Advanced Signal Processing for Industry 4.0, Volume 1

Evolution, communication protocols, and applications in manufacturing systems

Online at: https://doi.org/10.1088/978-0-7503-5247-5

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IOP Publishing, Bristol, UK

ISBN 978-0-7503-5247-5 (ebook)
ISBN 978-0-7503-5245-1 (print)
ISBN 978-0-7503-5248-2 (myPrint)
ISBN 978-0-7503-5246-8 (mobi)

DOI 10.1088/978-0-7503-5247-5

Version: 20230601

IOP ebooks

British Library Cataloguing-in-Publication Data: A catalogue record for this book is available from the British Library.

Published by IOP Publishing, wholly owned by The Institute of Physics, London

IOP Publishing, No.2 The Distillery, Glassfields, Avon Street, Bristol, BS2 0GR, UK

US Office: IOP Publishing, Inc., 190 North Independence Mall West, Suite 601, Philadelphia, PA 19106, USA

Dedicated to my better half Nuzra and lovely daughter Eimaan.

—Irshad Ahmad Ansari

Dedicated to my father the late Mahendra Bajaj, and family members.

—Varun Bajaj

Contents

Preface

Industry 4.0 is all about making a drastic change, a revolution in the industrial production, organization, and process in years to come. Industry 4.0 combines concepts like computer vision, machine learning, artificial intelligence (AI), cloud computing, the Internet of Things (IoT), etc., in order to make production, operation, and manufacturing more efficient. Industry 4.0 uses various sensor inputs for operation and IoT for communication. These sensors and fields like data analysis, Big Data, AI, robotics, computer vision, etc., generate a large amount of data; This makes signal processing a major area of research in this revolution. Industry 4.0 is not only about automation, it is about creating intelligent factories and production units. Industry 4.0 should not be seen just as the introduction of some gadgets into already existing industries, but as a space where the process, product, technology, and people are all intertwined. Industry 4.0 is about creating an environment where people can work with machines through seamless connectivity. It is about creating a cyber-physical system for the manufacturing sector. The communication and the field of advanced signal processing form the heart of the inevitable fourth Industrial Revolution.

Industry 4.0 is an amalgamation of digital technologies with the industries; it is required for enhancing production, flexibility, and scalability in industries. Industry 4.0 is a journey towards an integrated environment with human–machine interaction being its important aspect. With devices like cameras and different types of sensors an environment could be created for enhanced man–machine interaction. These sensors and cameras would generate a large amount of signals, making advanced signals processing an important area of research in manufacturing units. The real time/near real time signal processing for these sensors becomes a major research domain.

The main aim of this book is to bring together the frontier of research happening around advance signal processing for Industry 4.0. The main focus of volume 1 is on vision systems for Industry 4.0, communication protocols, human–machine interference and various applications of signal processing in the industrial domain. The chapter-wise description of this book is as follows.

Chapter 1 describes the role and importance of computer vision in industrial applications. Different types of industrial vision systems are discussed in this chapter. It also provides an example of implementing a vision based control mechanism for object sorting. Chapter 2 presents details of the crux of capnography systems for delivering precise capnogram signals in the advancement of Industry 4.0. This chapter also outlines the systematic analyses and prospective tools utilized in literature for incorporating capnography in medical facilities.

Industry 4.0 and the use of private 5G networks are covered in Chapter 3 along with the difficulties and challenges in its implementation. The advantages of private networks for Industry 4.0 are also discussed in this chapter. Chapter 4 proposes an algorithm for automatic defect detection and defect diameter estimation in fiber-reinforced polymer materials using signal and image processing approaches.

Frequency Modulated Thermal Wave Imaging (FMTWI) is discussed in detail for nondestructive testing in industrial applications. Chapter 5 presents a design and evaluation that underlines mission-strategic patterns in customer-centric health technology development that play a significant role in this change. Chapter 6 discusses the contribution of Industry 4.0 (IoT, digitalization, Big Data, AI, and cloud-based computing) for automatic surveillance and health monitoring during pandemics and post-pandemic life. More than 50 papers published in 2020–2022 were analyzed in this chapter.

Chapter 7 proposes a novel computational intelligence approach with applicability to Industry 4.0 in order to make effective judgments under parametric stochastic model uncertainty. In addition, examples from the real world are provided to demonstrate the use of the proposed technique. Chapter 8 aims to highlight some of those important impressions of AI on industries responsible for bringing a significant shift in their timeline and consistently altering the future with unprecedented potential efforts. Chapter 9 covers the use of some of Expert Systems (ES) in various manufacturing processes in flexible manufacturing systems (FMS). Chapter 10 discusses some of the present age applications of deep learning-based algorithms in the domain of the stock market, marketing industries, bioinformatics, and cybersecurity with an emphasis on how modern techniques are revolutionizing these fields.

Chapter 11 discusses the perspectives and application situations of family businesses undergoing digital transformation. In the application part of the study, the digital transformation process of Muratbey Cheese Company, a leading family business in the cheese manufacturing sector in Turkey, is presented as a situation analysis. Chapter 12 provides an analysis of a human–machine interface (HMI) system that can be used as an industrial robotic hand based on electromyogram (EMG) signals. A detailed analysis of figure movement identification is provided with various classification techniques. Chapter 13 focuses on data-driven models for the deployment of energy-efficient wireless networks in the context of Industry 4.0 applications, as Industry 4.0 heavily relies on IoT sensor data or knowledge-based data. Additionally, this chapter provides several automatic opportunistic relay selection methods for multi-input multi-output (MIMO) multi-relay cognitive networks (MRCNs) employing deep neural networks (DNN).

Acknowledgments

Dr Ansari expresses his gratitude and sincere thanks to his wife, family members, and teachers for their constant support and motivation. He really appreciates his wife for all the time that she has given him to work on this book, while she took care of everything.

Dr Bajaj expresses his heartfelt appreciation to his mother Prabha, wife Anuja, and daughter Avadhi, for their wonderful support and encouragement throughout the completion of this important book on Advanced Signal Processing for Industry 4.0, Volume 1: Evolution, communication protocols, and applications in manufacturing systems. His deepest gratitude goes to his mother in law and father in law for their constant motivation. This book is an outcome of sincere efforts that could be given to the book only due to great support of the family.

We sincerely give thanks to Prof. Bhartendu K. Singh, Director of PDPM IIITDM Jabalpur, for his support and encouragement. We would like to thank all our friends, well-wishers and all those who keep us motivated in doing more and more; better and better. We sincerely thank all contributors for writing relevant theoretical background and applications for this book.

We express our humble thanks to Dr John and all editorial staff of IOP for great support, necessary help, appreciation and quick responses. We also wish to thank IOP for giving us this opportunity to contribute on some relevant topic with a reputed publisher. Finally we want to thank everyone, in one way or another, who helped us editing this book.

Dr Bajaj especially thanks his family, who encouraged him throughout the time of editing this book. This book is heartily dedicated to his father who took the lead to heaven before the completion of this book.

Last but not least we would also like to thank God for showering us his blessings and strength to do this type of novel and quality work.

