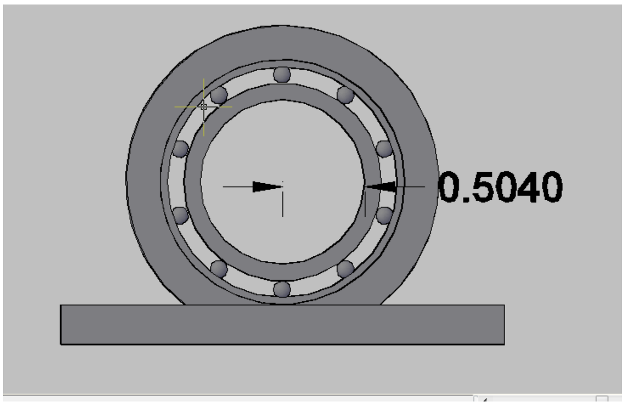


Figure 5.14 Front View (dimension is in inch)

5.6 CONVEYOR SYSTEM DESIGN:

The design of the system means deducing the final dimensions from the data which is given to us initially. The system of conveyor was designed according the time intervals and the synchronization which was required with different sub-systems in our project. The perfect design ensured the running of the entire project work was smooth and continuous.

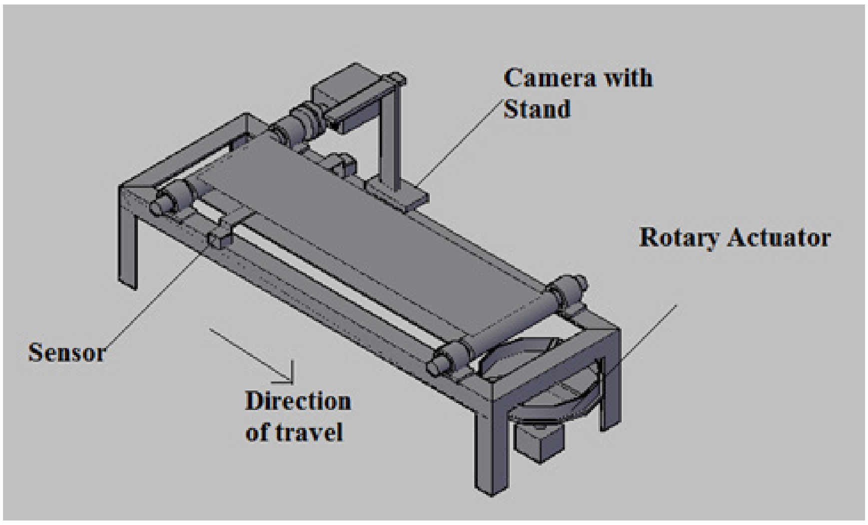


Figure 5.15 Illustration of entire system

1. Assumption of time intervals

This section was the first to be done in the designing. We assumed the time interval required for the components to reach from one station to another.

1. Time required to travel the distance between the start i.e. the point of feeding the components and the point where detection takes place i.e. location of the sensor = 3 seconds.

2. Time required to travel the distance between sensor and the point where image is captured for object differentiation, i.e. the point where camera is installed = 1 second.

3. Time required to travel the distance between the point of image capture to the point where sorting takes place, i.e. the position of the rotary actuator which collects the falling pieces from the belt = 9 to 11 seconds.

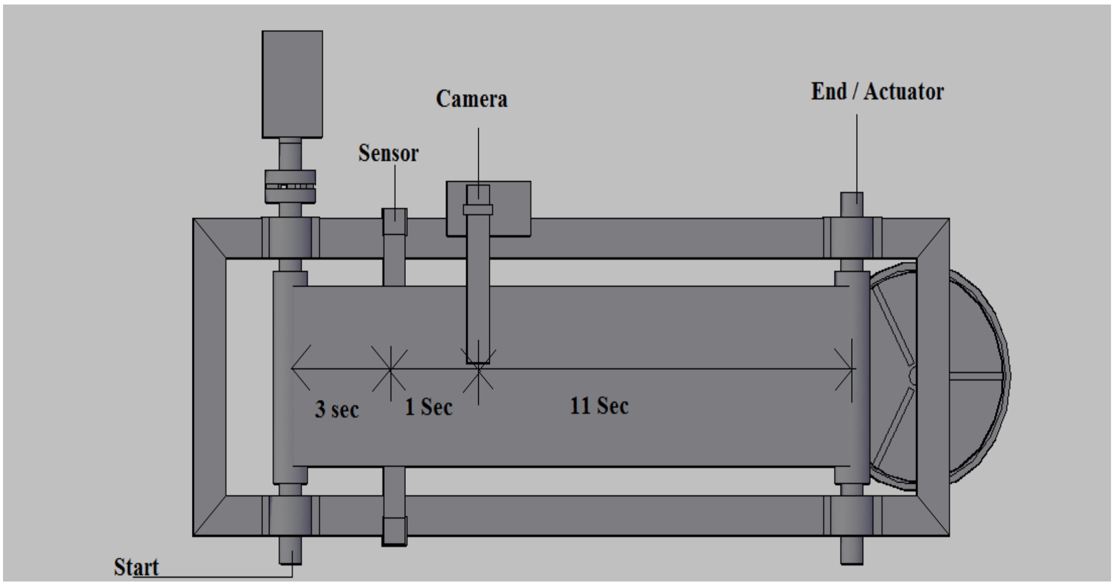


Figure 5.16 Time for travel between sub-systems (Time is in Seconds)

This provided ample time to the actuator to take the position for the particular component. This time can be further reduced subsequently in order to increase the effectness of the system.

2. Given Data:

1. Rpm of the motor = 20 rpm

Rpm was chosen after numerous trial and error attempts in order to achieve clarity in the snapshot taken by the camera i.e. we wanted minimum blurring to avoid error in the identification of the component (nut or bolt) and its dimensions.

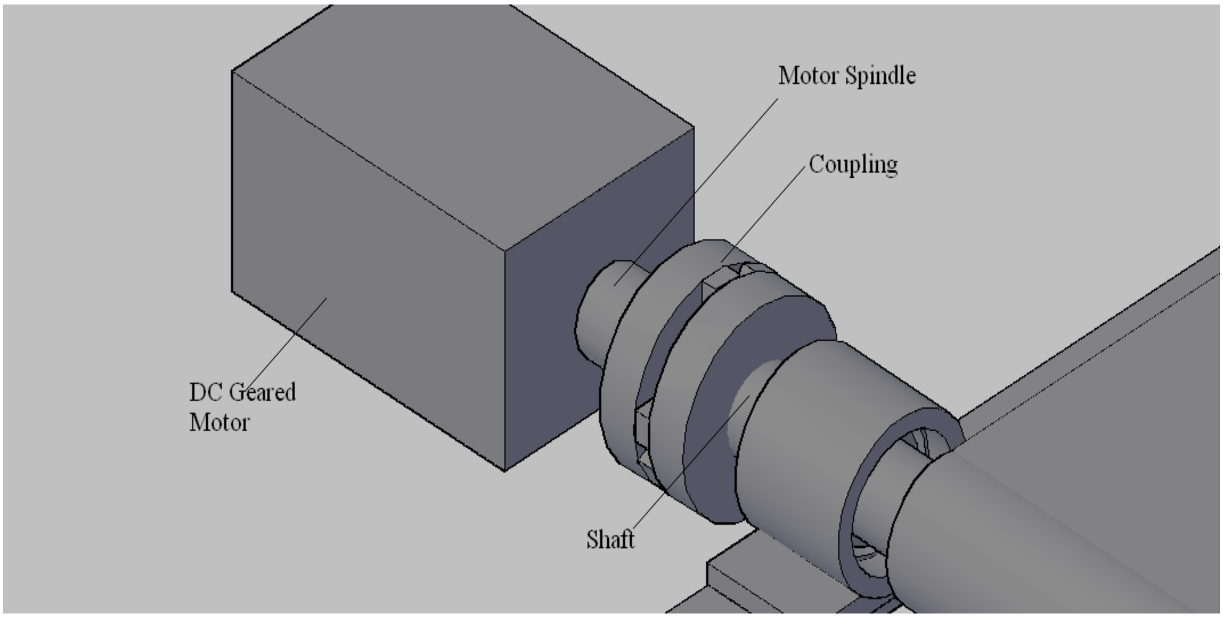


Figure 5.17 Motor Position wrt Shaft

2. Width of the Belt = 6 inch

The width was also chosen based on the field of the camera for which it produced pictures with best clarity. This was done through trial and error attempts with height of the camera and different width of the belt.

3. Diameter of the Shaft = 40 mm then step turned to 25 mm

This was an optimum size, chosen based on space available to place the metal sensor between the belt sides as well as based on the inertia of the system.

4. Weight of each component = 30 gm to 100 gm

This was randomly chosen.

3. Calculations:

Rpm of the pulley (n) = 20 rpm

Diameter of the drum (d) = 40 mm

= .04 m

Radius of the drum ($r = \frac{d}{2}$) = 20 mm

= .02 m

Angular Velocity of the shaft ($\omega = \frac{2\pi n}{60}$) = 2.09 rad/s

Linear Velocity of the belt ($v = \omega r$) = 2.09 x .02

= 0.0418 m/s

Time for travel between start and sensor (t1) = 3 s

Time for travel between sensor and camera (t2) = 1 s

Time for travel between camera and actuator (t3) = 11 s

Total Time for travel required (t = t1+ t2 + t3) = 15 s

Distance travelled between start and sensor (d1 = t1 x v) = 3 x .0418

= 0.1254 m

= 4.90 inch

Distance travelled between sensor and camera (d2 = t2 x v) = 1 x .0418 = 0.0418 m

= 1.64 inch

Distance travelled between start and sensor (d3 = t3 x v) = 11 x .0418

= 0. 4595 m

= 18.10 inch

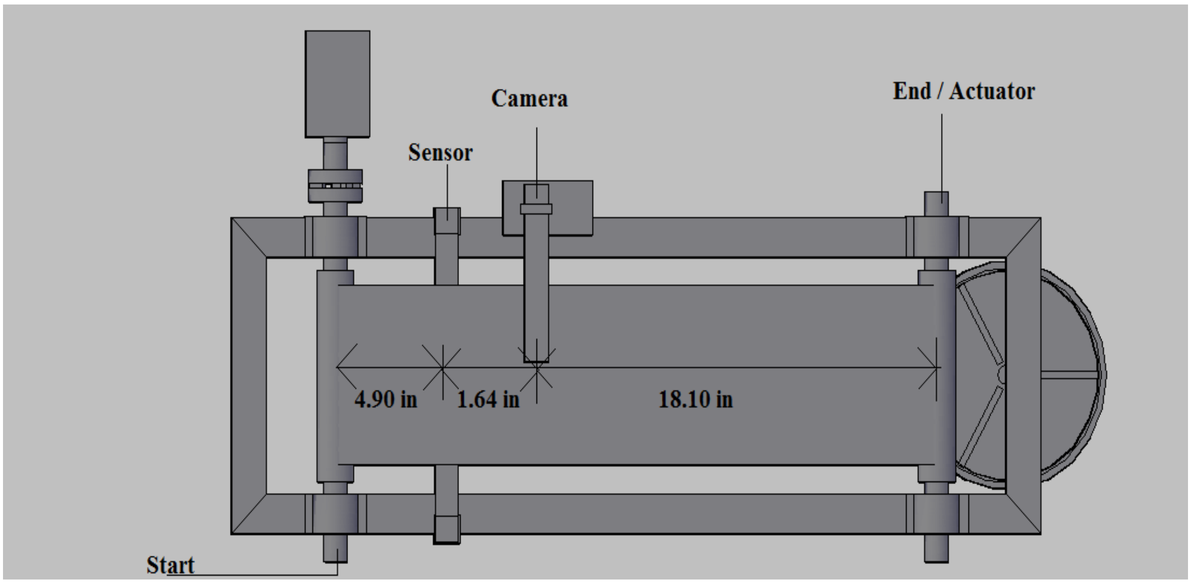


Figure 5.18 Distance travelled between different sub-systems (all dimensions are in inches)

Linear distance travelled by a point rotating with the drum = Distance between the two shaft axis = Path length for the components travelling on the belt = Distance travelled by the belt from start to end

(x = t x v) = 15 x 0.0418

= 0.627 m

= 62.7 cm

= 25.68 inch

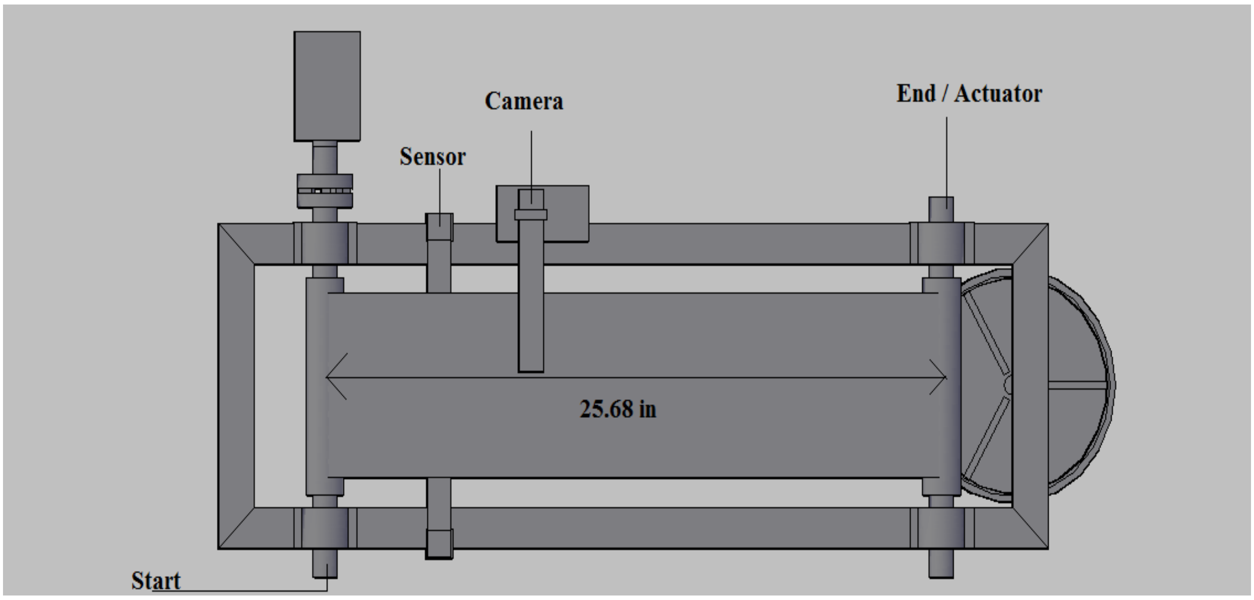


Figure 5.19 Total distance from start to end (in inches) (Top View)

