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Design and Development of an Automated Industrial Component Sorting System with Digital Image Processing

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Abstract: *Rapid industrialization and technological advancements in assembly lines, coupled with further introduction of mixed product lines, the need to correctly sort the components on the basis of their color, size and shape has become significant. Efficient and correct automation sorting systems are the need of the day, as performing the same manually is quite monotonous and prone to mistakes arising out of fatigue. The present work is an attempt to design and develop an automated sorting system for industrial components, fasteners in this case with the aim of matching them with corresponding mating components, nuts in this case. The technique of digital image processing has been used for this work to ensure that fasteners of similar dimensions are sorted and placed as a mated pair in a single bin. 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 along with error elimination. The work is aimed at automated classification of fasteners to ensure that both nuts and bolts of appropriate size are sorted as a single set and placed in a single bin. Present setup facilitates segregation of a 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 and bolts.*

Keywords*: digital image processing, assembly lines, mixed product lines, roundness ratio.*

1. INTRODUCTION

This research paper deals with the development of a sorting system, which performs automated classification and segregation of fasteners and ensures that nuts and bolts of appropriate size are sorted as a single set and placed in a single bin [1]. The system makes use of digital image processing to control a mechanical system which segregates and categorises the mixture of nuts and bolts into three sets namely: Small, Medium and Large. The sorting is no longer preferred to be done manually as it was done before [2].

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.

2. DESIGN AND DEVELOPMENT

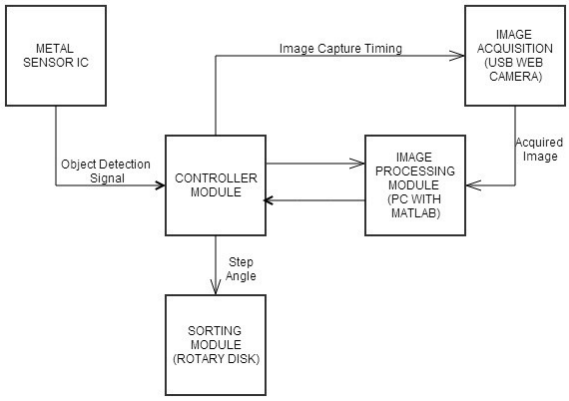


Fig. 1. Schematic representation of the system.

The metal sensor detects the position of any nut or bolt upon the conveyor and sends the signal to a controller which actuates the image acquisition device (camera). This image is then relayed to the Image Processing Module, which in the current setup is MATLAB's Image Acquisition Toolbox Version 4.5. Based on this analysis an actuating signal is sent to the stepper motor which turns it through a suitable step angle so as to facilitate the collection of parts in their corresponding bins. The process is therefore run accordingly as shown in figure 1 above.

Following are the sub systems that the design incorporates.

2.1. CONVEYER 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 have widespread usage 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 any other machine to move materials.
- They can move loads of all shapes, sizes and weights. Further, many safety features can be incorporated into conveyor system which can help prevent accidents.

The system comprises a motor, conveyer belt, rollers and suitable supporting mechanical assembly.

2.2. IMAGE ACQUISITION AND PROCESSING SYSTEM

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

a. IMAGE ACQUISITION: For development of a vision system, image acquisition is the first and one of the most important steps 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.

b. IMAGE PRE PROCESSING: After the image has been captured in the first stage, each image goes through the pre-processing stage to eliminate noise inside the image, to enhance the result of the output as the imaging sensors used including camera, rarely have evenly illuminated image.[3, 4] The steps followed in image processing are
    - Background subtraction
    - Conversion to gray scale
    - Filtering [5]

c. 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, colour, 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 known as Thresholding, to segment the pre-processed images of nuts and bolts. [6, 7]

d. FEATURE EXTRACTRION: 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.[8][7]

e. CLASSIFICATION: Based on the feature measurements the following classification criteria is formulated and selected [7, 9].

The system comprises a camera for image acquisition and a MATLAB tuned pc for image processing.

2.3. SORTING SYSTEM

This system is 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 comprises a Rotary disc collection bin [10] controlled by a stepper motor [11].

3. DETAILED DESCRIPTION OF COMPONENTS AND THEIR SELECTION

Following is a detailed description of the important components used in the system.

3.1. MOTORS

According to one classification, Motors can be classified as:

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

For the conveyer driving operation, 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. 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. DC motor was selected as we require constant speed operation of our conveyor belt.[11] For the sorting system bin, Stepper motors were chosen. 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.