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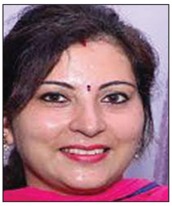

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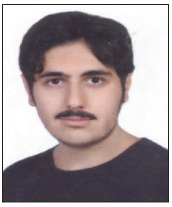
Amirhossein Koochekian



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IOP Publishing

Advanced Signal Processing for Industry 4.0, Volume 1
Evolution, communication protocols, and applications in manufacturing systems
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Chapter 1

Robotics vision for industrial automation

Shivam Vyas, Irshad Ahmad Ansari and Varun Bajaj

This chapter describes the role and importance of computer vision in industrial applications. First, it describes the different aspects and applications of computer vision such as code scanning, machine control and so on, and the way it will be helpful in making industries smarter, more productive, more reliable and more efficient. Then a colour-based sorting system is implemented that is able to detect the colour of objects and sort it out accordingly. Also, a demo of colour-based apple sorting is implemented based on industrial sorting. The tools used are raspberry pi, OpenCV Python.

1.1 Introduction

Industrial automation is the process of controlling mechanical, electrical computational, chemical, or hydraulic machinery to produce a given product and to automate all the processes by means of autonomous systems. This is automated through the integration of measurement, control, and computer software [1].

There are many aspects in the field of industrial automation that are subject to implementation of computer vision like code scanning, robotic guidance, machine control, and sorting. These areas will be described in detail in the upcoming sections.

1.1.1 Code scanning

Code scanning, which is normally carried out by either a camera or a laser scanner, is the process of decoding the information encoded in binary format. There are many other encoding systems, but the two that we use the most frequently in daily life are the QR code and the barcode. The codes are typically used for inventory management, administrative operations, and tracking purposes [2].

1.1.1.1 QR code

A QR code consists of a two-dimensional grid that can store information. The grid is a square matrix and consists of small squares inside which are either black or white,

doi:10.1088/978-0-7503-5247-5ch1

Figure 1.1. A simple QR code.

Figure 1.2. A linear barcode.

see figure 1.1. The size of the grid defines the amount of data stored in it; a small grid holds less information whereas a large grid holds a considerably high amount of information in it. A QR code is created with the help of an encoder which encodes the supplied data, and a scanner is used to decode the QR code and retrieve the data. Initially it was developed to track the parts of a vehicle in manufacturing but later on with time has found many applications [3].

1.1.1.2 Barcode

A barcode consists of a sequence of white and black stripes. The information is encoded in the width of the stripes. The code comprises of several segments with an equal number of stripes, where different characters are encoded by different segments [4]. The most commonly used barcode is the linear bar, see figure 1.2.

1.1.2 Robotic guidance

A robot can be guided with the help of a camera or computer vision. Considering the present scenario, robots are of two types; the first is the robotic arm and the second one is mobile robots. Presently in automobile manufacturing companies a lot of work like welding, joining parts and painting vehicles is done by robotic arms [5], as these tasks are tedious and require a lot of precision. Robotic arms can do these tasks without any stoppage and with better precision as compared to a human. Mobile robots are also replacing conventional tools as they are far better in terms of consistency, precision, and cost effectiveness. Mobile robots needs sensors like an ultrasonic distance sensor to calculate nearby distances and computer vision to monitor the nearby environment. The information generated by these sensors is processed through a feedback control system and required actions are to be taken. With the help of the feedback system the robot can maintain its position and speed very precisely as it gets closer to an object [6].

1.1.3 Machine control

Machine control is the act of controlling a machine or a process, with the help of some sensor or some feedback mechanism [1]. In industries generally controllers like programmable logic controllers (PLCs) are used for automation purposes. A PLC consists of both inputs and outputs; inputs such as temperature, pressure, and velocity are taken from the sensors and based on the logic defines inside the PLC programming. Certain actions are taken, and PLC output can be connected to a motor, an actuator/valve, or some switch depending upon the application. A practical application of machine control is a control valve fitted on a steam line, which is connected to a reactor, and a temperature sensor is fitted on the reactor, which continuously senses the reactor temperature and the controller accordingly adjusts the valve of the steam line to maintain the temperature.

1.1.4 Sorting

Sorting refers to the process of arranging/ordering data in a defined way, such as in increasing/decreasing order, or arranging it in a more meaningful way such that it can fulfil our requirements. In many industries a sorting process is carried out; a practical example is the food products manufacturing industry. For example, a tomato sauce producing company uses sorting to pick only ripe and red tomatoes and reject unripe tomatoes [7]. Sorting can be done in many ways, such as colour-based sorting, size-based sorting, and product-based sorting. In a waste product management industry wastes like plastic, metal, paper, and recyclable and non-recyclable waste are sorted out and processed separately [8, 9].

1.2 Computer vision system

1.2.1 Image representation

This section explains the technicalities of an image and how to represent one. An image is made up of a 2D array of pixels, each of which describes the light at a given point in the image. A pixel can be represented in a variety of ways, and the three most popular in computer graphics are described below.

1.2.2 RGB colour model

The RGB colour model is a three-channel colour model with red, green, and blue values for each pixel. The three hues are then mixed together in various quantities to create a specific colour. Since a pixel typically consists of a red, green, and blue LED, the RGB colour model is extensively employed in display technology because it is straightforward to alter the intensity of each LED. This model has the disadvantage of being sensitive to non-uniform illumination and having a non-linear relationship between colours [10].

1.2.3 HSV colour model

Researchers created the Hue-Saturation-Value (HSV) colour model in the 1970s with the goal of creating a colour model that interprets colour in a way that is more akin to how humans see colour [11]. A HSV colour model consists of three components: hue, saturation and value. The hue component defines the colour portion, saturation defines amount of grey component present, and value and saturation work together and define the intensity of the colour. The HSV colour model can be represented in the form of a cylindrical model, in which hue varies around the circumference of the cylinder where red is at 0°, green at 120°, and blue at 240°. Saturation ranges from 0 to 100 where 0 implies greyscale and 100 implies pure colour. Value also ranges from 0 to 100, where 0 indicates pure black while a colour with value 100 indicates that no black component is present in the colour [12].

1.2.4 Greyscale image

A greyscale image is made up of only black, white, and grey colours, where the intensity of each pixel varies from 0 to 255. 0 represents pure black, 255 represents pure white, and the intermediate values represent multiple levels of grey. greyscale images are often used for image segmentation and image processing purposes [13, 14].

1.2.5 Image segmentation

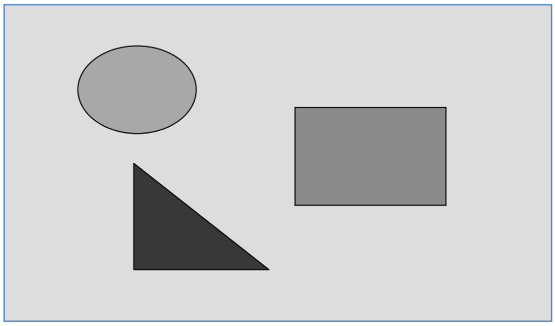
Image segmentation refers to the process of transforming a picture into a binary image where pixel's value is either 0 or 1, from any kind of representation, such as a greyscale image. This is done to simplify the image and to highlight the important elements present in the image. Image segmentation can be used to find edges, detect objects, and in further image analysis, since it is one of the most significant process in the area of computer vision [1].