Total length of the belt required = 56 to 57 inch

Width of the belt = 6 inch

Width of the angle iron used = 1.5 inch

Total width of the iron (one used on either side) = 2 x 1.5 = 3 inch

Distance between shaft axis and frame = 3 inch

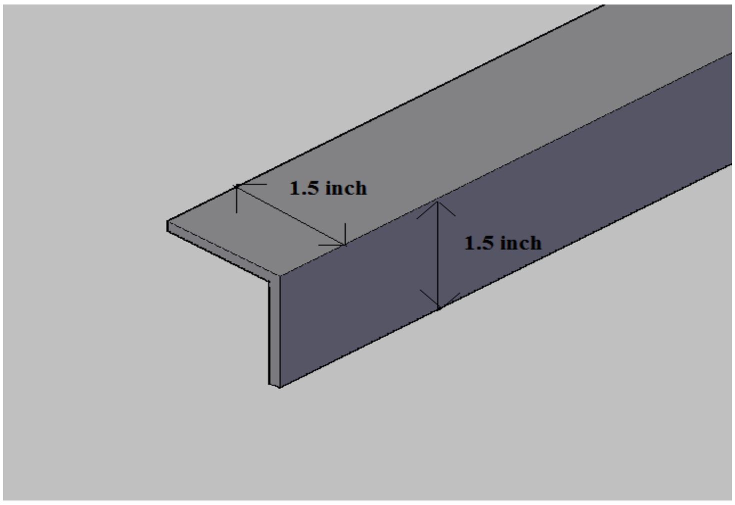


Figure 5.20 Angle Iron used for construction

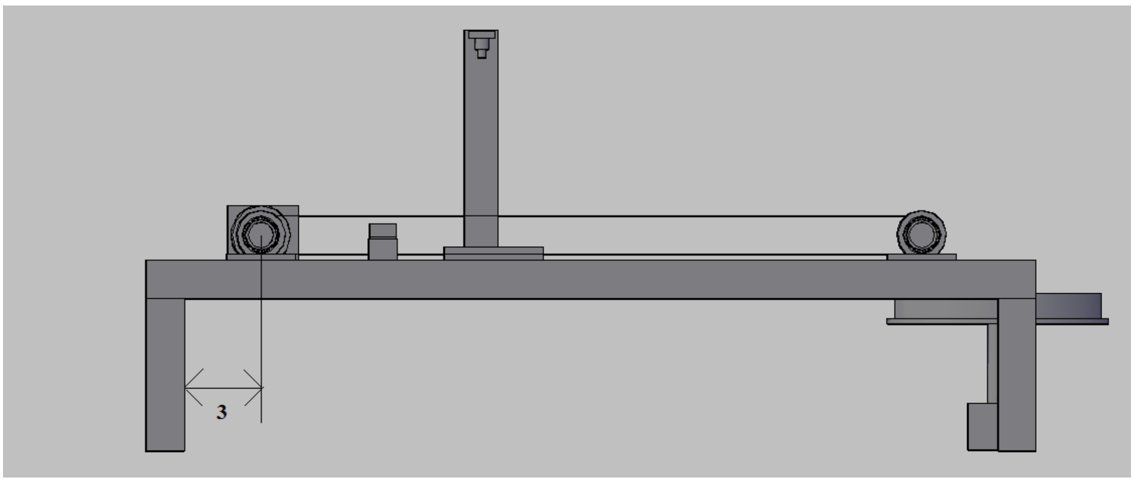


Figure 5.21 Distance between Start (or end) and Shaft's axis (in inches)

Total distance on either side = 2 x 3 inch = 6 inch

Total Length of the frame = 25 + 3 + 6 = 35 inch

Distance between Drum and the Bearing = 0.5 inch

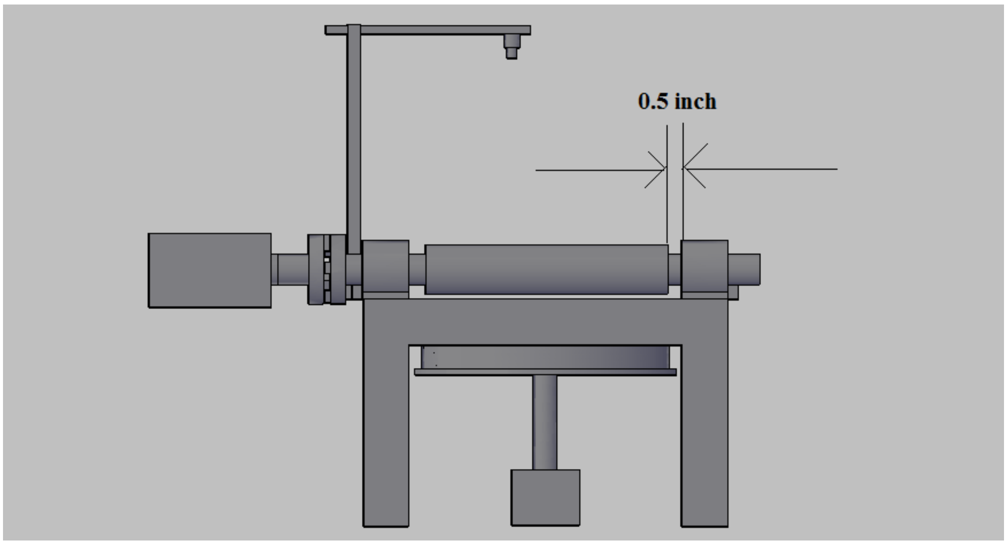


Figure 5.22 Distance (in inch) between drum and bearing.

Distance between Drum and Bearing on both sides = 2 x 0.5 = 1 inch

Total Width of the frame (w) = 3 + 8 + 1 = 12 inch

Therefore according to above calculations we have designed a frame of length 35 inch and width 12 inch, i.e. 35 x 12 inch frame.

5.7 BELT SELECTION

The belt is the important component of our project and was selected after number of trial and errors with different materials for their slipping capacity with the nylon material of the shaft. The selection was also base on the cost of the material of the belt.

The following belt materials were considered initially:

1) Fabric

2) Rubber

3) PVC

We chose the colored PVC belt for following reasons:

1) No slipping on the nylon drum at the load and torque we are working.

2) The green color was selected as it provides a good background and enhanced the object in the foreground. This led to clearer pictures with high contrast from camera which enhanced our project's efficiency in identifying and measuring the components.

3) PVC material is wear resistant and provided us with opportunities to re-run our system again and again.

4) Optimum friction which prevented the components over the belt from slipping. This property prevented the components to change their orientation time and again.

5) The PVC has property to resist edge wear and tear, so the belt can run smoothly within the drum area even when it comes in contact with the shaft ends.

CHAPTER - 6

DC Motor Selection

DC Geared Motor is used to transfer the drive to the pulleys and thus giving a motion to the conveyor system. A variable input DC Motor has been proposed to be used which could give maximum rpm of approximately 45 when given a rated supply voltage of 24 V. This motor was suitable for the desired purpose with adequate torque and was easily available in markets at an affordable cost. It was coupled to the drum shaft with Star coupling.

We have chosen DC Centre shaft gear Motor with following specifications:

- RPM: 45 at 24V
- Rated Voltage: 24V
- Dynamic torque: 10 Kg-cm
- Shaft diameter: 6mm
- Shaft length: 18mm
- Gear assembly: Spur (Metal)
- Brush type: Carbon
- Motor weight: 178gms
- Motor Diameter: 37mm

Motor runs smoothly from 4V to 24V and gives about 20 RPM at 12V. Motor shaft has 6mm diameter, 18mm length drive shaft with D shape for excellent coupling.

Geared DC Motor was chosen so as to provide adequate torque at rated speed and thus without stopping the belt, controller and camera can perform their respective functions. [16]

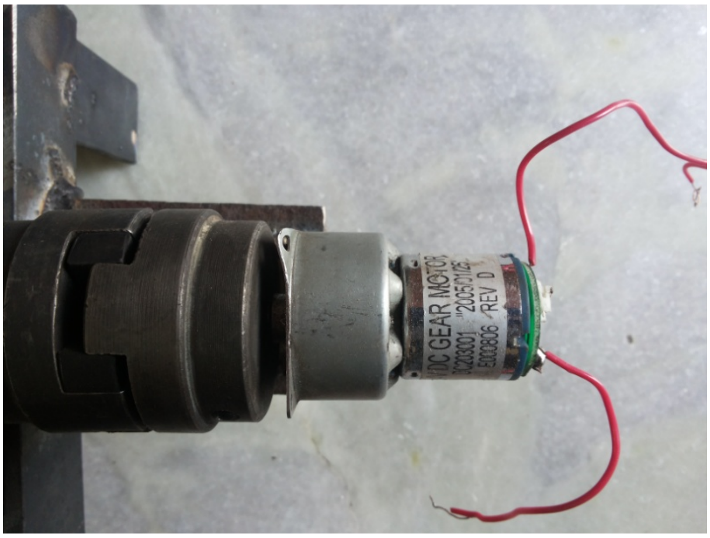


Figure 6.1: DC Geared motor with star coupling

Star Coupling

Star coupling is used to couple motor shaft to the driving shaft of the system. It has the one side diameter of 6 mm which fits the motor shaft and other side has a diametric hole of 25 mm which fits the driving shaft.

Rubber between the star coupling devices is used for perfect alignment and to absorb the jerk produced by the motor.

Material of the star coupling is Mild Steel.

Figure 6.2: Star Coupling

CHAPTER - 7

Sorting System Design

7.1 STEPPER MOTOR SELECTION

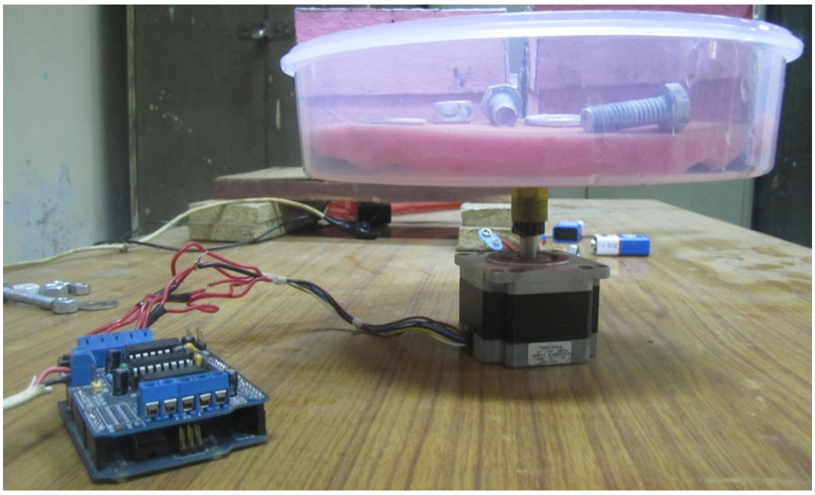


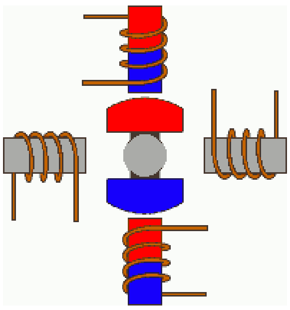
Figure 7.1 Sorting Setup

Step Modes

Stepper motor "step modes" include Full, Half and Micro step. The type of step mode output of any stepper motor is dependent on the design of the driver.

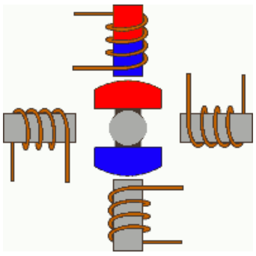
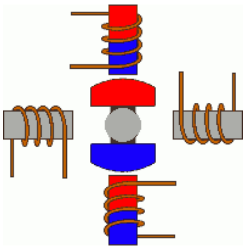
1. Full Step

Standard hybrid stepping motors have 200 rotor teeth, or 200 full steps per revolution of the motor shaft. Dividing the 200 steps into the 360° of rotation equals a 1.8° full step angle. Normally, full step mode is achieved by energizing both windings while reversing the current alternately. Essentially one digital pulse from the driver is equivalent to one step.



2. Half Step

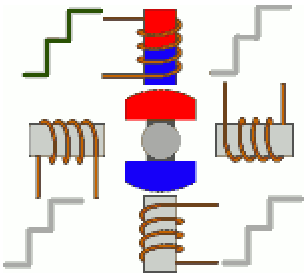
Half step simply means that the step motor is rotating at 400 steps per revolution. In this mode, one winding is energized and then two windings are energized alternately, causing the rotor to rotate at half the distance, or 0.9°. Although it provides approximately 30% less torque, half-step mode produces a smoother motion than full-step mode.

3. Micro Step

Micro stepping is a relatively new stepper motor technology that controls the current in the motor winding to a degree that further subdivides the number of positions between poles. Micro stepping is typically used in applications that require accurate positioning and smoother motion over a wide range of speeds. Like the half-step mode, micro stepping provides approximately 30% less torque than full-step mode.

In this project we have used micro stepping mode as we require precise control and relatively less torque.



Choosing a Stepper Motor

The followings steps must be kept in mind while choosing a Stepper Motor:

1) If a motor is rated to more amps or volts than your driver can produce, your motor will not produce the manufacturer's rated torque.

2) A motor can safely exceed its rated voltage with a chopping stepper driver. It cannot exceed its rated current (amps) without severely overheating and dying a quick death.

3) Stepper motors are generally rated for a 50 °C temperature rise at rated current/torque.

4) ABS melts at 105-120 °C but softens at 80 °C. Therefore you probably can't run your steppers at their full rated torque without melting your plastic motor mounts.

5) Power made available to a motor will be turned into heat and motion.

6) The more power made available to the motor the higher the amount of heat and motion. Heat is proportional to current squared while motion is proportional to current, so losing a little motion (torque) can lose a lot of heat.

7) Current and torque are related. The more current, the more torque. More current also means more power requirement and more heat on motor and stepper driver.

8) A motor's rated amps, volts, or ohms can be calculated with the other two numbers using Ohm's law.

Advantages of a Stepper Motor [16]

The following are the advantages of a Stepper Motor:

1) The rotation angle of the motor is proportional to the input pulse.

2) The motor has full torque at standstill (if the windings are energized).

3) Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3 to 5% of a step and this error is non-cumulative from one step to the next.

4) Excellent response to starting/stopping/reversing.

5) Very reliable since there are no contact brushes in the motor. Therefore the life of the step motor is simply dependant on the life of the bearing.

6) The stepper motors response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.

7) It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.

8) A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

7.2 ROTARY DISK DESIGN

The disc is mounted on a stepper motor which rotates with desired steps according to the signal received. This is based on the position which the disc has to occupy to collect the work piece. One of the disc's wall acts as the reference for the stepper motor. The motor has that point as its home position or zero degree angle and moves in reference to it. [11]

The height of the disc and the height of the walls on the disc have been chosen on following considerations:

1) The height is such that falling component does not bounce of the disc base and fall outside or in another compartment.

2) The optimal height of the entire sorting assembly is such that it does not touch the conveyor frame and moves unhindered.