3.2. CONTROLLER

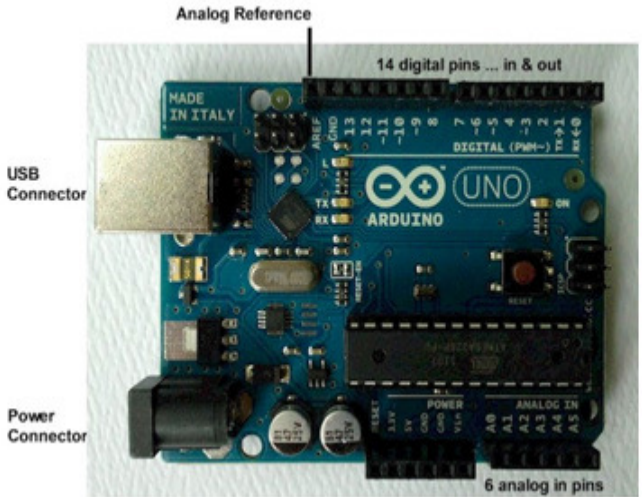


Fig. 2. Arduino UNO controller

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. The motors in the system are governed by arduino and the Arduino controller is shown in figure 2.

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:

1. Debugging:-The Arduino Environment provide easiest debugging environment which is cross-platform and is accepted by every member of the family.
2. 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.
3. The Input-Output pins of the microcontroller are typically already fed out to sockets/headers for easy access.
4. 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.
5. 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.
6. Libraries: A lot of libraries and IC's have already been build for the same which is crucial a lot of times.

3.3. IMAGE ACQUISITION MODULE

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.

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 megapixels
Focus Range – 30mm minimum

3.4 SENSOR

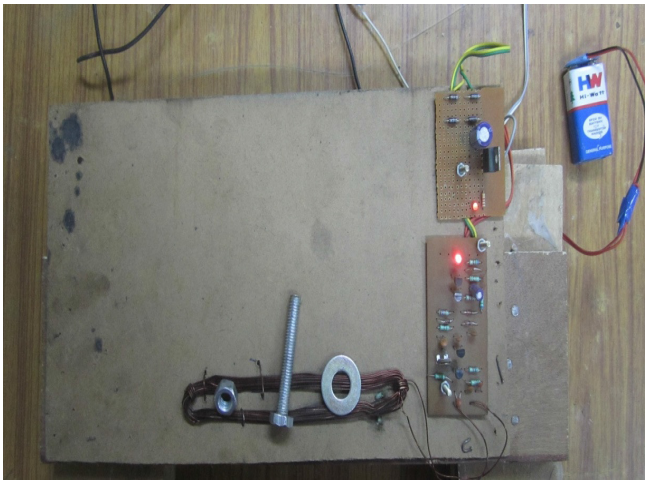


Fig. 3. Metal sensor

A 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. [12]

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 metal sensor used in the system is shown in figure 3, as we can see, the transmit and receive coils are the same. 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.

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.

3.5 MECHANICAL SUPPORT

Various mechanical components are used in the system for providing support to the system. These include frame, bearings, rollers, conveyers etc

1. 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.

2. 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.

3. 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.

4. 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

5. 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.

6. Other small components namely the camera stand, the collection bin were selected accordingly keeping in mind the mechanical constraints as well as the system requirements.

3.6. TEST SPECIMEN

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]

- 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.

For our project, we have selected the most commonly used threaded fasteners - hexagonal nuts and bolts. [13]

The standard dimensions of nuts and bolts were taken. [14]

4. WORKING OF THE SYSTEM

4.1. 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 in figure 4 below. Once the batch is done, the observations are taken and calculations are performed to find out the speed of the proposed sorting system (in parts per min) and the accuracy percentage.