1.2.6 Thresholding

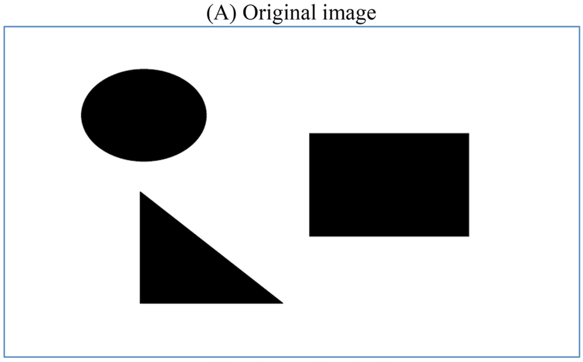
Thresholding is a widely used technique for image segmentation. The key concept is to fix a thresholding value for a pixel, where all pixel values exceeding the threshold can be set either to black or white and pixels below the threshold are set to opposite colours. There are many types of thresholding methods, and the most widely used is Otsu's method [15]. A commonly used thresholding technique in image segmentation is the binary thresholding method, which uses a fixed value to differentiate between an object and its background [16], refer to figure 1.3.

1.2.7 Blurring

Blurring is a very common and extensively used method in image processing, used to smooth an image and reduce the noise present. There are various factors which can cause an image to be noisy, such as sensor malfunction, or environmental factors



(A) Original image



(B) Binary Threshold

Figure 1.3. Binary thresholding: (A) original image and (B) binary threshold of 150.

like poor lightning, direct lighting, and dust present in the air. Blurring can be related to mixing of a pixel intensity with its neighbouring pixel intensities.

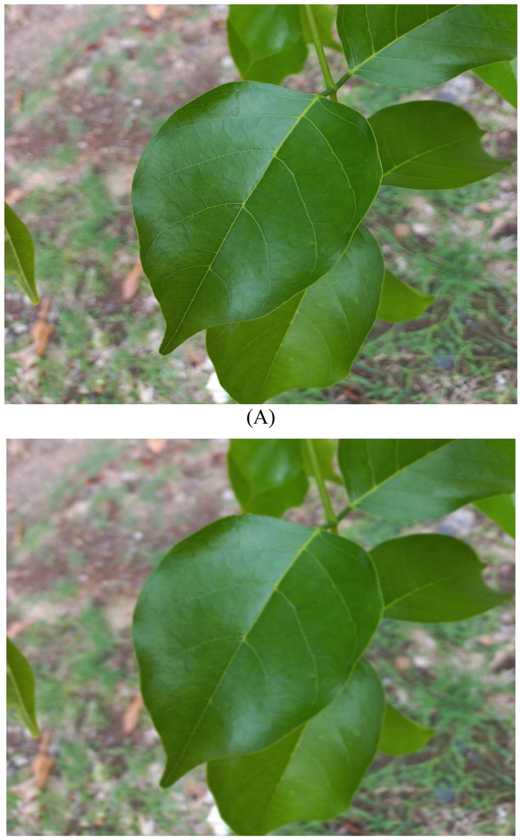
The mostly commonly used filtering methods are Gaussian blurring, median blurring and bilateral blurring.

1.2.7.1 Gaussian blurring

In Gaussian blurring, the neighbouring pixels that are nearer the central pixel give the average more weight. It is preferable to use Gaussian blurring, which utilises a Gaussian kernel rather than a conventional one, when the image contains Gaussian-like noise. The kernel value should be an odd number. As the name implies, noise that roughly follows a Gaussian distribution is removed using the technique known as 'Gaussian smoothing' [17]. An example of Gaussian blurring can be seen in figure 1.4.

1.2.7.2 Median blurring

With median blurring, the centre element is changed to the median value obtained from all the pixels within the kernel area. Median blurring finds its use case mostly in removing salt-and-pepper type noise. Salt-and-pepper noise is a kind of random noise consisting of black and white pixels presented randomly in an image, and in a



(A)

(B)

Figure 1.4. Image after Gaussian blurring: (A) original image and (B) Gaussian filtered.

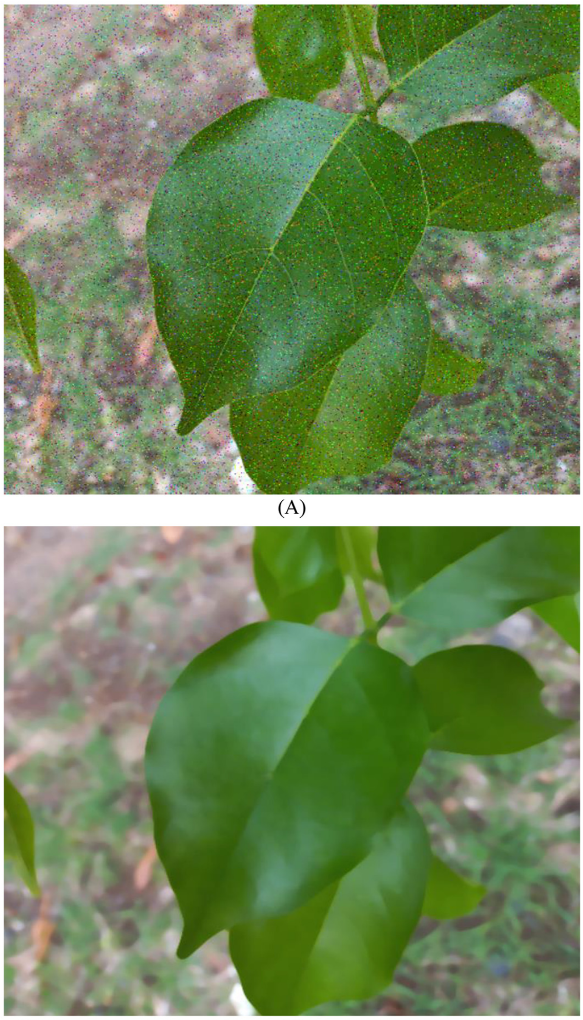
coloured image instead of black and white dots, random colour dots might appear, as illustrated in figure 1.5 [17, 18].

1.2.7.3 Bilateral blurring

Bilateral blurring is useful where edge preservation is important, as it removes the noise from the image while preserving the edges (see figure 1.6). Based on a weighted average of the pixels around it, the filter determines a value for every pixel. The weight is determined by the intensity difference and how close the neighbouring pixels are to one another [19].

1.2.8 Edge detection

Edge detection refers to the process of identifying boundaries of an object in an image. There are many algorithms available to identify edges, but the base method for detecting edges in an image is to detect certain changes in values of pixel intensities or where a sudden change in brightness occurs. It can be used to detect



(A)

(B)

Figure 1.5. Image after median blurring: (A) original image and (B) median filtered.

different objects in an image, as seen in figure 1.7, to separate background and foreground, or to identify shapes of objects [14].

1.2.9 Object detection

Identifying items in a digital image, such as automobiles, people, or a workpiece, is the idea behind object detection. It combines localisation with classification with the goal of identifying attributes, such as an object's shape and colour [20].