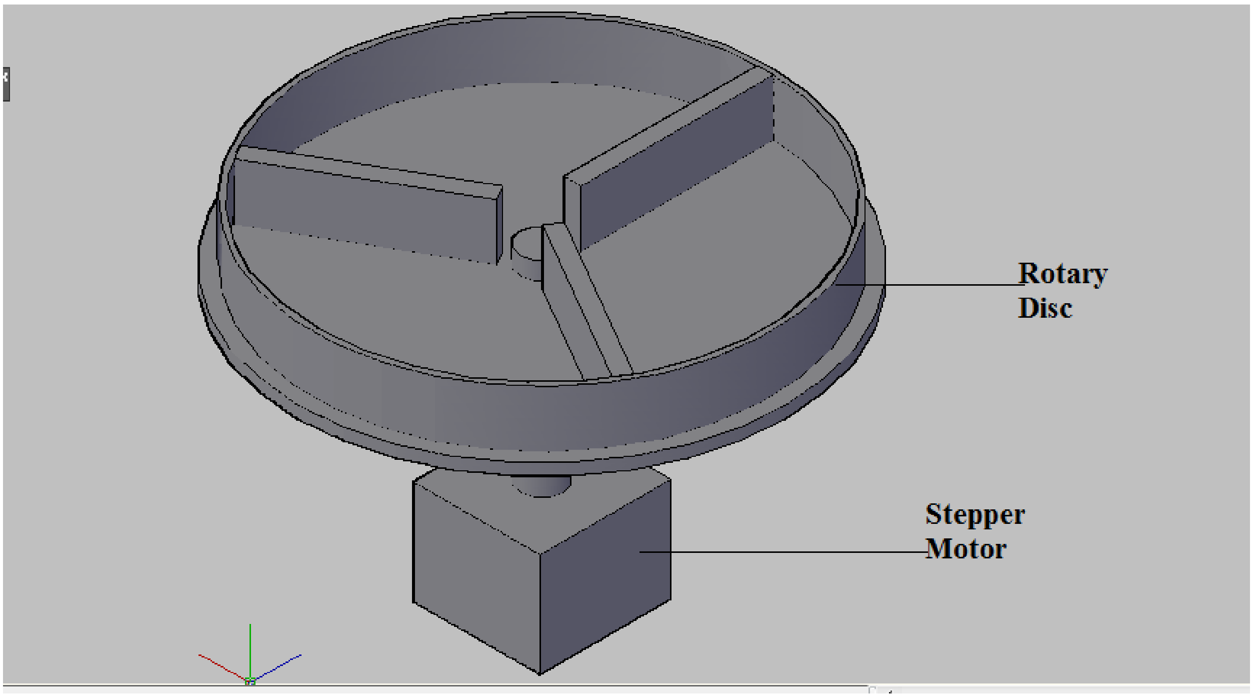


Figure 7.2 Rotary Sorting System (Isometric View)

Design of Rotary Disc:

Belt Width assumed = 6 inches

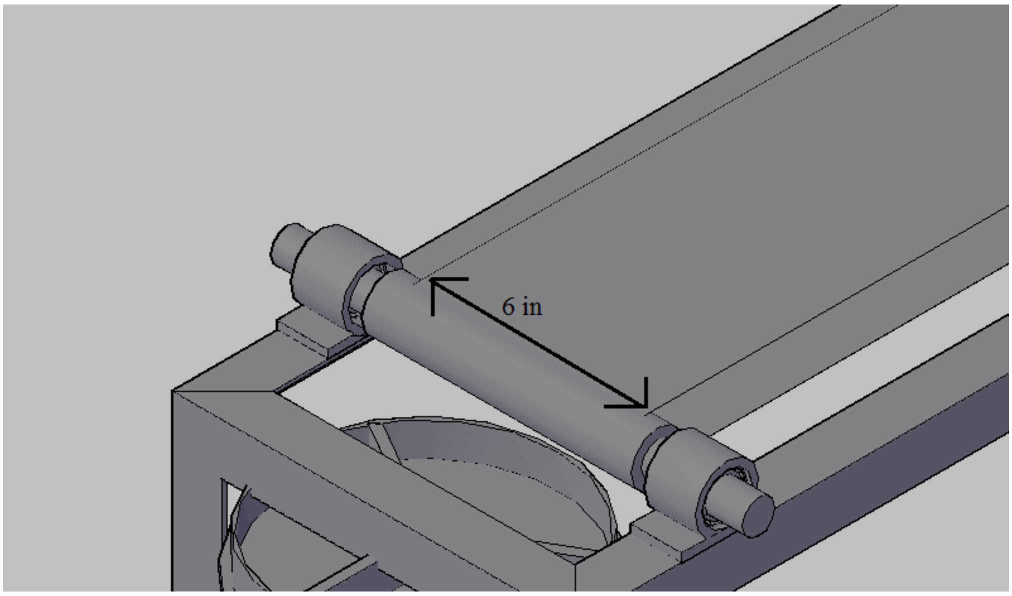


Figure 7.3 Positioning of Rotary Disc. (in = inches)

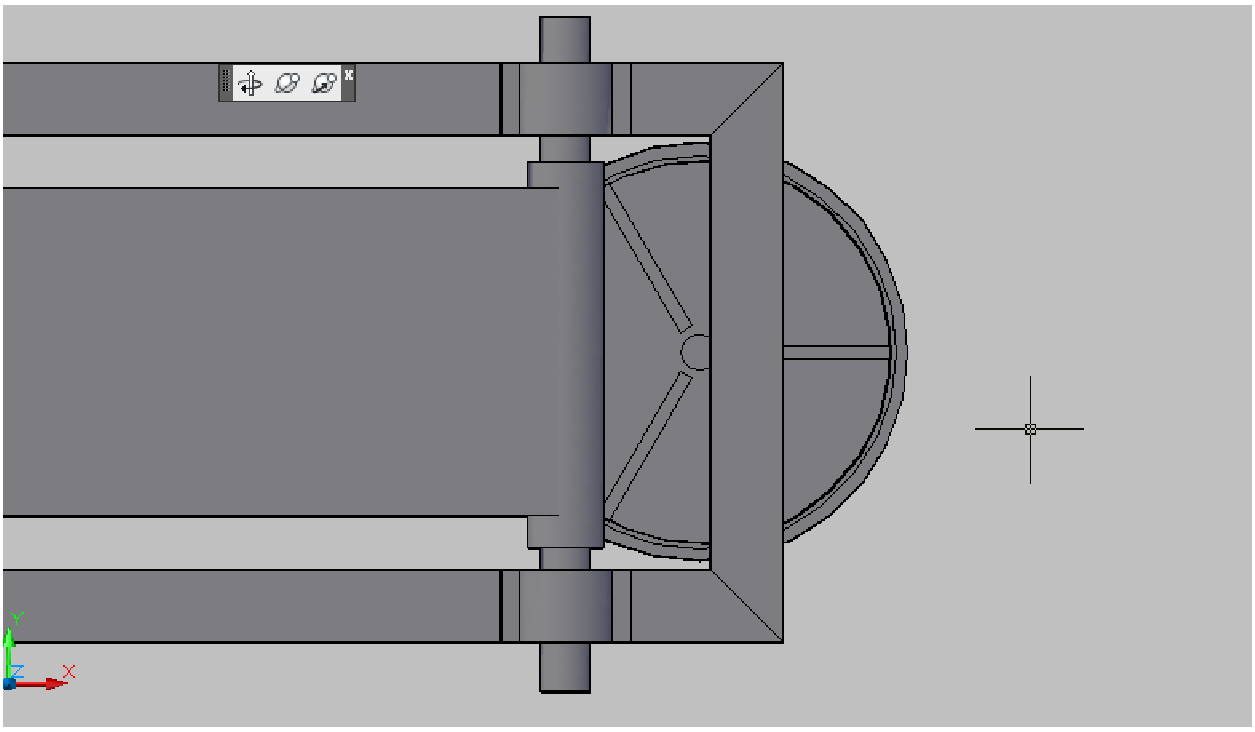


Figure 7.4 Top View of the belt end showing position of the Rotary Disc. It is situated below it and its chord is parallel and equal to the belt width.

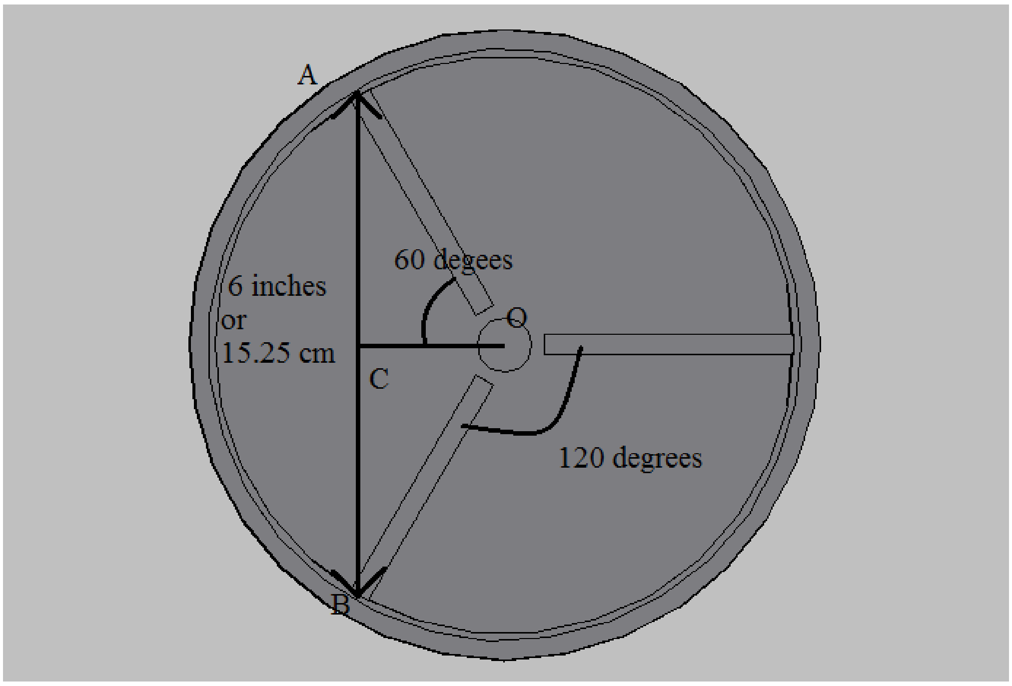


Figure 7.5 Top View showing the dimensions (cm = centimeters)

Angle AOB = 120^{o}

Angle AOC = $\frac{\text{Angle AOB}}{2}$ = 60^{o}

Length AB = 6 inches = 15.24 cm

Length AC = $\frac{\text{AB}}{2}$ = 3 inches = 7.62 cm

Length AO = Radius of the Disc

Sin (Angle AOC) = Sin (60^{o})

$= \frac{\sqrt{3}}{2}$

$= \frac{AC}{AO}$

AO = $\frac{2}{\sqrt{3}}$ x AC

AO = $\frac{2}{\sqrt{3}}$ x 3

= 3.464 inches

= 8.81 cm

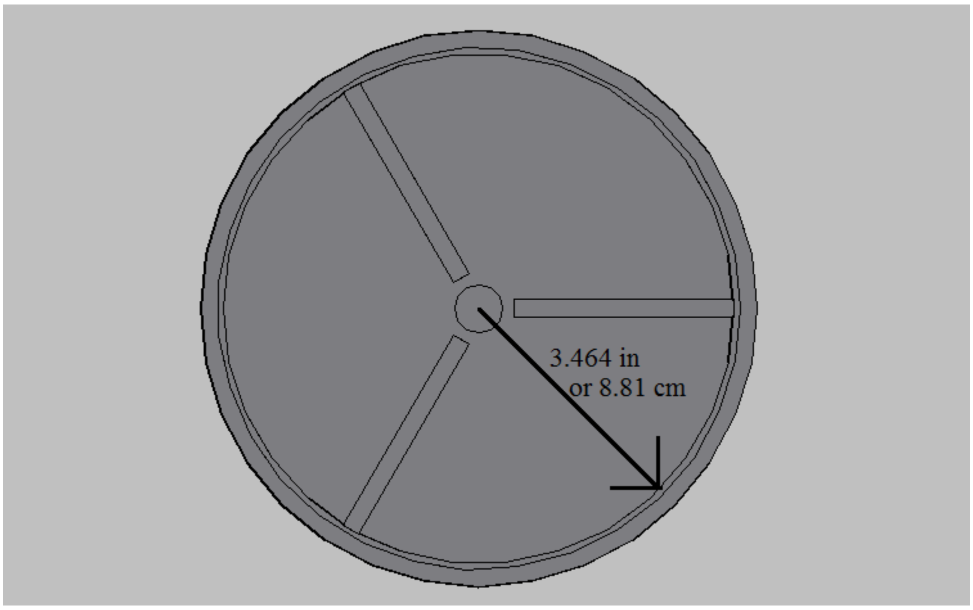


Figure 7.6 Top View showing Radius of the Rotary Disc. *(in = inches, cm = centimeters)*

CHAPTER - 8

Electronic Circuitry

8.1 ARDUINO UNO CONTROLLER

Arduino is a single-board microcontroller, intended to make the application of interactive objects or environments more accessible. The hardware consists of an open-source hardware board designed around an 8-bit Atmel AVR microcontroller, or a 32-bit Atmel ARM. Current models feature a USB interface, 6 analog input pins, as well as 14 digital I/O pins which allow the user to attach various extension boards.

An Arduino board consists of an Atmel 8-bit AVR microcontroller with complementary components to facilitate programming and incorporation into other circuits. An important aspect of the Arduino is the standard way that connectors are exposed, allowing the CPU board to be connected to a variety of interchangeable add-on modules known as shields.

An Arduino's microcontroller is also pre-programmed with a boot loader that simplifies uploading of programs to the on-chip flash memory, compared with other devices that typically need an external programmer. This makes using an Arduino more straightforward by allowing the use of an ordinary computer as the programmer.

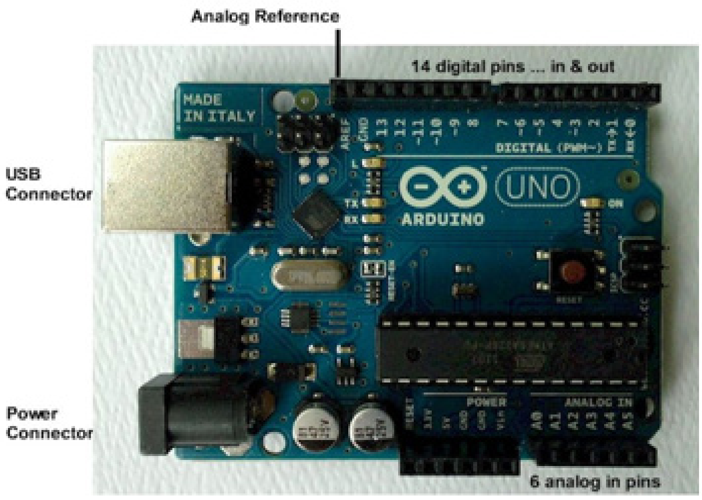


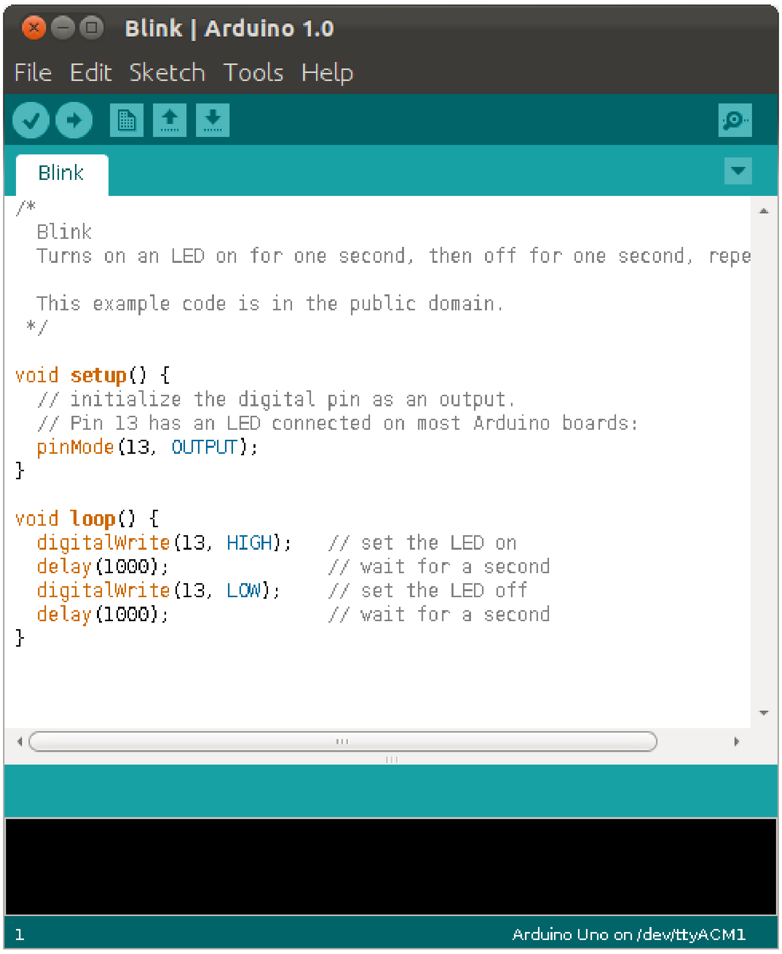
Figure 8.1: Arduino UNO

Arduino Software

The Arduino integrated development environment (IDE) is a cross-platform application written in Java, and is derived from the IDE for the Processing programming language and the Wiring projects. It is designed to introduce programming to artists and other newcomers unfamiliar with software development. It includes a code editor with features such as syntax highlighting, brace matching, and automatic indentation, and is also capable of compiling and uploading programs to the board with a single click. A program or code written for Arduino is called a "sketch".