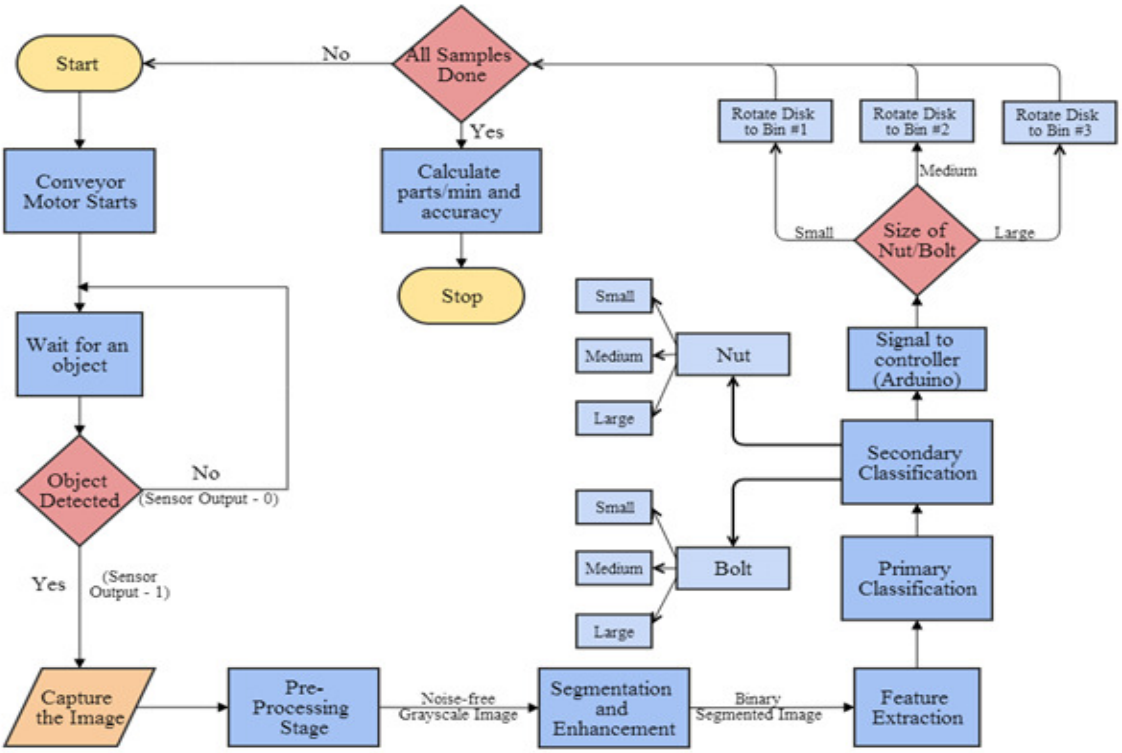


Fig. 4. Flow Chart of the Complete Process

4.2. COMPLETE MODEL AND SETUP

Following are the complete model and set up of the design-

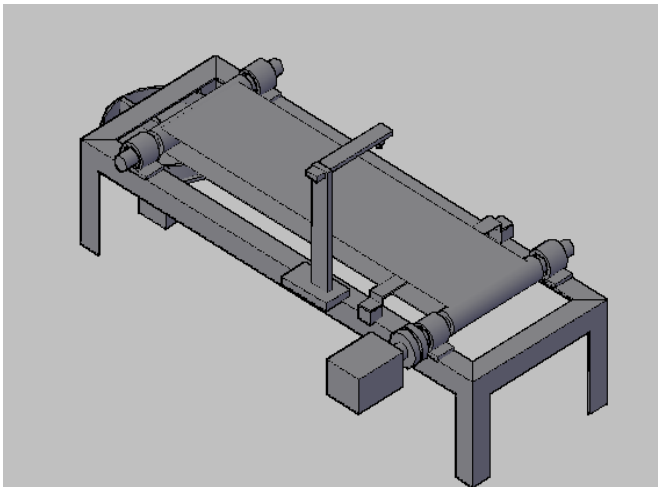
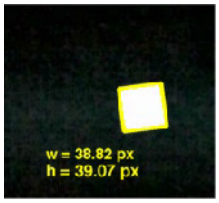


Fig. 5. CAD Model

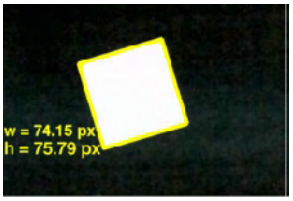
Fig. 6. Complete setup

4.3. CALIBRATIONS

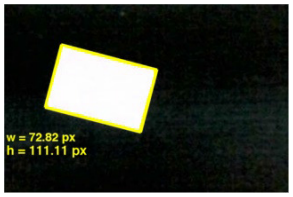
Calibration is done by measuring a known length using the proposed image processing algorithm and comparing it with real world measurements to calculate the calibration factor which has a unit pixel/mm. In this experiment we have chosen three different rectangles of known lengths. [7]



10mm x 10mm



20mm x 20mm



20mm x 30mm

TABLE 1: Calculations for calibration factor

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**

The calculations and calibrations are done on the basis of table 1 above.

Calibration factor, $Cf = \Sigma Cf, avg/n = 3.7387$

5. CONCLUSIONS

The designed system is capable of successfully performing the following functions

1. Successfully sort parts (mechanical fasteners) on the basis of size.
2. Efficiently transfer parts and collect them in the respective bins.
3. Transfer the compatible nuts and bolts in the same bin.
4. The system can be further improved to increase speed and performance.[2, 15]

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