To detect an object, an image is passed through several steps. For example, if our aim is to detect a square in an image, then our first step is to convert that image to a greyscale image, then convert the greyscale image to a binarized form, since in a

(A)

(B)

Figure 1.6. Image after bilateral blurring: (a) original image and (b) bilateral filtered.

binary image there are only two colours (black and white) and therefore it would be very easy to detect edges in that image. In the next step the square box can be separated out from the enclosed objects by setting a certain range of criteria [21]. The steps can be visualised in figure 1.8.

1.2.10 Region of interest (ROI)

During image processing in computer vision applications a region of interest (ROI) is to be defined. Selecting an ROI in an image means selecting an area on which image processing is to be applied. Areas other than the ROI are of no use and can be excluded, and only relevant parts can be considered for further processing. This process can be very helpful, saving a lot of computational resources and a lot of time, as the processing is to be done on a selected region only [22].

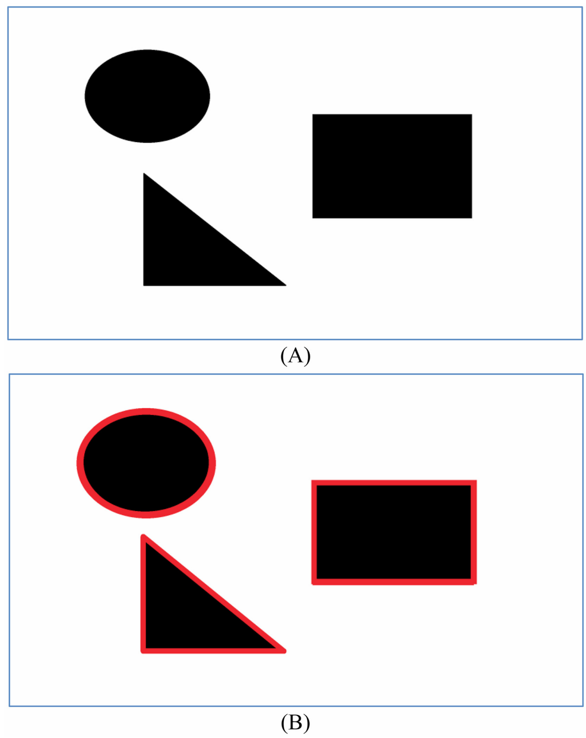


Figure 1.7. Edge detection: (A) original image and (B) edges detected with red colour in original image.

1.3 Applications of vision system

1.3.1 Vision controlled robotic arm

The development of technology is also causing industries to get more high-tech and modern, ND with the development of modern industries, the applications of modern machineries and robotic technologies are increasing rapidly. In particular, robotic arms have gained a lot of applications in industries. These arms are capable of doing heavy and repetitive tasks which a human cannot do easily [23]. Currently in most of the automobile manufacturing companies robotic arms are replacing humans because a lot of power and precision is needed to manufacture the parts and components of a vehicle [24, 25]. A robotic arm consists of links and joints, and can be described by transformation matrices with the help of a Cartesian coordinate system and joint angles provided by the arm. The mathematical modelling of a robotic arm is classified as one of two types: forward kinematics and inverse kinematics. Forward kinematics takes joint angles as an input and calculates the position and orientation of the end point, whereas inverse kinematics takes the orientation and position of the end effector as an input and provides the joint angles as an output. In a vision-based pick-and-place manipulator the robotic arm has a camera in it, which is used to calculate the position of the object which is to be picked [26, 27]. The coordinates or the position of the object is calculated with the

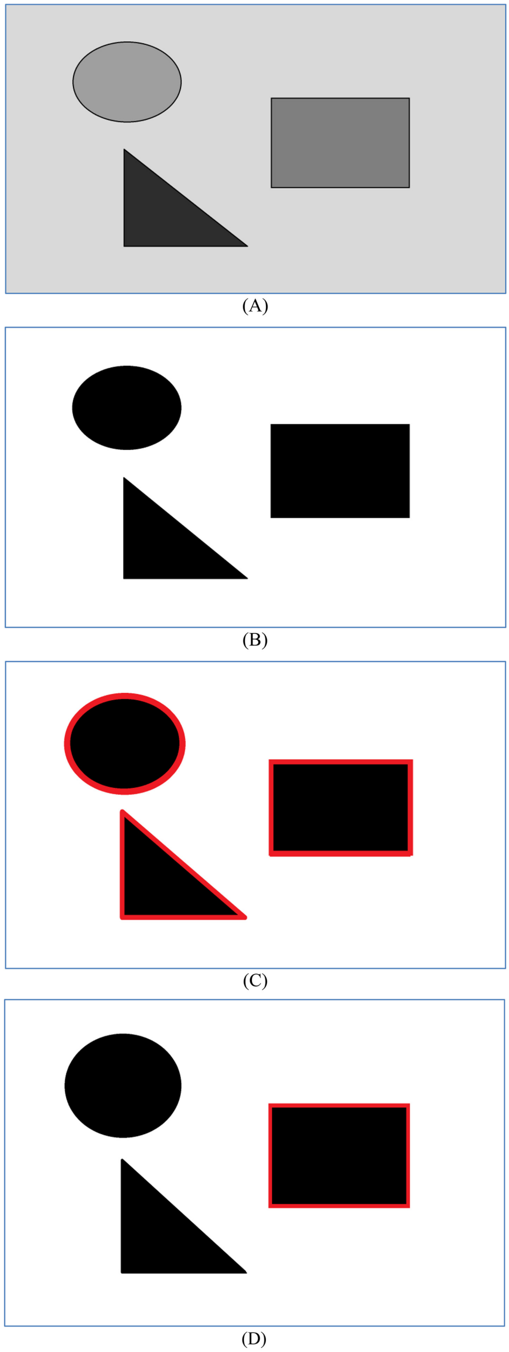


Figure 1.8. Object detection: (A) original image, (B) segmented image, (C) edge detection and (D) object detection.

Figure 1.9. Camera mounted robotic arm. Image Courtesy-Mechatronics Lab PDPM IIITDMJ.

help of image processing algorithms and then with the help of inverse kinematics the joint angles are calculated and provided to the arm to reach the object [28, 29]. A vision controlled robotic arm is shown in figure 1.9.

1.3.2 In manufacturing and mining

1.3.2.1 Quality control

Quality control is a very important part of every industry, as it regulates and maintain the quality of the product. It is the process of ensuring that manufactured items fulfil the manufacturer's quality standards. The conventional method of quality control is to personally verify a sample in a batch to confirm the overall batch quality. When it comes to the pharmaceutical industry it is very important to maintain the product quality as it can effect human health. Therefore, high precision computer vision systems are used in their manufacturing line, which assures the quality and grade of the product, and if any kind of error or defect is found in the product it will be rejected [30–32].

1.3.2.2 Intelligent monitoring systems

Companies can undertake remote inspections of their sites and assets with the help of drone-assisted technology. This use of computer vision is crucial in the mining industry, which is dangerous for employees and requires operators to gather visual data in challenging locations. Operators have been able to cut back on routine site visits by half thanks to visual inspections of well sites utilising the Osprey Reach system [33].