Arduino programs are written in C or C++. The Arduino IDE comes with a software library called "Wiring" from the original Wiring project, which makes many common input/output operations much easier. Users only need define two functions to make a runnable cyclic executive program:

- setup(): a function run once at the start of a program that can initialize settings
- loop(): a function called repeatedly until the board powers off



Arduino Pin Mapping

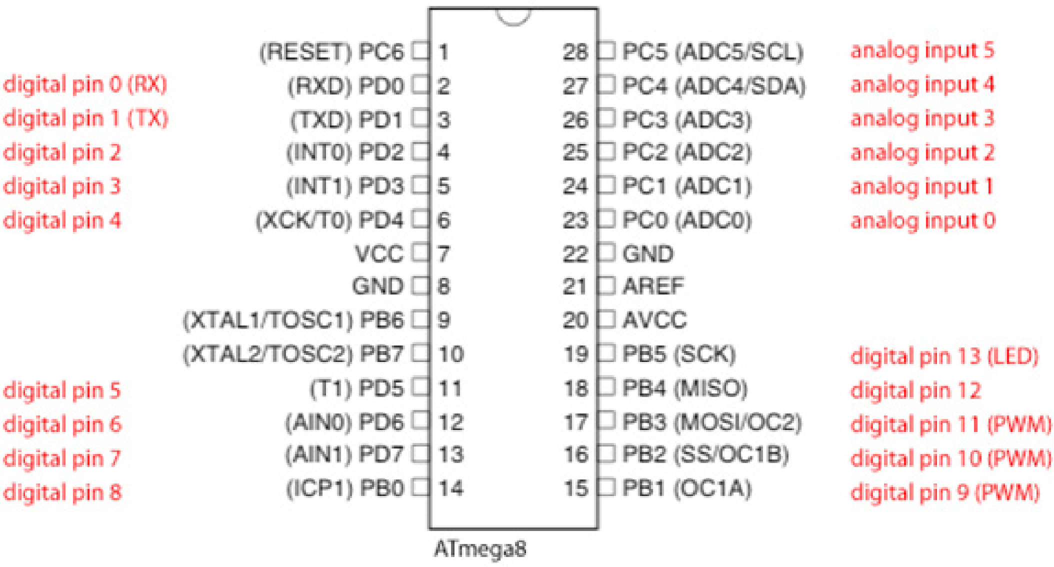


Figure 8.2: Arduino Pin Map

Technical Specifications:

Microcontroller:	ATmega328
Operating Voltage:	5V
Input Voltage (recommended):	7-12V
Input Voltage (limits):	6-20V
Digital I/O Pins:	14 (of which 6 provide PWM output)
Analog Input Pins:	6
DC Current per I/O Pin:	40 mA
DC Current for 3.3V Pin:	50 mA
Flash Memory:	32 KB of which 0.5 KB used by bootloader
SRAM:	2 KB
EEPROM:	1 KB
Clock Speed:	16 MHz

The power pins are as follows:

- **VIN:** The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.

- **5V:** The regulated power supply used to power the microcontroller and other components on the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated 5V supply.

- **3V3:** A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.

- **GND:** Ground pins.

Motor Shield

The Arduino Motor Shield is based on the L298 (datasheet), which is a dual full-bridge driver designed to drive inductive loads such as relays, solenoids, DC and stepping motors. It lets you drive two DC motors with your Arduino board, controlling the speed and direction of each one independently.

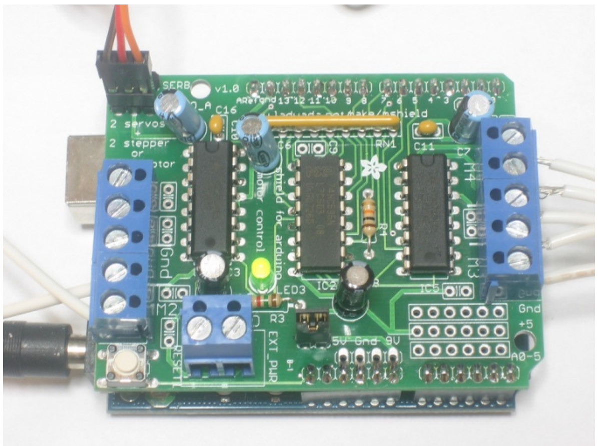


Figure 8.3: Arduino Motor Shield

Motor Shield Configurations are:

The Motor shield can be powered directly from Arduino or from external power source. It is strongly recommended to use external power supply to power the motor shield.

- Logic Control Voltage：5V (From Arduino)
- Motor Driven Voltage：4.8～35V (From Arduino or External Power Source)
- Logic supply current (Iss) ≤36mA
- Motor Driven current Io：≤2A
- Maximum power consumption：25W（T=75℃）
- PWM、PLL Speed control mode

- Control signal level:

  High：2.3V≤Vin≤5V

  Low：-0.3V≤Vin≤1.5V

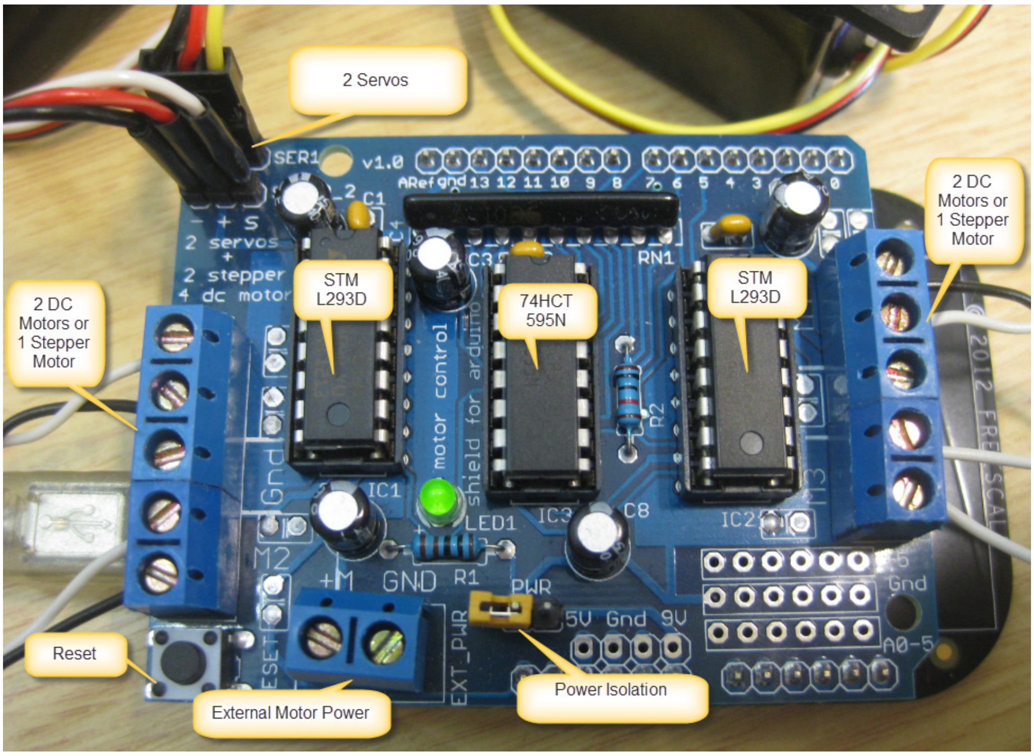


Figure 8.4: Motor Shield

Motor Shield is connected to Arduino through Pins present on the Motor Shield. Motor Shield is used to control two or more motors from Arduino. Figure shows the connections for the motor shield used for the Arduino.

Arduino Motor Shield can power up to two stepper motors and two servo motors. External power supply of 12 V or 9 V can be used to power motor shield by removing the jumper (Power Isolation).

In our system, we have used stepper motor to be driven by Motor shield and an AC to DC adaptor of configuration 220 V to 12 V DC is used having current value of 1 mA.

Controlling Motors

There are number of motor types that can be driven by Arduino directly or by other driver ICs. Considering a motor, it shows attributes such as speed, direction of rotation, etc. Software control over these factors is greatly considered in real life applications.

1. RC servo
2. DC motors controlled by a H-bridge
3. Stepper motor

Therefore the basic outline is once a shield with supporting hardware for the motors is connected, a simple program written for Arduino could drive them while communication with a computer could control over their attributes.

A simple terminal program can be used to control the direction, speed and the braking of the motor. The possible motor controls with the INPUT pins are as follows.

INPUT 1	INPUT 2	Result
1	0	Clockwise rotation
0	1	Anti-clockwise rotation
1	1	Brake [1*]
0	0	Free run [2*]

1* Brake- Motor comes to a sudden stop

2* Free run- Motor free runs to stop

8.2 METAL SENSOR

This metal sensor can be used to detect metallic objects. It uses a sensing Coil. This Coil should be kept near metallic objects for detection. Input of Circuit is a weak colpitt's R.F. range Oscillator. Sensing coil forms parts of tuned Oscillator. [17]

When coil is brought near a metallic object magnetic energy is absorbed and Oscillator falls to work. Then final transistor conducts and LED is activated. 9 volts battery is used. After connecting battery, the 4.7K preset is adjusted till LED just stops glowing.

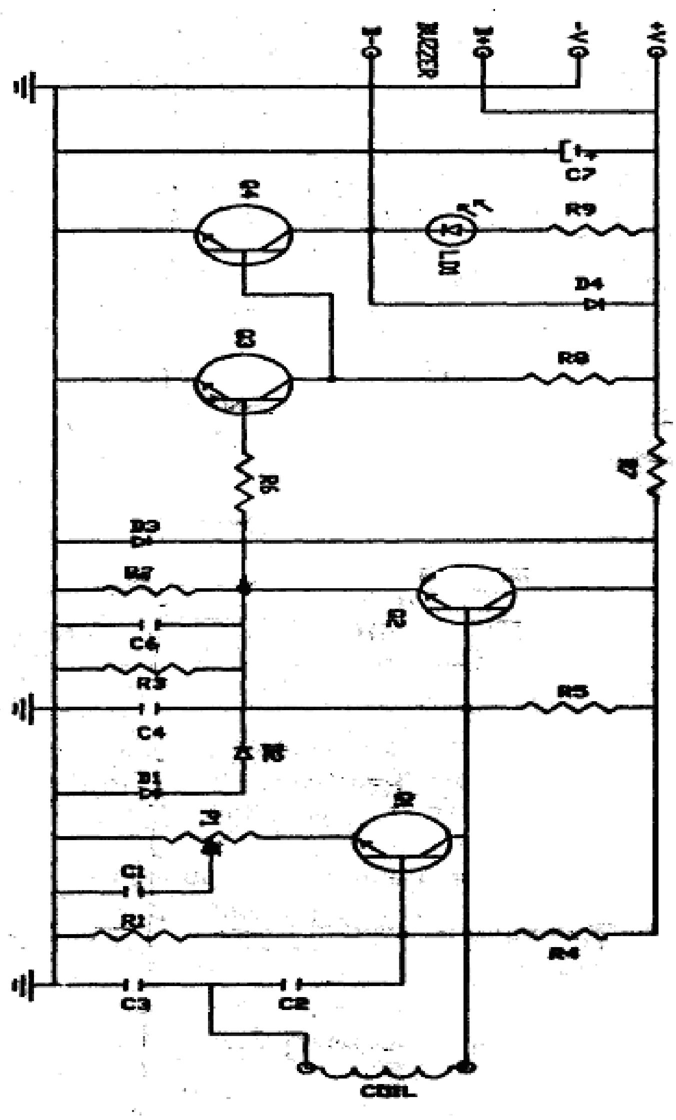


Figure 8.5: Metal detector circuit

CHAPTER - 9

Software Module and Sorting Algorithm

9.1 STEPS SEQUENCE

The logical sequence of steps for the image processing algorithm is as follows -

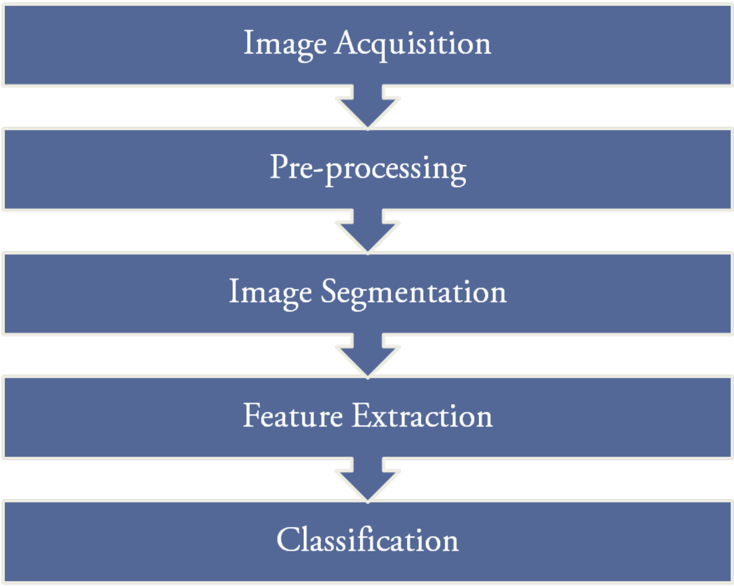


Figure 9.1 Flowchart of Image Processing

9.2 IMAGE ACQUISITION

For development of a vision system, image acquisition is the first and one of the most important step to be taken care of. Any deficiency of the initial image can cause a major problem while processing and analyzing the image. Hardware equipment carries a very important role to acquire image with sufficient contrast and sharp focusing. However in this project, an ordinary low-end webcam has been used as an image acquisition device so that focus is more on the software framework.

Using MATLAB's Image Acquisition Toolbox Version 4.5 following properties for the live video source from the webcam are set -

Device Specific Properties:

BacklightCompensation = on
Brightness = 180
Contrast = 90
Exposure = -6

ExposureMode = manual
FrameRate = 30.0000
Gain = 64
HorizontalFlip = off
Pan = 0
Saturation = 50
Sharpness = 24
Tilt = 0
VerticalFlip = off
WhiteBalance = 4000
WhiteBalanceMode = auto
Zoom = 0

Figure 9.2: Acquired Image

9.3 IMAGE PRE PROCESING MODULE

After the image has been captured from the first stage, each image will go through the pre-processing stage to eliminate noise inside the image, to enhance the result of the output. Imaging sensors including camera-like devices, rarely have evenly illuminated image. Even in the absence of vignetting (this causes off-axis rays to be lost by collision with the lens mount at large apertures - typically f/2 or greater) image brightness falls off rapidly away from the axis of the imaging lens. [1][2]

The steps involved in pre-processing are -

- Background Subtraction
- Conversion to Grayscale
- Filtering

9.3.1 Background Subtraction

Background subtraction is a process of extracting foreground objects in a particular scene. A foreground object can be described as an object of attention which helps in reducing the amount of data to be processed. Here Fig. 9.3 shows the image after background subtraction of nuts and bolts.

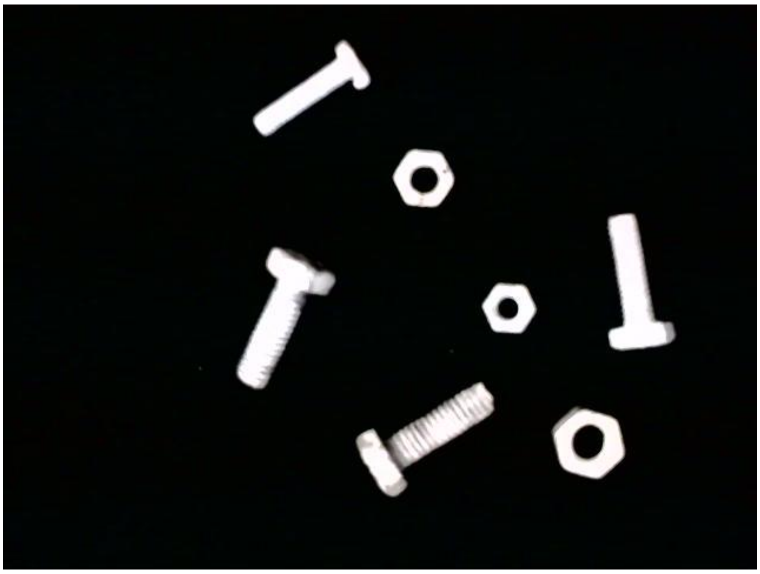


Figure 9.3: Image after background subtraction

9.3.2 Conversion to Grayscale

The input image acquired from camera is in RGB format. In RGB colormap, an image is represented with three matrices of sizes matching the image format. The three matrices in each image corresponds to one of the colours red, green and blue and also says that of how much of each of these colours a certain pixel should use.

Gray scale images have the only colour which is a shade of only gray in between. Monochromatic is another name of gray image, denoting the presence of only one (mono) colour (chrome). To convert any colour to a gray scale representation of its luminance, we must obtain the values of its red, green, and blue (RGB) primaries in linear intensity encoding, by gamma expansion.

MATLAB function *I = rgb2gray(RGB)* converts RGB values to grayscale values by forming a weighted sum of the R, G, and B components: [7]

$$0.2989 * R + 0.5870 * G + 0.1140 * B$$

9.3.3 Filtering

The purpose of smoothing is to reduce noise and improve the visual quality of the image. Often, smoothing is referred to as filtering. Here filtering is carried out by median filter since it is very useful in preserving edges. The best known order-statistics filter is the median filter, which replaces the value of a pixel by the median of the gray levels in the neighborhood of that pixel-

$$\hat{f}(x,y) = \underset{(s,t)\in S_{xy}}{\text{median}} \{g(s,t)\}$$

The original value of the pixel is included in the computation of the median. Median filters are quite popular because, for certain types of random noise they provide excellent noise reduction capabilities, with considerably less blurring than linear smoothing filters of similar size. The median value is not affected by the actual value of the noise cells. The Median filter is particularly good at removing isolated random noise and also preserves edges and line features better than the Low Pass / Average filter, but does produce some blurring. [3]

9.4 IMAGE SEGMENTATION

Image segmentation is the fundamental step to analyze images and extract data from them. Image segmentation is a mid-level processing technique used to analyze the image and can be defined as a processing technique used to classify or cluster an image into several disjoint parts by grouping the pixels to form a region of homogeneity based on the pixel characteristics like gray level, color, texture, intensity and other features. The main purpose of the segmentation process is to get more information in the region of interest in an image which helps in annotation of the object scene.

For this project, we have used intensity based segmentation method, also called as **thresholding,** to segment the pre-processed images of nuts and bolts.

9.4.1 Thresholding

Threshold based segmentation technique classifies the image into two classes and works on the postulate that pixels belonging to certain range of intensity values represents one class and the rest of the pixels in the image represents the other class. The pixels that pass the threshold test are considered as object pixel and are assigned the binary value “1” and other pixels are assigned binary value “0” and treated as background pixels. [9]

$$g(x,y) = \begin{cases} 1 & for\ i(x,y)\ \geq t \\ 0 & for\ i(x,y) < t \end{cases}$$

where g(x,y) is the output image; i(x,y) is the input image and t is the threshold value.

Of the available techniques for threshold based segmentation, threshold selection based on the histograms suggested by Nobuyuki Otsu in 1979 is used with minor modifications.[9]

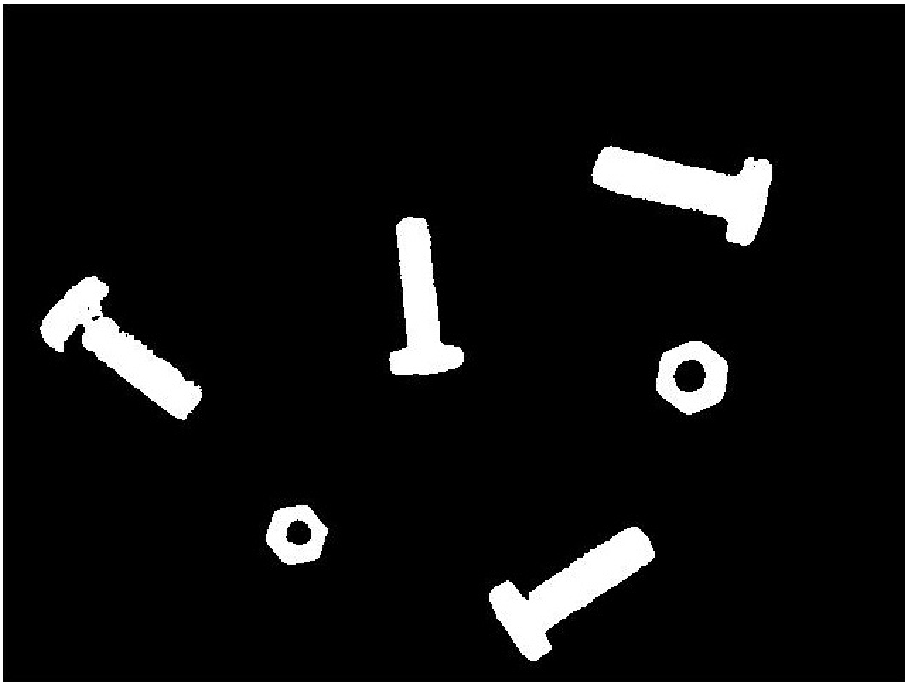


Figure 9.4: Image after thresholding

9.4.2 Morphological Operations

The basic principle of mathematical morphology is the extraction of geometrical and topological information from an unknown set (an image) through transformations using another, well-defined, set known as *structuring element*.[7]

Morphological Opening

The morphological opening of set A by B, represented as $A \circ B$, is the erosion of A *by* B followed by the dilation of the result by B.

Mathematically

$$A \circ B = (A \ominus B) \oplus B$$

where B is the structural element.

Morphological Closing

The morphological closing of set A by B, represented as $A \bullet B$, is the dilation of A by B followed by the erosion of the result by B.

Mathematically,

$$A \bullet B = (A \oplus B) \ominus B$$

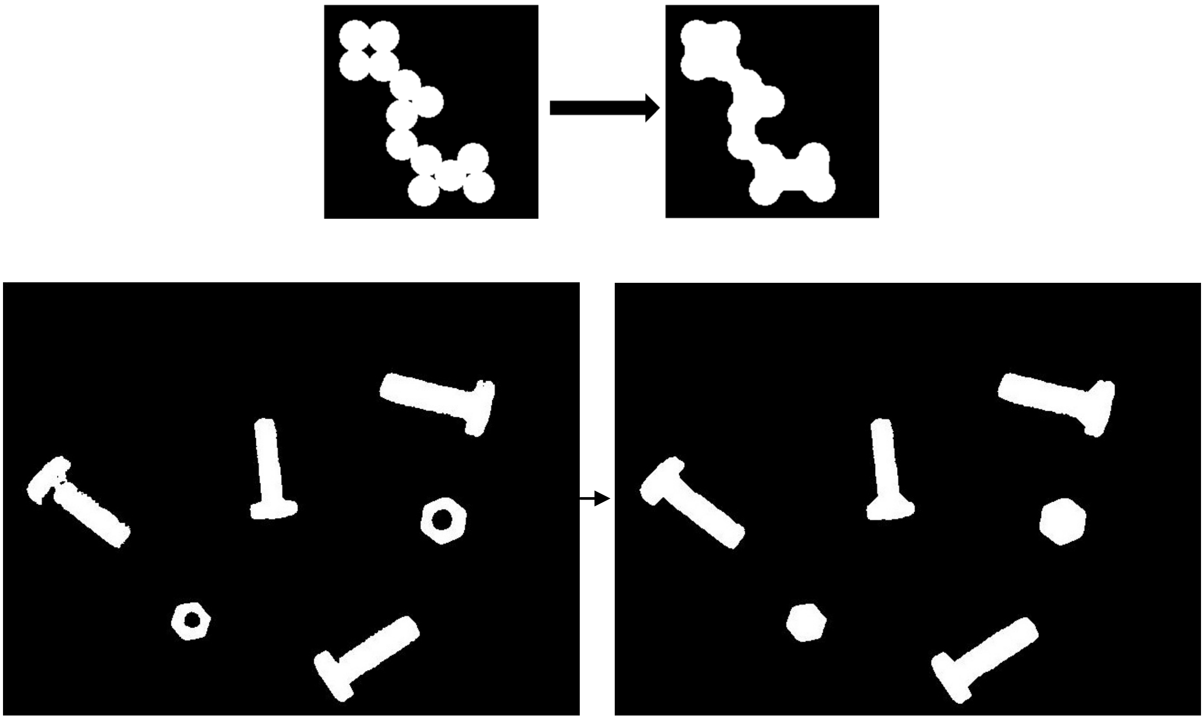


Figure 9.5: Morphological Operations

9.5 FEATURE EXTRACTION

The goal of feature extraction technique is to convert the segmented objects into representations that better describe their main features and attributes. Feature extraction is the process by which certain features of interest within an image are detected and represented for further processing. It is a critical step in most computer vision and image processing solutions because it marks the transition from pictorial to non pictorial (alphanumerical, usually quantitative) data representation. The resulting representation can be subsequently used as an input to a number of pattern recognition and classification techniques, which will then label, classify, or recognize the semantic contents of the image or its objects.

Invariance and Robustness [6]

A common requirement for feature extraction and representation techniques is that the features used to represent an image be invariant to rotation, scaling, and translation, collectively known as *RST*. RST invariance ensures that a machine vision system will still be able to recognize objects even when they appear at different size, position within the image, and angle (relative to a horizontal reference).

Binary Object Features [7]

A binary object, in this case, is a connected region within a binary image $f(x, y)$, which will be denoted as O_i, $i > 0$.

Mathematically, we can define a function $O_i(x, y)$ as follows:

$$O_i(x, y) = \begin{cases} 1 & \text{if } f(x, y) \in O_i \\ 0 & \text{otherwise} \end{cases}$$

Area [7]

The area of the *i*th object O_i, measured in pixels, is given by

$$A_i = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} O_i(x, y)$$

Perimeter [7]

The perimeter of a binary object O_i can be calculated by counting the number of object pixels (whose value is 1) that have one or more background pixels (whose value is 0) as their neighbours. An alternative method consists in first extracting the edge (contour) of the object and then counting the number of pixels in the resulting border. Due to some inevitable imperfections in the digitization process (e.g., jagged curve outlines and serrated edges), the value of perimeter computed using either method is not 100% accurate; it has been suggested [Umb05] that those values should be multiplied by $\pi/4$ for better accuracy.

Thinness Ratio or Roundness

The thinness ratio *Ti* of a binary object *Oi* is a figure of merit that relates the object's area and its perimeter by equation: [7]

$$T_i = \frac{4\pi A_i}{P_i^2}$$

where *Ai* is the area and *Pi* is the perimeter.

This ratio tells how close a shape is to a perfect circle.[13] A perfectly round shape will have $T_i = 1$ (in our case washer). Range of T_i is between 0 and 1 and the different values obtained for each nut, bolt and washer helps us group them together and classify accordingly.

The roundness values obtained for different specimens are shown in Fig 9.6 and Fig 9.7 -

Typically for bolts T_i ranges between 0.1 for low diameter : height ratio to about 0.4 for high diameter : height ratio.

Washers being completely circular, have a roundness ratio ranging between 0.95 and 1.

Nuts, being hexagonal, typically have their roundness ratio less than 0.9 but greater than 0.7.

According to these observations, the following classification scheme is proposed :

- If $T \geq 0.95$, object is a *washer*.
- If $0.70 \leq T < 0.95$, object is a *nut*.
- If $T < 0.70$, object is a *bolt.*

Following figures show the calculated roundness values for the nuts and bolts used in the project.

Figure 9.6: Roundness ratios for bolts

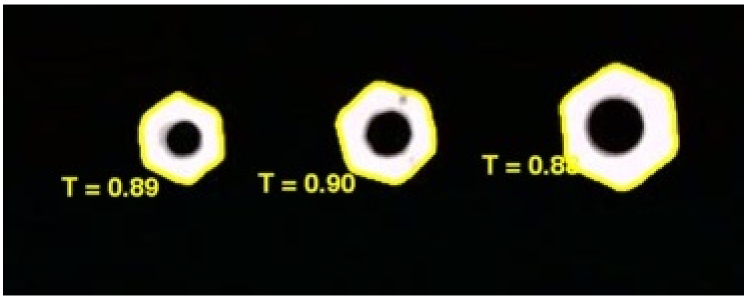


Figure 9.7: Roundness ratios for nuts

Measurement of Nominal Diameter, d

Once the object has been classified as nut or bolt, next step is to measure the nominal diameter.

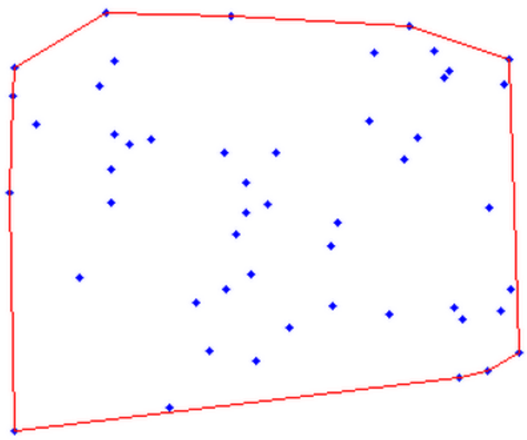
- For bolts, this is done by measuring the "width across corners" of bolt head from the top view of the image and dividing it by 2 to obtain the nominal diameter.
- For nuts, nominal diameter is calculated by measuring the "width across flats" or the chamfer circle diameter from the top view image and dividing it by 1.732 to obtain the nominal diameter.
- For washers, the outer circle diameter is measured from the top view image and matched with the corresponding nominal bolt diameter from the ISO standards table. (Section 2.7)

Measurement of object features

The technique used to measure these features is common for all 3 types of fasteners. We first find out the minimal bounding rectangle which completely surrounds the object of interest and compute it's corresponding height and width.

a) Convex Hull [7]

The convex hull of a set of points in N-D space is the smallest convex region enclosing all points in the set. In our case, we obtain a 2D convex hull using the *convhull* function in MATLAB, with input being the set of all boundary points (x, y) of the object of interest.



b) Minimal Bounding Rectangle [10]

In this approach, we assume that the minimum bounding rectangle must have one (or more) edges parallel to one of the edges of the convex hull. We check every edge of the convex hull, effectively spreading a pair of callipers around the object at that angle. One chooses that edge which produces the minimum area from all the possible rectangles. This scheme will generally be a quite efficient one, since most of the time a convex hull is composed of relatively few edges. Even in the rare event where every single point supplied is also found to be a part of the convex hull itself, the rectangle computation is fast enough to be efficient.