1.3.3 In industry application

1.3.3.1 Warehouse management system

A warehouse management system's primary role is to track inventory arrivals and departures. From there, capabilities such as documenting the specific placement of merchandise inside the warehouse, maximising the use of available space, and coordinating tasks for optimal efficiency are implemented. It is a collection of policies and practises designed to organise the work of a warehouse or distribution centre and guarantee that such a facility can run efficiently and accomplish its goals. Utilising computer vision technology in inventory management can reduce a lot of effort and can cut time from hours to minutes, resulting in significant operational cost reductions. One of these technologies is the Gather AI platform, which links to IoT devices and employs drones to scan and count goods. Another example is Amazon, which claims that the Pegasus robot technology it is implementing at its sorting facilities would increase sorting accuracy by 50% [24, 34].

1.3.3.2 Safety-monitoring solutions

Safety monitoring is a subset of error detection and recovery where the malfunction poses a safety risk. When the automated system sensors indicate that a safety situation has evolved that might be dangerous to the equipment or individuals in the area of the equipment, decisions must be made. The goal of the safety-monitoring system is to recognise hazards and take the right action to eliminate or decrease them. This may just involve pausing the operation and notifying maintenance staff of the problem, or it may entail a more sophisticated series of procedures to resolve the safety issue. Computer vision assisted in maintaining public space safety during the pandemic by identifying sick staff or pupils and keeping track of social distance or exposure times. Computer vision systems like IRIS, which monitor behaviour-based safety on the production floor and at construction sites, can safeguard workers by warning machine operators of impending danger [35].

1.4 Proposed work

1.4.1 Proposed model

A colour-based sorting system is implemented in the proposed model, which identifies the colour of the object using a basic sorting algorithm and sorts it accordingly. In the proposed work two models are implemented; the first model separates out red and green coloured objects, while the second model separates red, green, and blue coloured objects.

1.4.2 Model design

In order to implement a computer vision-based colour sorting machine, it is important to understand its basic functionality and working. There are four main components in this sorting machine. These components are the conveyor belt, camera module, raspberry pi as an image processor, and servo motor for separating out the objects.

1.4.2.1 Conveyor belt

A conveyor belt is used to carry an object from one location to another, and is a part of the belt conveyor system. It consists of two or more pulleys, with a closed loop of carrying medium which rotates about the conveyor belt [36]. Refer to figure 1.10.

1.4.2.2 Camera module

A camera module is an image capturing device, which is used to take images of the objects whose colour is to be detected. In this model a Logitech C270 webcam camera system has been used to capture images. The reason behind using this camera is that the image quality of the pictures obtained from this camera is of very high quality with a resolution of 720p. Refer to figure 1.11.

1.4.2.3 Raspberry pi

A raspberry pi is a low-cost computer system, which is used to create hardware projects, projects related to image processing, and home and industry automation. It works on the Linux operating system, and it provides a set of general input/output (GPIO) pins which allow a user to take input from a sensor or can be used to connect a motor as an output. Refer to figure 1.12.

1.4.2.4 Servo motor

A servo motor is a custom DC motor which uses DC power for its operation and a pulse width modulating (PWM) signal to change its position. The advantage of using a servo motor is that the position or angle of the tool attached to the servo

Figure 1.10. Conveyor belt. Image Courtesy-Mechatronics Lab PDPM IIITDMJ.

Figure 1.11. Camera module. Image Courtesy-Mechatronics Lab PDPM IIITDMJ.

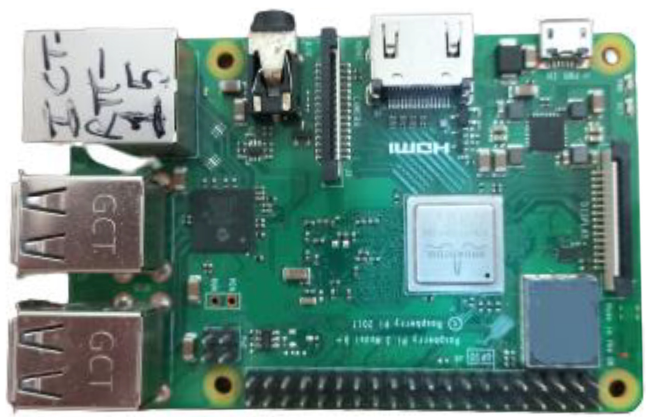


Figure 1.12. Raspberry pi. Image Courtesy-Mechatronics Lab PDPM IIITDMJ.

motor can be changed or can be set easily by changing the width of the PWM signal. Generally the frequency of a PWM signal is 50 Hz. Refer to figure 1.13.

1.4.3 Working (model-I)

The process starts with placing an object on to the conveyor belt. The placed object passes through a camera module system which continuously captures images of the object. Then the captured images are processed by the image processor. First, the RGB colour format image is converted into a HSV colour format image and then a sample from the centre of the image is taken out to extract its colour properties. Values of hue, saturation, and value are taken out from the pixel's colour properties,

Figure 1.13. Servo motor. Image Courtesy-Mechatronics Lab PDPM IIITDMJ.

then these HSV values are compared to a range of standard HSV colour values obtained from the HSV colour format. After comparison a known colour is obtained and then accordingly the angle of the servo motor is set such that the object reaches its predefined location.

1.4.3.1 Using servo motors

The total length of the conveyor belt is 88 cm and the distance between the camera and the servo motor is 30 cm. It takes around 2 s for the object to travel from camera to servo motor. When a red object passes through the camera, the raspberry pi sends instructions to the servo motor and the servo motor actuates after 2 s, separating the red object from the conveyor. When a blue object is detected it allows the object to pass through and blue objects are collected at the end of the conveyor belt, and hence red and blue objects get separated. Refer to figure 1.14.

1.4.3.2 Using robotic arm

A robotic arm is a sort of mechanical arm that is generally programmable and performs duties comparable to a human arm; the arm may be the sum total of the mechanism or it may be part of a larger robot. The manipulator's linkages are joined by joints that allow either rotating motion (as in an articulated robot) or translational (linear) displacement. The manipulator's linkages may be thought of as a kinematic chain. The end effector is the terminal of the manipulator's kinematic chain, and it is equivalent to the human hand. A 5 degrees of freedom (DOF) robotic arm is used to separate red and blue objects. The distance between camera and robotic arm is 20 cm,

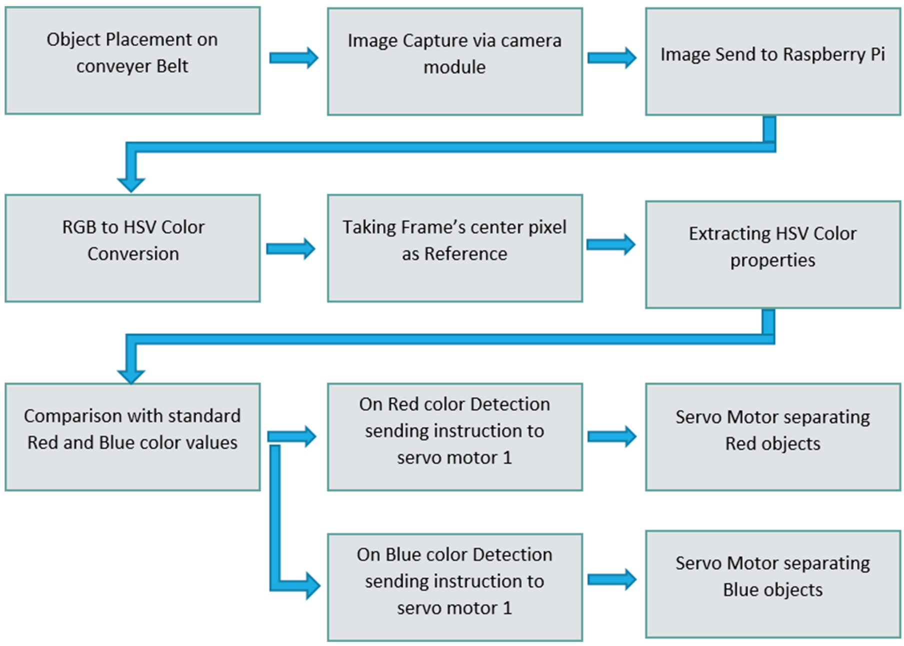


Figure 1.14. Working block diagram-I.

and it takes around 1.2 s for an object to reach near the robotic arm. If the detected object is blue, the arm displaces that object on the left-hand side of it while if the object is red it displaces it on the right-hand side of the arm. Refer to figure 1.14.