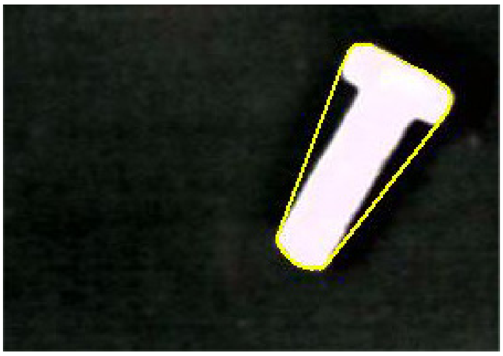


Figure 9.8: Convex Hull

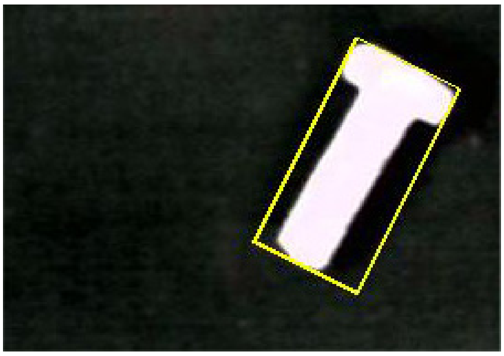


Figure 9.9: Minimal Bounding Rectangle

In the above figure, convex hull and minimum bounding rectangle methods are compared for bolts. Although, convex hull more closely approximates the convex shape of the object, minimal bounding rectangle approximation is more suitable because it gives us a direct and simple measure of width of the rectangle which is simply twice the nominal diameter, also known as **width across corners** (denoted by *e*) .

For the nut, we find out the minimum of the two lengths of rectangle and that length is said to be **width across flats** (denoted by *s*) which is 1.732 times the nominal diameter.

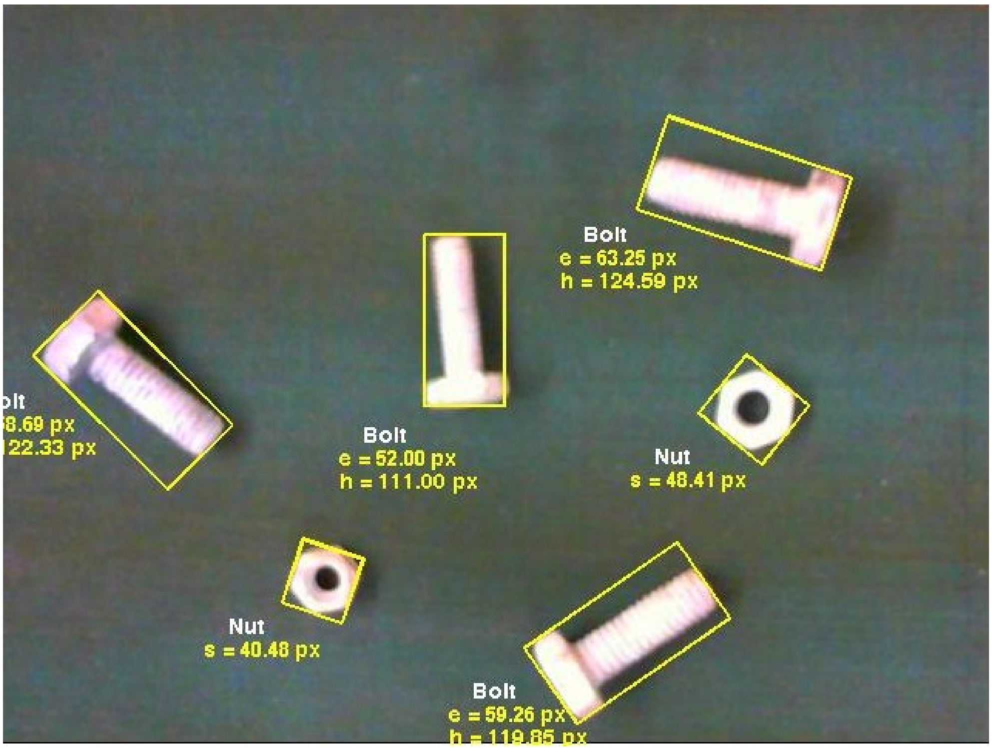


Figure 9.10: Minimal Bounding Rectangle for nuts and bolts

Calibration Factor

The pixel measurement obtained needs to be converted to its corresponding real world value. For this, we experimentally find out the calibration factor (see Chapter 11) which when multiplied with the mm value directly gives the measurement in pixels. [7]

$$Calibration\ factor\ = \frac{measurement\ from\ image\ (in\ pixels)}{actual\ or\ true\ measurement\ of\ object\ (in\ mm)}$$

9.6 CLASSIFICATION

Based on the feature measurements the following classification criteria is formulated and selected.

Roundness Ratio, T	**Object**	**Minimum width of MBR (in pixels)**	**Conclusion**
0 to 0.7	Bolt	≤ 47	Small Bolt
		> 47 and < 59	Medium Bolt
		≥ 59	Large Bolt
0.7 to 0.95	Nut	≤ 47	Small Nut
		> 47 and < 55	Medium Nut
		≥ 55	Large Nut
0.95 to 1	Washer		

Table 2: Classification Criteria

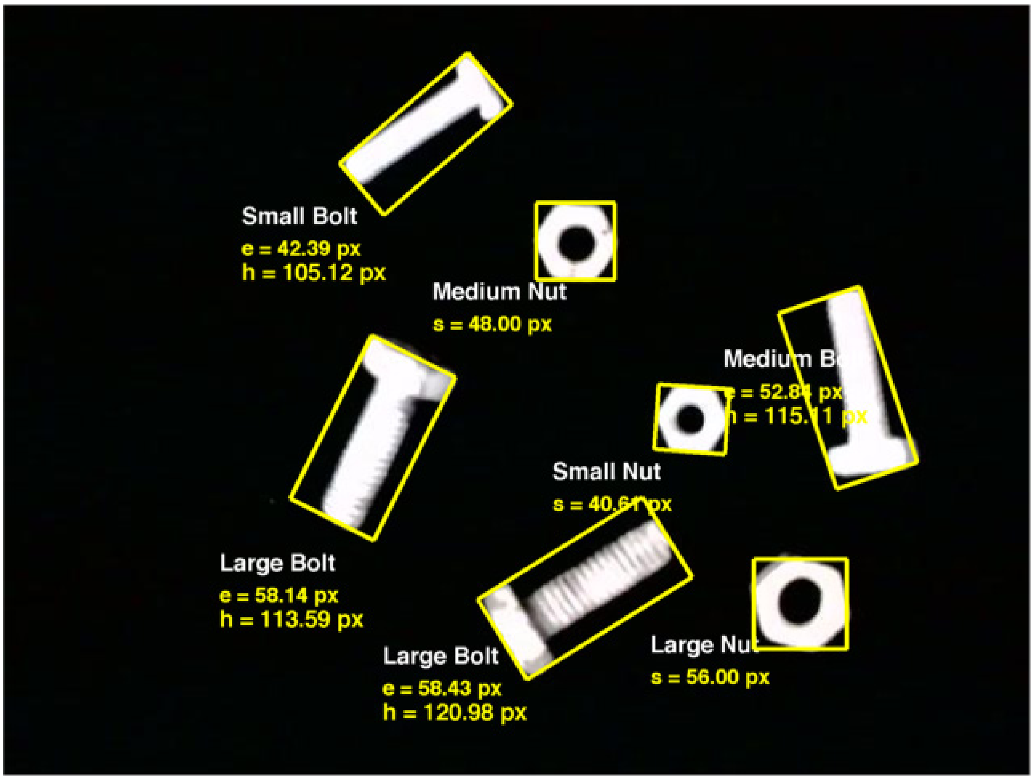


Figure 9.11: Results after Classification

e = width across corners
s = width across flats
h = height of bolt

CHAPTER - 10

Working of the System

10.1 COMPLETE CAD MODEL

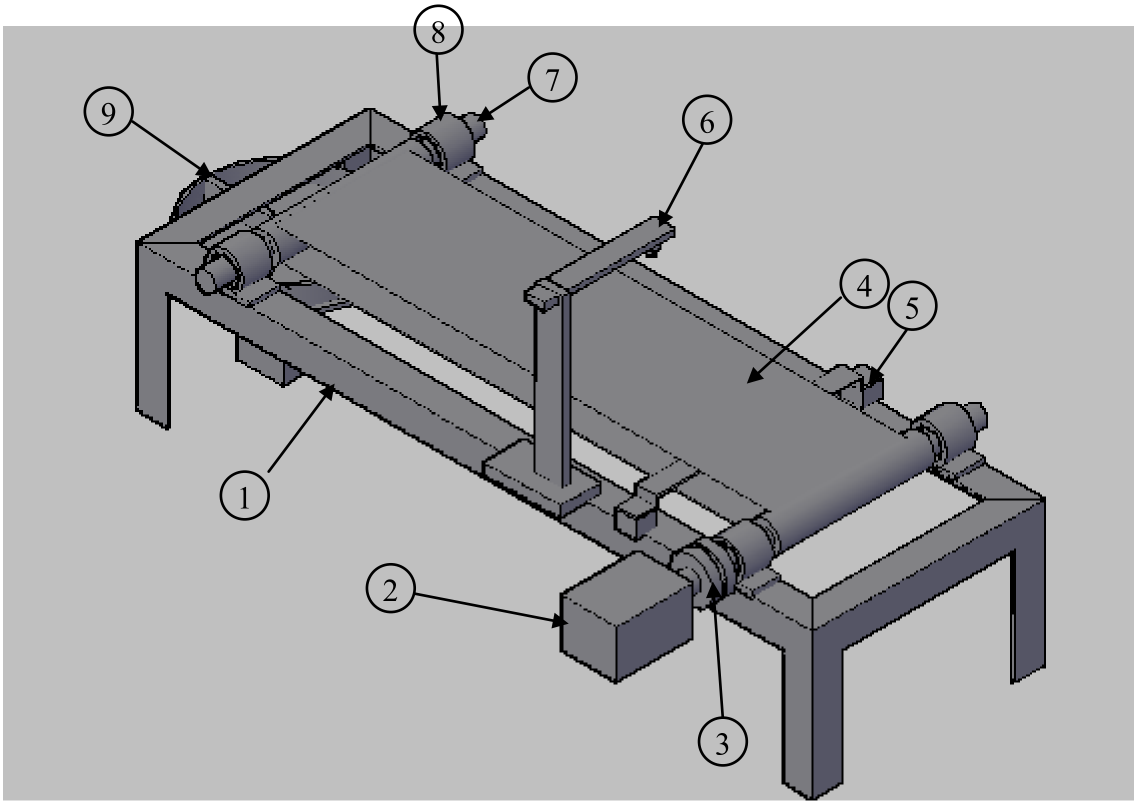


Figure 10.1 Complete CAD Model

1 - Frame

2 - DC geared motor

3 - Star Coupling

4 - Belt

5 - Metal Sensor

6 - Camera with stand

7 - Nylon shaft

8 - Bearing

9 - Sorting Disk

10.2 FLOW CHART

Entire flow of operation can be summarized in the flow chart below. For every batch, number of parts to be sorted is fixed at the start and the whole process thereafter forms a closed loop as shown. Once the batch is done, the observations are taken and calculations are performed (Chapter 11) to find out the **speed** of the proposed sorting system (in parts per min) and the **accuracy** percentage.

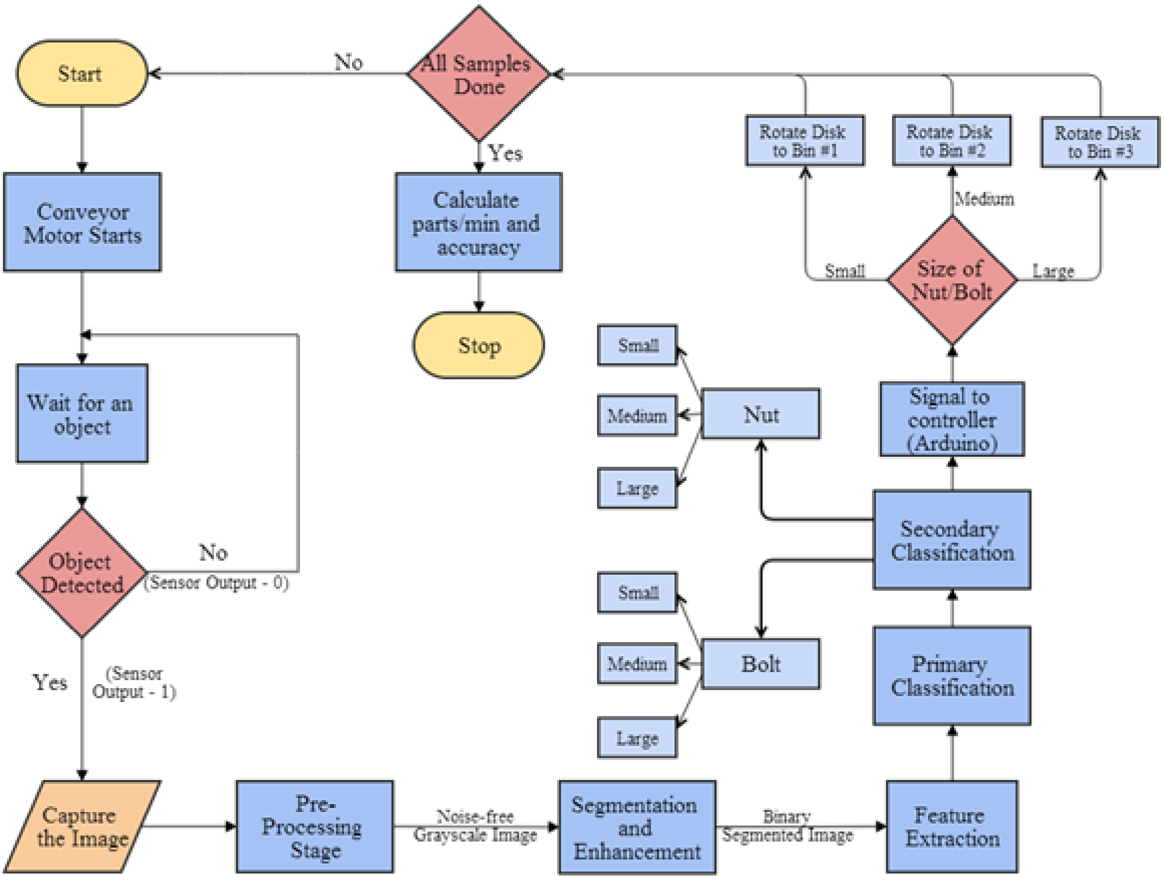


Figure 10.2 Flow Chart

10.3 SETUP PHOTOS

Images below show the working setup of our project with all the components installed and assembled.

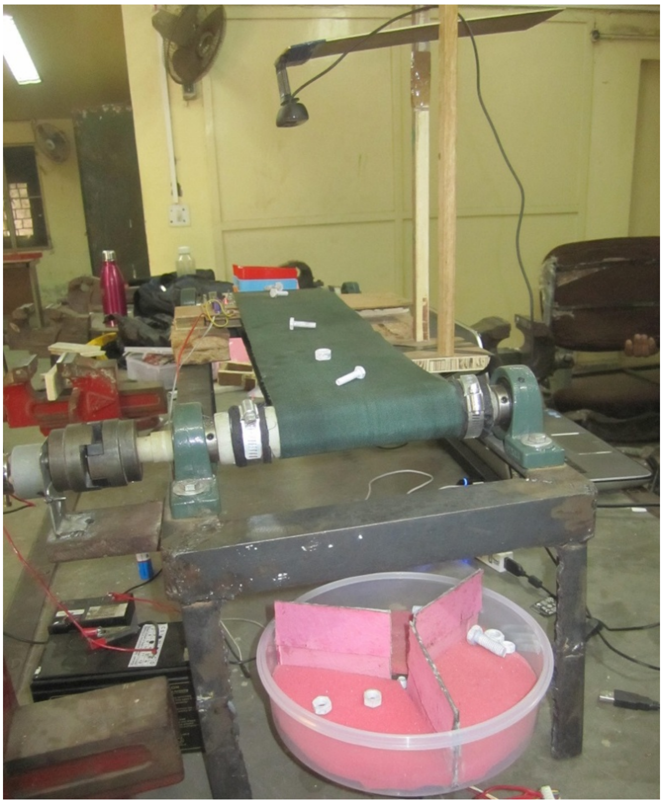


Figure 10.3 Actual Setup of the system

CHAPTER - 11

Calculations and Results

11.1 CALLIBRATION FACTOR

Calibration is done by measuring a known length using the proposed image processing algorithm and comparing it with real world measurements to calculate the calibration factor which has units pixel/mm. [7]

In this experiment we have chosen three different rectangles of known lengths as shown in figure.

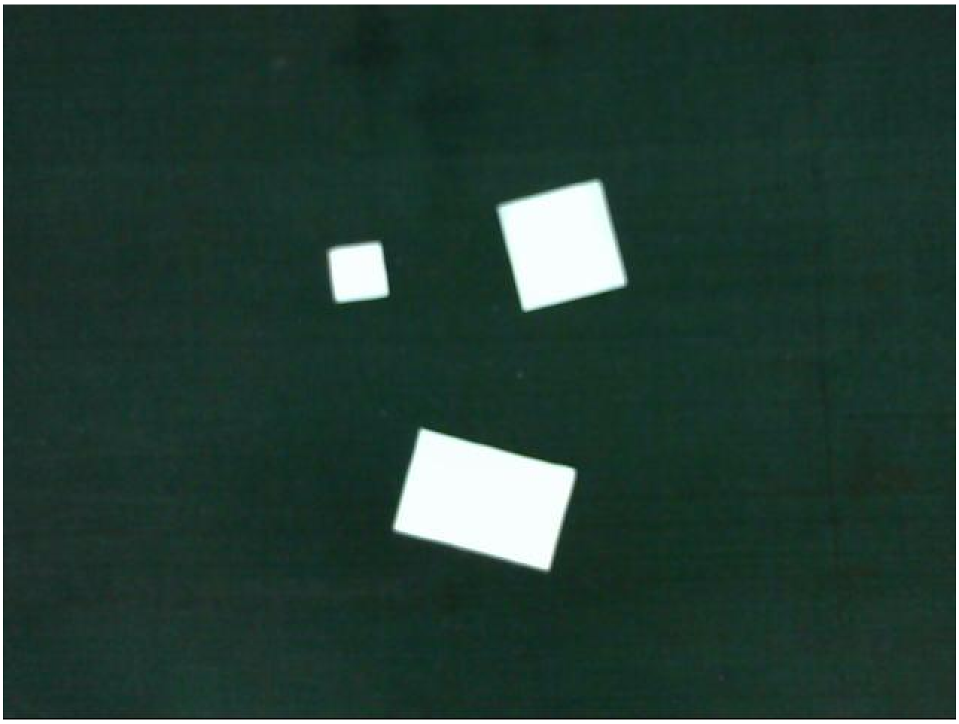


Figure 11.1: Rectangles of known lengths

Rectangle 1: 10 x 10 mm

Rectangle 2: 20 x 20 mm

Rectangle 3: 20 x 30 mm

The image processing algorithm discussed in Chapter 9 is now applied to the images of rectangles to find out the width, w and height, h of each rectangle. Figure shows the algorithm applied to one sample of each rectangle. Table summarizes calculation of calibration factor.

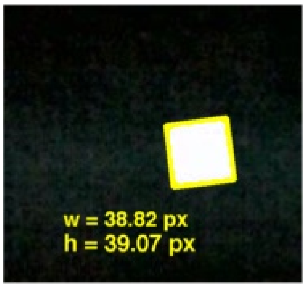


Figure 11.2: Rectangle 1

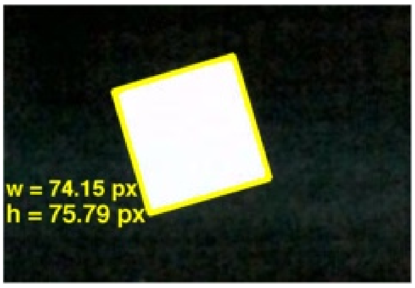


Figure11.3: Rectangle 2

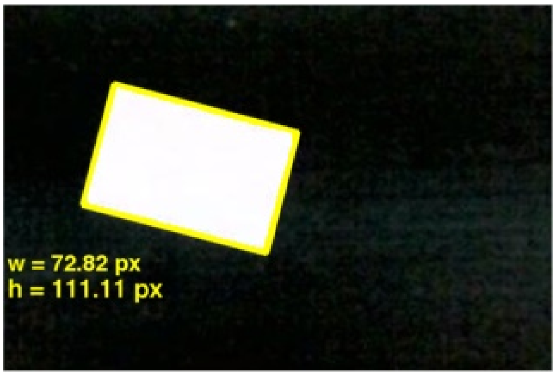


Figure11.3: Rectangle 3

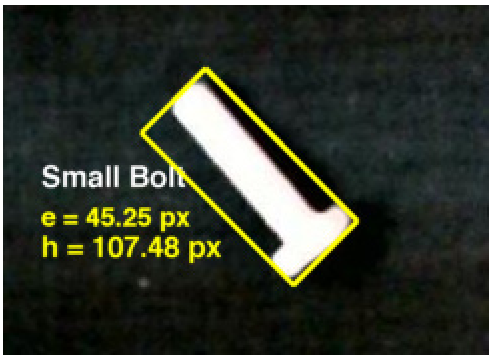
Actual Measurement (mm)	Measured w (px)	$C_{f,w}$ (px/mm)	Measured h (px)	$C_{f,h}$ (px/mm)	$C_{f,avg}$ (px/mm)
10 x 10 (Rectangle 1)	38.19	3.819	38.82	3.882	**3.851**
	38.07	3.807	38.80	3.880	**3.845**
	38.32	3.832	37.52	3.752	**3.792**
	38.32	3.832	38.81	3.881	**3.857**
20 x 20 (Rectangle 2)	74.05	3.7025	74.13	3.707	**3.705**
	73.33	3.667	73.93	3.697	**3.682**
	72.9	3.645	74.61	3.7305	**3.688**
	74.53	3.726	74.73	3.736	**3.7315**
20 x 30 (Rectangle 3)	74.88	3.744	108.78	3.626	**3.685**
	73.07	3.6535	110.30	3.676	**3.66475**
	73.56	3.678	111.51	3.717	**3.696**
	74	3.700	109.170	3.639	**3.6695**

Table 3: Calculation of calibration factor

Calibration factor, $C_f = \frac{\sum C_{f,avg}}{n} = \mathbf{3.7387}$

11.2 MEASUREMENT OF NOMINAL DIAMETER

11.2.1 Small nut and bolt



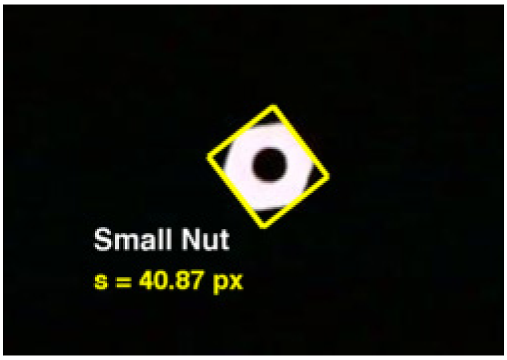


Figure 11.5 Small Nut and Bolt

A) Bolt

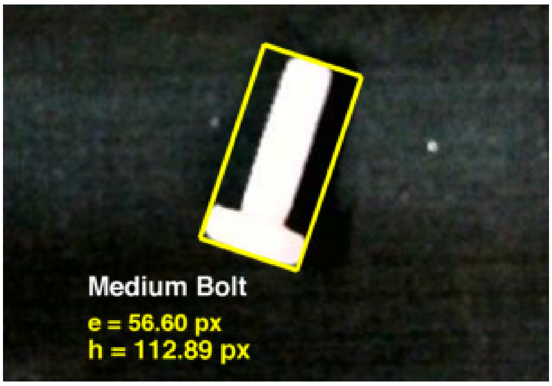
Actual Measurement (mm)			Measurement from Image (px)		Calculated (mm)	Error
d	**e**	**h**	**e′**	**h′**	$d' = \frac{e'}{2C_f}$	**|d′- d|**
6	12	30	45.25	107.48	6.052	0.052
			45.01	108.36	6.019	0.019
			45.25	109.37	6.052	0.052
			46.39	109.74	6.204	0.204
			45.00	108.60	6.018	0.018
			45.62	108.67	6.102	0.102

B) Nut

Actual Measurement (mm)		Measurement from Image (px)	Calculated (mm)	Error (mm)
d	**s**	**s′**	$d' = \frac{s'}{1.732C_f}$	**|d′- d|**
6	10.39	40.87	6.311	0.311
		40.00	6.177	0.177
		41.00	6.332	0.332
		40.63	6.275	0.275
		41.20	6.362	0.362
		40.00	6.177	0.177

Table 4: Dimensions of small nut and bolt

11.2.2 Medium Nut and Bolt



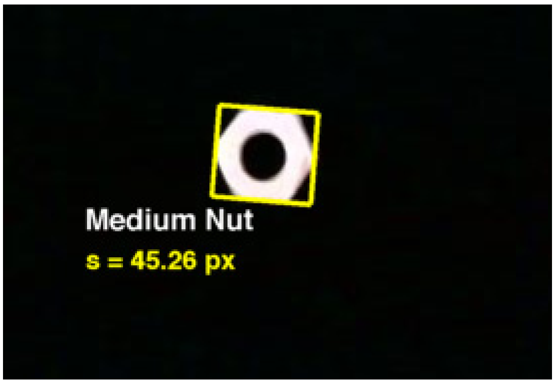


Figure 11.6 Medium Nut and Bolt

A) Bolt

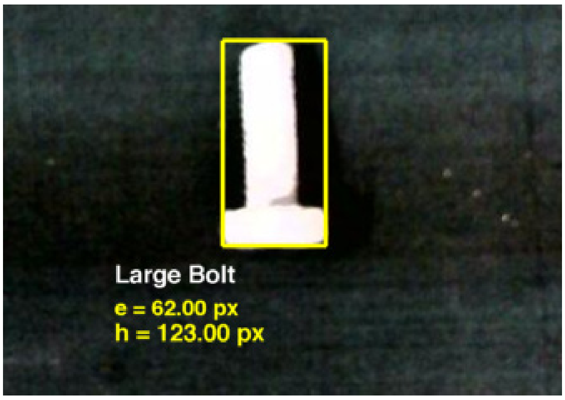
Actual Measurement (mm)			Measurement from Image (px)		Calculated (mm)	Error
d	**e**	**h**	**e′**	**h′**	$d' = \frac{e'}{2C_f}$	**|d′- d|**
8	16	30	55.86	115.26	7.471	0.529
			55.97	117.10	6.485	0.514
			57.13	115.16	7.640	0.360
			56.10	118.29	7.502	0.498
			56.32	113.60	7.530	0.470
			56.60	112.90	7.435	0.430

B) Nut

Actual Measurement (mm)		Measurement from Image (px)	Calculated (mm)	Error (mm)
d	**s**	**s′**	$d' = \frac{s'}{1.625C_f}$	**|d′- d|**
8	13	45.34	7.460	0.537
		45.25	7.448	0.552
		46.34	7.627	0.373
		46.12	7.591	0.409
		41.20	7.466	0.534

Table 5: Dimensions of medium nut and bolt

11.2.3 Large nut and bolt



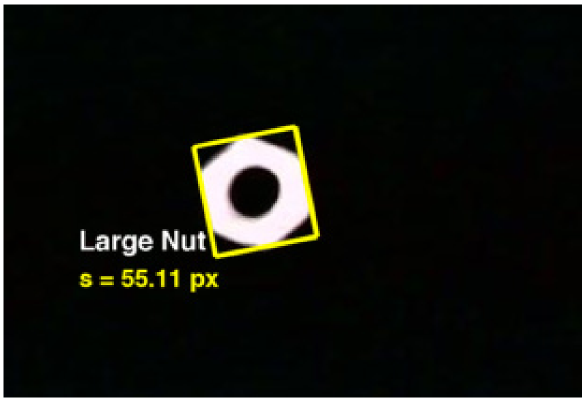


Figure 11.7 Large nut and bolt

A) Bolt

Actual Measurement (mm)			**Measurement from Image (px)**		**Calculated (mm)**	**Error**
d	**e**	**h**	$\mathbf{e'}$	$\mathbf{h'}$	$d' = \dfrac{e'}{1.8C_f}$	$\|d' - d\|$
10	18	32	64.24	123.70	9.55	0.450
			63.91	123.21	9.49	0.510
			64.31	121.94	9.56	0.440
			62.00	123.00	9.21	0.790
			65.14	124.41	9.68	0.320
			65.10	120.24	9.67	0.330

B) Nut

Actual Measurement (mm)		**Measurement from Image (px)**	**Calculated (mm)**	**Error (mm)**
d	**s**	$\mathbf{s'}$	$d' = \dfrac{s'}{1.55C_f}$	$\|d' - d\|$
10	15.5	55.00	9.490	0.510
		54.62	9.425	0.575
		55.86	9.640	0.360
		56.01	9.670	0.330
		56.23	9.703	0.297

Table 6: Dimensions of large nut and bolt

11.3 PARTS PER MINUTE

Time for 1 part to traverse the belt = 11 to 12 seconds

At all times it was made sure there were at most two parts at a time on the belt to obtain minimum sorting speed. 5 batches of 10 parts each were prepared and respective times of completion were notes using a stopwatch. Table below summarizes the same.

Batch #	**No. of Parts**	**Time Taken (seconds)**
1	10	101
2	10	99
3	10	95
4	10	110
5	10	105

Table 7: Parts per min

Total time taken for 50 parts = 101 + 99 + 95 +110 + 105 = 510 seconds

In 60 seconds, number of parts sorted = 50/510 x 60 = 5.88 = 6 parts (aprox.)

11.4 ACCURACY

Accuracy of the system is measured on the basis of number of parts which are classified and sorted correctly. Some of the factors directly or indirectly affecting the accuracy of the system are -

1. Efficiency of image processing algorithm - This includes the efficiency of minimum bounding method and segmentation algorithm accuracy.
2. Lightning conditions and exposure.
3. Calibration Accuracy - Any error in calculation of calibration factor directly affects the overall accuracy. Also the height between camera position and the belt surface must be fixed at all times to maintain the same calibration factor.

4. Sensor accuracy - If sensor fails to detect a part, no image acquisition and hence processing takes place.
5. Precise control of stepper motor.
6. Uniform conveyor belt speed.
7. Fixed distance between sensor, camera and sorting disk at all times.
8. Errors in actual dimensions of parts.

11.4.1 Accuracy calculation

Batch #	No. of Parts	Parts correctly sorted
1	10	8
2	10	10
3	10	8
4	10	7
5	10	9

Table 8: Accuracy

Total Parts sorted = 50

No. of parts correctly sorted = 8 + 10 + 8 + 7 + 9 = 42

Accuracy = 42/50 x 100 = 84%

11.5 RESULTS

Parts per minute sorted = 6

Accuracy of parts sorted = 84

CHAPTER - 12

Conclusions

12.1 ADVANTAGES OF THE SYSTEM

1. The parts can be kept in any orientation and at any position on the conveyor belt.
2. The system can be used as a measurement system to measure certain features of objects in applications where physical contact is not possible, difficult or monotonous.
3. Feeding rate does not need to be constant as the processing initiates only when sensors detects the part. Feeding can be done both by automated means or by hand as per requirements.
4. The conveyor does not stop anywhere during the whole batch operation. This ensures continuous workflow, no braking load on conveyor motor and better efficiency.
5. The entire sorting apparatus is distinct from the conveyor setup . The system does not use common sorting apparatus like sorting arms or push plungers on sides of conveyor belt which saves a lot of space.
6. The system can be adjusted for sorting components based on shape and color as well. This is possible with minor changes in the main computer program without changing the hardware components
7. The system does not use any mechanical or pneumatic arms which helps us save space, extra circuitry, setting delays and power requirements. No extra collection boxes are required as components are collected within compartments of the rotary disc.
8. The system is low cost, light in weight, and can be fully operated on batteries so that the system can be portable and assembled over wherever its working is required.
9. The system utilizes image processing technique which uses a low cost camera instead of pneumatic or mechanical systems, which makes the system more rugged and fine differences in components can be easily and exactly pointed out.