1.4.4 Evolution (model-I)

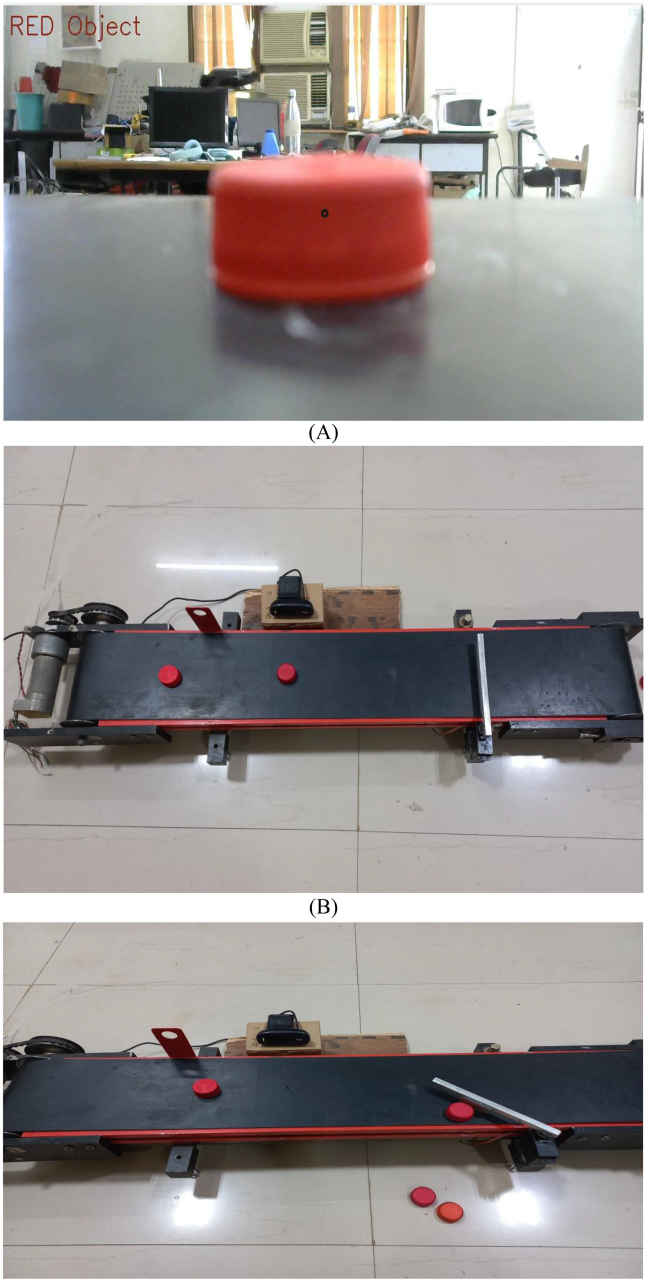
1.4.4.1 Using servo motors

In this section, red and blue objects are used to determine whether the model is working properly or not. For this the objects are placed on a conveyor that passes through a camera sensor, and the image data will be calculated and sent to the raspberry pi for further processing. The algorithm inside it will check whether the object's colour is red or blue and accordingly it commands the servo to separate out the object. Refer to figures 1.15 and 1.16.

1.4.4.2 Using robotic arm

A 5 DOF robotic arm is used to separate red and blue objects. The distance between camera and robotic arm is 20 cm, and it takes around 1.2 s for an object to reach near the robotic arm. If the detected object is blue, the arm displaces that object on the left-hand side of it while if the object is red it displaces it on the right-hand side of the arm. Refer to figure 1.17.

• **Red and blue object detection and separation**



(A)

(B)

(C)

Figure 1.15. Red object detection and separation: (A) object, (B) belt, (C) separation mechanism. (Courtesy: Mechatronics Lab IIITDMJ.)

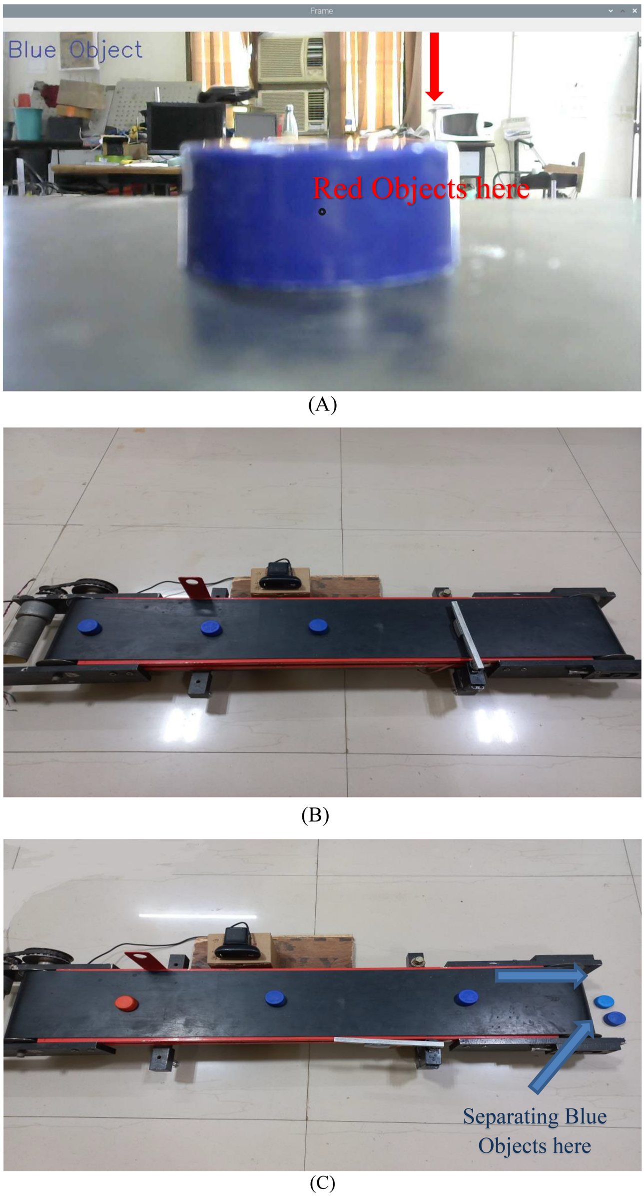


Figure 1.16. Blue object detection and separation: (A) object, (B) belt, (C) separation mechanism.