12.2 LIMITATIONS OF THE SYSTEM

1. The system can fail completely if one component comes into field of sensor while another is already there in the field of camera or sensor.

2. The belt in the conveyor system tends to have a variable speed due to slip which can disturb the flow and execution of entire operation.

3. The system is susceptible to light conditions of operating region. The amount and direction of light source tends to increase or decrease the accuracy of the system due to changes in the clarity of the snapshot of component.

4. Only metallic components can be sorted as we have installed metal detector sensor.

5. The camera once installed cannot be disturbed in any way which might result in change in its height with respect to belt surface. This will result in error in the calculated calibration factor which will directly affect the accuracy of the system.

6. Small electronic circuitry is involved which can create cluttering at the time of assembly.

7. The human visual inspection method is still a faster approach despite the aspect of monotony.

8. The minimal bounding rectangle method does not always give accurate results. This method is based on convex hull method which only finds convex boundaries of objects. So, in the case of concave cross sections (in bolts especially), some error might creep in.

9. The quality and resolution of camera affects the accuracy and effectiveness of the entire system.

12.3 FUTURE PROSPECTS

1. The accuracy of the system can be improved tremendously with proper, uniform and maintained light conditions for industry application.

2. The speed of the belt can be increased, but to have the same accuracy we need to install high resolution camera which reduces blurring due to high speed and identifies the component correctly.

3. Blurring at high speeds can also be reduced by reducing the exposure time to "freeze" the motion or by using flash strobe lamps.

4. The system can be made fully automatic by designing the appropriate feeder to feed the parts one at a time. A uniform parts/min feeder will also eliminate the need for a sensor and hence components of any material can be sorted.

5. The system can be modified to be used as a measurement system for applications where it is not possible or is difficult or monotonous to physically measure the component features. [12]

6. The system can be extended to include more sizes classification by reducing the incorporating more ranges.

7. Other fasteners like washers and square headed nuts and bolts can be also be included with minor changes.

8. System's accuracy can be improved by incorporating learning methods like neural networks or feedback control. [13]

APPENDIX 1

Cost Analysis

S.No.	***Component***	***Quantity***	***Amount (Rs.)***
1.	Angle Iron	12 Feet Length	510
2.	Bearing (with Bracket)	4	600
3.	Nylon Shaft	2.5 Feet Length, 40 mm Diameter	200
4.	Belt	6 Inches Wide, 57 Feet Length	300
5.	Nut, Bolts and Washers for Assembly and Mounting	20	40
6.	Nut and Bolts for Sorting Purpose	20	40
7.	DC Motor	1	225
8.	Coupling	1	75
9.	Stepper Motor	1	150
10.	Rotary Disc	1	80
11.	Arduino Controller	1	800
12.	Arduino Motor Shield	1	350
13.	Camera	1	550
14.	Metal Detector Sensor	1	500
15.	Wooden Stand for Camera and Sensor	2	200
16.	Battery	1	300
17.	Wires for Electrical Connections	5 Meters	150
18.	Terminal Clips	2	40
19.	Setup Cost	-	1200
20.	Miscellaneous Expenditure	-	1000

Total Estimated Cost = **Rs. 7,310**

APPENDIX 2

Minimal Bounding Rectangle Suite

(Matlab Script, given by John D'Errico)

```
function [rectx,recty,area,perimeter] = minboundrect(x,y,metric)
% minboundrect: Compute the minimal bounding rectangle of points in the
plane
% usage: [rectx,recty,area,perimeter] = minboundrect(x,y,metric)
%
% arguments: (input)
%  x,y - vectors of points, describing points in the plane as
%        (x,y) pairs. x and y must be the same lengths.
%
%  metric - (OPTIONAL) - single letter character flag which
%        denotes the use of minimal area or perimeter as the
%        metric to be minimized. metric may be either 'a' or 'p',
%        capitalization is ignored. Any other contraction of 'area'
%        or 'perimeter' is also accepted.
%
%        DEFAULT: 'a'    ('area')
%
% arguments: (output)
%  rectx,recty - 5x1 vectors of points that define the minimal
%        bounding rectangle.
%
%  area - (scalar) area of the minimal rect itself.
%
%  perimeter - (scalar) perimeter of the minimal rect as found

if (nargin<3) || isempty(metric)
  metric = 'a';
elseif ~ischar(metric)
  error 'metric must be a character flag if it is supplied.'
else
  % check for 'a' or 'p'
  metric = lower(metric(:)');
  ind = strmatch(metric,{'area','perimeter'});
  if isempty(ind)
    error 'metric does not match either ''area'' or ''perimeter'''
  end

  % just keep the first letter.
  metric = metric(1);
end

% preprocess data
x=x(:);
y=y(:);

% not many error checks to worry about
n = length(x);
if n~=length(y)
  error 'x and y must be the same sizes'
end

% start out with the convex hull of the points to
```

```
% reduce the problem dramatically. Note that any
% points in the interior of the convex hull are
% never needed, so we drop them.
if n>3
  edges = convhull(x,y);  % 'Pp' will silence the warnings

  % exclude those points inside the hull as not relevant
  % also sorts the points into their convex hull as a
  % closed polygon

  x = x(edges);
  y = y(edges);

  % probably fewer points now, unless the points are fully convex
  nedges = length(x) - 1;
elseif n>1
  % n must be 2 or 3
  nedges = n;
  x(end+1) = x(1);
  y(end+1) = y(1);
else
  % n must be 0 or 1
  nedges = n;
end

% now we must find the bounding rectangle of those
% that remain.

% special case small numbers of points. If we trip any
% of these cases, then we are done, so return.
switch nedges
  case 0
    % empty begets empty
    rectx = [];
    recty = [];
    area = [];
    perimeter = [];
    return
  case 1
    % with one point, the rect is simple.
    rectx = repmat(x,1,5);
    recty = repmat(y,1,5);
    area = 0;
    perimeter = 0;
    return
  case 2
    % only two points. also simple.
    rectx = x([1 2 2 1 1]);
    recty = y([1 2 2 1 1]);
    area = 0;
    perimeter = 2*sqrt(diff(x).^2 + diff(y).^2);
    return
end
% 3 or more points.

% will need a 2x2 rotation matrix through an angle theta
Rmat = @(theta) [cos(theta) sin(theta);-sin(theta) cos(theta)];

% get the angle of each edge of the hull polygon.
ind = 1:(length(x)-1);
```

```
edgeangles = atan2(y(ind+1) - y(ind),x(ind+1) - x(ind));
% move the angle into the first quadrant.
edgeangles = unique(mod(edgeangles,pi/2));

% now just check each edge of the hull
nang = length(edgeangles);
area = inf;
perimeter = inf;
met = inf;
xy = [x,y];
for i = 1:nang
  % rotate the data through -theta
  rot = Rmat(-edgeangles(i));
  xyr = xy*rot;
  xymin = min(xyr,[],1);
  xymax = max(xyr,[],1);

  % The area is simple, as is the perimeter
  A_i = prod(xymax - xymin);
  P_i = 2*sum(xymax-xymin);

  if metric=='a'
    M_i = A_i;
  else
    M_i = P_i;
  end

  % new metric value for the current interval. Is it better?
  if M_i<met
    % keep this one
    met = M_i;
    area = A_i;
    perimeter = P_i;

    rect = [xymin;[xymax(1),xymin(2)];xymax;[xymin(1),xymax(2)];xymin];
    rect = rect*rot';
    rectx = rect(:,1);
    recty = rect(:,2);
  end
end
% get the final rect

% all done

end % mainline end
```

APPENDIX 3

A) Dimensions of ISO metric hexagon head bolts

Nominal size (mm)	Pitch (mm)	Diameter of unthreaded shank (mm)				Width across flats (mm)		Width across corners (mm)		Height of head (mm)		Radius under head (mm)	
		Faced under head		Faced under head and turned on shank									
		max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.
M6	1	6.48	5.52	6.00	5.82	10.00	9.64	11.5	10.89	4.24	3.76	0.4	0.25
M8	1.25	8.58	7.42	8.00	7.78	13.00	12.57	15.0	14.20	5.74	5.26	0.8	0.4
M10	1.5	10.58	9.42	10.00	9.78	17.00	16.57	19.6	18.72	7.29	6.71	0.8	0.4
M12	1.75	12.70	11.30	12.00	11.73	19.00	18.48	21.9	20.88	8.29	7.71	1.25	0.6
M16	2	16.70	15.30	16.00	15.73	24.00	23.16	27.7	26.17	10.29	9.71	1.25	0.6
M20	2.5	20.84	19.16	20.00	19.67	30.00	29.16	34.6	32.95	13.35	12.65	1.78	0.8
M22	2.5	22.84	21.16	22.00	21.67	32.00	31.00	36.9	35.03	14.35	13.65	1.78	0.8
M24	3	24.84	23.16	24.00	23.67	36.00	35.00	41.6	39.55	15.35	14.65	1.78	0.8
M27	3	27.84	26.16	27.00	26.67	41.00	40.00	47.3	45.20	17.35	16.65	2.28	1.0
M30	3.5	30.84	29.16	30.00	29.67	46.00	45.00	53.1	50.85	19.42	18.58	2.28	1.0
M33	3.5	34.00	32.00	33.00	32.61	50.00	49.00	57.7	55.37	21.42	20.58	2.28	1.0
M36	4	37.00	35.00	36.00	35.61	55.00	53.80	63.5	60.79	23.42	22.58	2.7	1.0
M39	4	40.00	38.00	39.00	38.61	60.00	58.80	69.3	66.44	25.42	24.58	2.7	1.0
M42	4.5	43.00	41.00	42.00	41.61	65.00	63.80	75.1	72.09	26.42	25.58	2.8	1.2
M45	4.5	46.00	44.00	45.00	44.61	70.00	68.80	80.8	77.74	28.42	27.58	3.3	1.2
M48	5.0	49.00	47.00	48.00	47.61	75.00	73.80	86.6	83.39	30.42	29.58	3.8	1.6

M52	5.0	53.20	50.80	52.00	51.54	80.00	78.80	92.4	89.04	33.50	32.50	4.7	1.6
M56	5.5	57.20	54.80	56.00	55.54	85.00	83.60	98.1	94.47	35.50	34.50	4.9	2.0
M60	5.5	61.20	58.80	60.00	59.54	90.00	88.60	103.9	100.12	38.50	37.50	4.9	2.0
M64	6	65.20	62.80	64.00	63.54	95.00	93.60	109.7	105.77	40.50	39.50	4.9	2.0
M68	6	69.20	66.80	68.00	67.54	100.00	98.60	115.5	111.42	43.50	42.50	4.9	2.0

B) Dimensions of ISO metric hexagon nuts

Nominal size (mm)	Pitch of thread (mm)	Width across flats (mm)		Width across corners (mm)		Thickness of nut (Faced one side) (mm)		Thickness of thin nut (Faced both sides) (mm)	
		max.	min.	max.	min.	max.	min.	max.	min.
M5	0.8	8.00	7.64	9.20	8.63	4.0	3.52	—	—
M6	1	10.00	9.64	11.50	10.89	5.00	4.52	—	—
M8	1.25	13.00	12.57	15.00	14.20	6.50	5.92	5.00	4.52
M10	1.5	17.00	16.57	19.60	18.72	8.00	7.42	6.00	5.52
M12	1.75	19.00	18.48	21.90	20.88	10.00	9.42	7.00	6.42
M16	2	24.00	23.16	27.70	26.17	13.00	12.30	9.00	8.42
M20	2.5	30.00	29.16	34.60	32.95	16.00	15.30	9.00	8.42
M22	2.5	32.00	31.00	36.90	35.03	18.00	17.30	10.00	9.42
M24	3	36.00	35.00	41.60	39.55	19.00	18.16	10.00	9.42

M27	3	41.00	40.00	47.30	45.20	22.00	21.16	12.00	11.30
M30	3.5	46.00	45.00	53.10	50.85	24.00	23.16	12.00	11.30
M33	3.5	50.00	49.00	57.70	55.37	26.00	25.16	14.00	13.30
M36	4	55.00	53.80	63.50	60.79	29.00	28.16	14.00	13.30
M39	4	60.00	58.80	69.30	66.44	31.00	30.00	16.00	15.30
M42	4.5	65.00	63.80	75.10	72.09	34.00	33.00	16.00	15.30
M45	4.5	70.00	68.80	80.80	77.74	36.00	35.00	18.00	17.30
M48	5	75.00	73.80	86.60	83.39	38.00	37.00	18.00	17.30
M52	5	80.00	78.80	92.40	89.04	42.00	41.00	20.00	19.16
M56	5.5	85.00	83.60	98.10	94.47	45.00	44.00	—	—
M60	5.5	90.00	88.60	103.90	100.12	48.00	47.00	—	—
M64	6	95.00	93.60	109.70	105.77	51.00	49.80	—	—
M68	6	100.00	98.60	115.50	111.42	54.00	52.80	—	—

REFERENCES

[1] Akbar H. and Prabuwono A. S., "The design and development of automated visual inspection system for press part sorting," in *Proc. International Conference on Computer Science and Information Technology (ICCSIT'08)*, 2008, pp. 683-686.

[2] Akbar H. and Prabuwono A. S., "Webcam based system for press part industrial inspection," *International Journal of Computer Science and Network Security*, vol. 8, pp. 170-177, Oct. 2008.

[3] Akbar H., Prabuwono A. S., Izzah Z., and Tahir Z., "Image processing algorithm in machine vision approach for industrial inspection," in *Proc. the 1st Makassar International Conference on Electrical Engineering and Informatics (MICEEI'08)*, 2008, pp. 58-62.

[4] V. B. Bhandari. "Design of Machine Elements"

[5] Jindal U. C. "Machine Design" *Pearson Education India*, 2010, pp. 239-285.

[6] Ambarish Salodkar, M.M.Khanapurkar "Recognition of Bolt and Nut using Stationary Wavelet Transform". *International Conference on Emerging Frontiers in Technology for Rural Area (EFITRA) 2012 Proceedings published in International Journal of Computer Applications® (IJCA)*

[7] Oge Marques. "Practical Image and Video Processing using MATLAB", Wiley, 2011

[8] S. E. Umbaugh. *Computer Imaging: Digital Image Analysis and Processing*, CRC Press, Boca Raton, FL, 2005.

[9] A. M. Khan, Ravi. S. "Image Segmentation Methods: A Comparative Study", *International Journal of Soft Computing and Engineering (IJSCE),* Volume-3, Issue-4, September 2013.

[10] John R. D'Errico. "Minimal Bounding Shapes in 2 and 3 Dimensions", January 2007.

[11] Vishnu R. Kale, V. A. Kulkarni , "Object Sorting System using Rotary Disk" , International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, July 2013.

[12] A. AL-Marakeby, Ayman A. Aly, Farhan A. Salem, “Fast Quality Inspection of Food Products using Computer Vision” , International Journal of Advanced Research in Computer and Communication Engineering , November 2013.

[13] L.N. Wayne, The Automated Inspection of Moving Webs using Machine Vision, IEE Colloquium in Application of Machine Vision, 1995,

[14] David Mease, Vijayan N Nair, “Selective Assembly in Manufacturing”, Journal of Industrial Engineering, 2012.

[15] Binni Varghese, Fook Chiong Cheong, Swaminathan Sindhu, “Size Selective Assembly of Colloidal Particles on a Template by Directed Self-Assembly Technique”, International Conference on Emerging Frontiers in Technology for Rural Area (EFITRA) 2012.

[16] Tim Deodlas, Will Johnson “Electrical Machinery”, Prestige Hall Publications, 2009.

[17] Wang Qian Xin, "Metal Detector Basics and Theory", Minelabs Publications, 2008