1.4.5 Working (model-II)

The process starts with placing an object on to the conveyor belt. The placed object passes through a camera module system which continuously captures the images of the object. Then the captured images are processed by the image

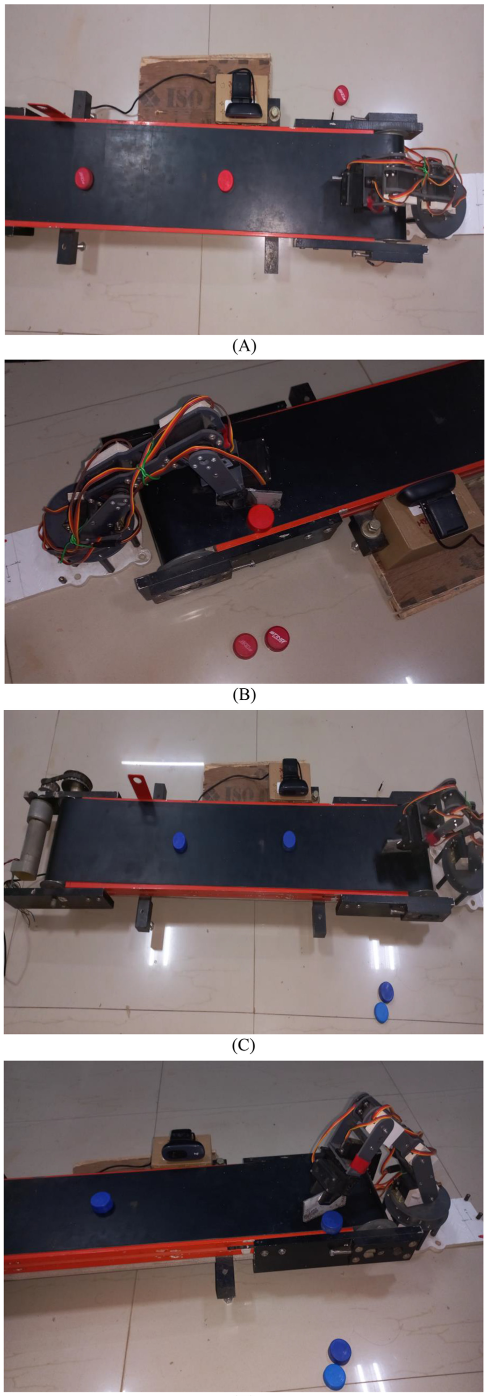


Figure 1.17. Red and blue object detection and separation: (A) red object detection, (b) red object separation, (c) blue object detection and (D) blue object separation. (Courtesy: Mechatronics Lab IIITDMJ.)

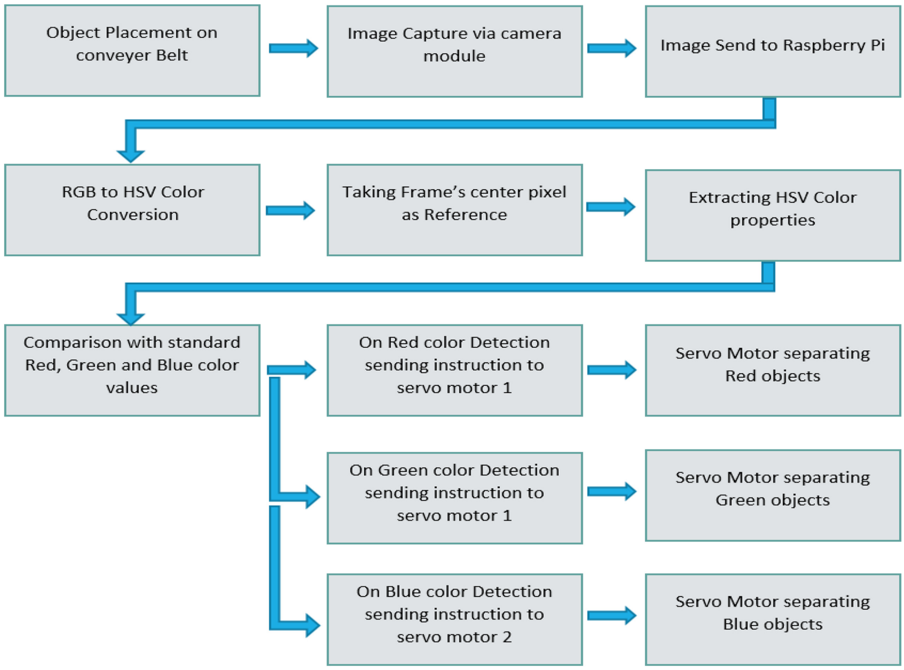


Figure 1.18. Working block diagram-II.

processor. First, the RGB colour format image is converted into a HSV colour format image and then a sample from the centre of the image is taken out to extract its colour properties. Values of hue, saturation, and value are taken out from the pixel's colour properties, then these HSV values are compared to a range of standard HSV colour values obtained from the HSV colour format. After comparison a known colour is obtained and then accordingly the angle of the servo motor is set such that the object reaches its predefined location. Refer to figure 1.18.

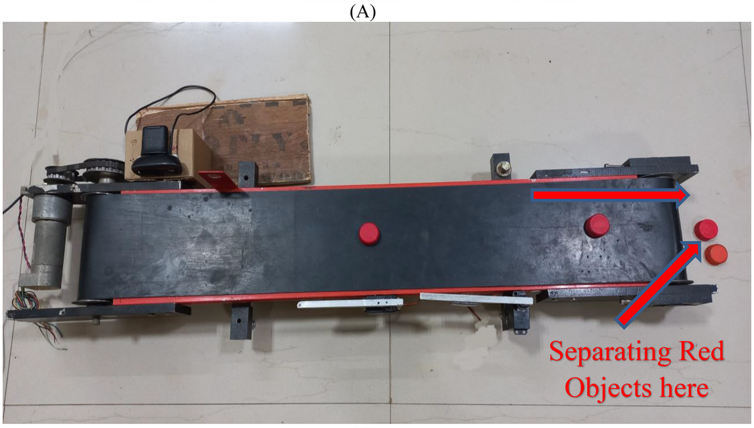
1.4.5.1 Using servo motors

When a red object passes through the camera, the raspberry pi commands both servo motors to pass the red object from the conveyor, while when a blue object gets detected it commands the servo1 to separate the object from the conveyor and when a green objects is detected servo2 separates the object from the conveyor, hence red, green, and blue objects gets separated. Refer to figures 1.19–1.21.

1.4.6 Evaluation (model-II)

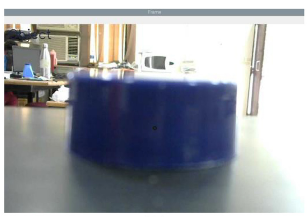
In this section, red, green, and blue objects are used to determine whether the model is working properly or not. For this, the objects are placed on the conveyor and

(A)

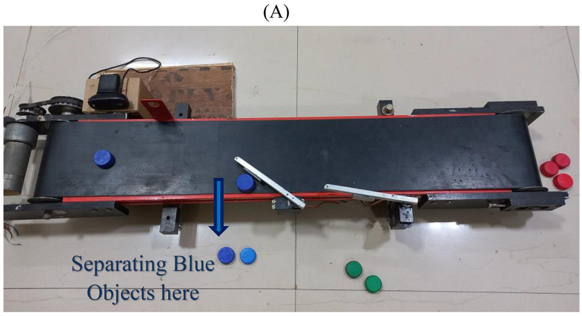


(B)

Figure 1.19. Red object detection and separation: (A) object and (B) belt. (Courtesy: Mechatronics Lab IIITDMJ.)

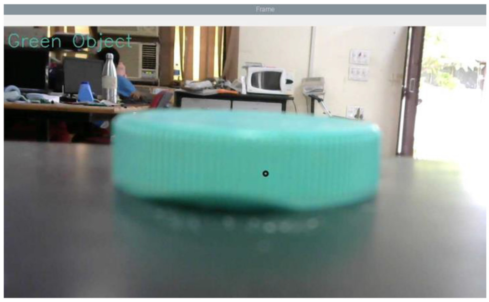


(A)

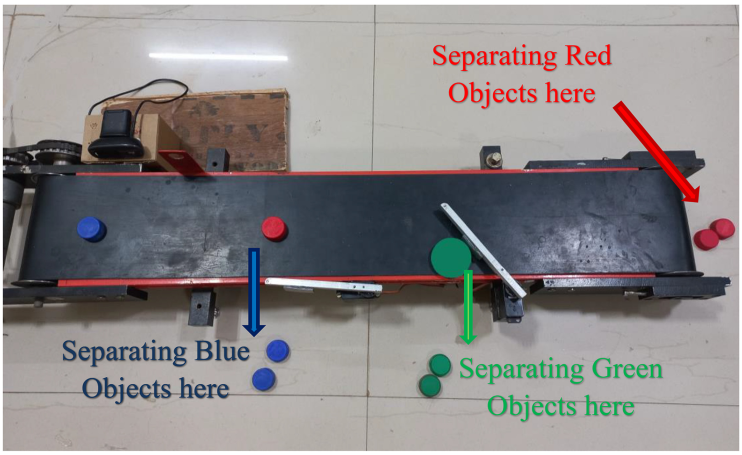


(B)

Figure 1.20. Blue object detection and separation: (A) object and (B) belt. (Courtesy: Mechatronics Lab IIITDMJ.)



(A)



(B)

Figure 1.21. Green object detection and separation: (A) object and (B) belt. (Courtesy: Mechatronics Lab IIITDMJ.)

passed through camera sensor. The image data is calculated and sent to the raspberry pi for further processing. The algorithm inside it checks whether the object's colour is red, green, or blue and accordingly it commands the servo to separate out the object.

1.5 Industrial demo (apple sorting)

A demo example of colour-based apple sorting is implemented based on sorting done in the food industry. The process implemented is very much similar to the process implemented in examples above.

In this process, apples of two colours, red/dark red and yellowish/greenish colours, are passed via a camera system on a conveyor belt. The images of apples are continuously captured by the camera and monitored with a raspberry pi system. If the colour of apple is found to be red, then the red apple is collected at the end of the conveyor belt, and if the colour of the apple is found to be yellow/green then the apple is separated by a servo motor to the side of the conveyor belt. Refer to figures 1.22 and 1.23.

1.5.1 Yellow apple sorting

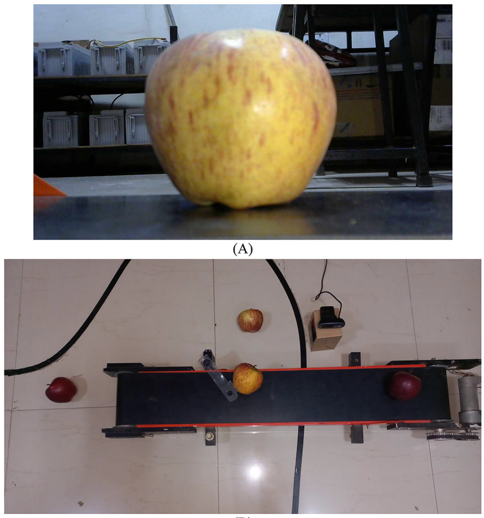


Figure 1.22. Yellow apple detection and separation: (A) object and (B) belt. (Courtesy: Mechatronics Lab IIITDMJ.)

1.5.2 Red apple sorting

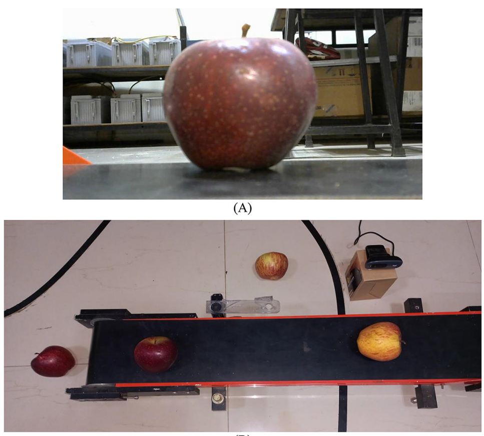


Figure 1.23. Red apple detection and separation: (A) object and (B) belt. (Courtesy: Mechatronics Lab IIITDMJ.)

1.6 Conclusion

This chapter gives a brief overview about the role of computer vision in industries, and has implemented an autonomous colour-based sorting system using a servo motor for object separation. A camera was installed on the conveyor system for object image capturing and a raspberry pi module was used for image processing and motor control. The objectives of the project were (see also figure 1.24):

- To determine the object's specification using image processing techniques.
- To extract colour properties of the object from images.
- To separate the object based on colour.

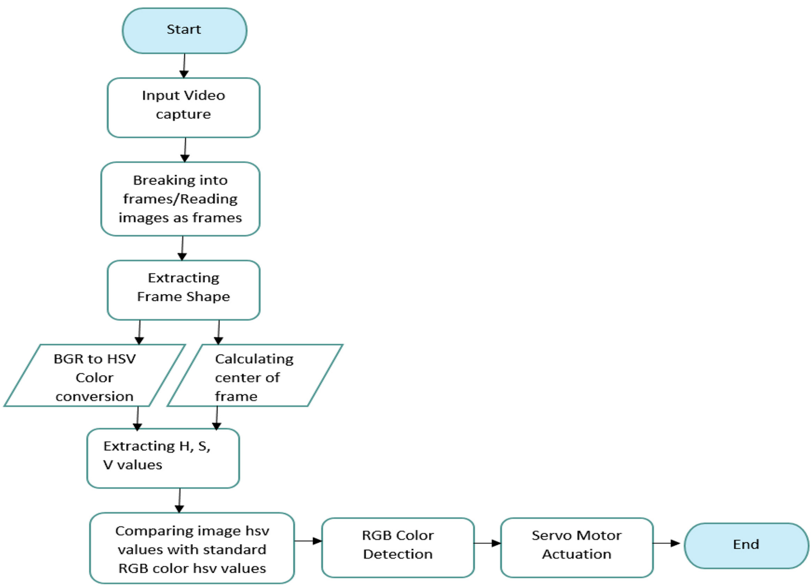


Figure 1.24. Working algorithm flow-diagram.

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Chapter 13

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