BATCH-PRINT SORTIFY: AUTOMATED BATCH NUMBER PRINT, VERIFICATION AND SORTING SYSTEM

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FINAL YEAR PROJECT REPORT

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Abstract

In today's manufacturing environment, accurate variable data printing, verification, and sorting of products is important for maintaining quality standards. This project aims to develop an automated system capable of efficiently printing batch numbers and expiry dates on the boxes, detecting misprints using image processing, and sorting the boxes based on printing details.

Industrial automation plays an important role in modern manufacturing, enabling industries to enhance productivity, improve quality and reduce costs through the implementation of automated systems and processes. The system integrates hardware components such as sensors, cameras, actuators, conveyor belt with software algorithms. Development of algorithms for accurate misprint detection is also a focus area of this project.

Additionally, the project includes the design and implementation of a user-friendly interface for monitoring and controlling, the printing sorting and verification processes. Through testing, the system aims to achieve high accuracy and efficiency in printing operations.

Nomenclature

Symbol	***Abbreviation***
F	Force applied to conveyor belt (N)
m	Mass of conveyor belt and load (kg)
b	Damping coefficient (friction)
v	Velocity of conveyor belt (m/s)
V	DC motor voltage (V)
I	DC motor current (A)
T	Motor torque (Nm)
K_t	Torque constant of motor (Nm/A)
r	Radius of motor pulley (m)
τ	Time constant (s)
K	Gain of system
s	Laplace transform variable
DPI	Dots Per Inch (printing resolution)
OCR	Optical Character Recognition
$YOLOv5$	You Only Look Once version 5 (Object detection algorithm)
AI	Artificial Intelligence
ML	Machine Learning
ROI	Region of Interest (image processing)
CSI	Camera Serial Interface (connection for camera module)
$Solenoid\ Valve\ 5/2$	Pneumatic valve with 5 ports and 2 positions
$Pneumatic\ Actuator$	Device that converts compressed air energy to linear motion
LED	Light Emitting Diode (used for lighting in vision system)
A	Cross-sectional area of piston (m^2)
P	Pressure (Pa)
V	Volume (m^3)
F_p	Force from pneumatic actuator (N)
CNN	Convolutional Neural Network
$ML\ model$	Machine Learning model

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1 Introduction

Wide assessment was done for picking a project that would help society in various ways before picking FYP. Following considering the overview of project that was shared with us, we decided to plan and cultivate a Mechanized variable data printing, verification and sorting. With the speed at which advancement is making and the rapidly creating demands put on creation and collecting processes for accuracy, constancy and capability, it is essential to find imaginative approaches to accelerating factor data printing, verification and sorting.

Figure 1.1 Prototype [1]

These procedures are frequently impacted from errors, delays and resource shortages when manual interventions are made. This emphasizes the need for automated solutions that can give results give that are dependable and consistent.

To overcome these difficulties, this project is making a coordinated arrangement that utilizes best in class innovation to enable automated data printing, sorting, and detecting misprints. The targets of this project are to ensure industry principles, improve productivity, and transform industrial workflows.

1.1 Background and Motivation:

Ensuring efficiency, accuracy, and compliance in batch printing, verification, and sorting operations is crucial in today's industrial environment to maintain product quality and comply with regulations. Conventional manual batch processing methods require a lot of labor and are prone to errors, which can cause production delays and inefficiencies as well as legal action against businesses. Innovative solutions that may boost productivity and cut costs are desperately needed as sectors seek for greater automation and optimization.

The motivation for taking this project arises from the understanding of remarkable challenges and opportunities inherent for batch number, verification, and sorting within production parameters is what inspired me to take this project. Manual interventions in these processes limit scalability and flexibility, increasing the risk of human mistake and making it more challenging for industrial systems to adapt to shifting market demands. Furthermore, as the need for customized goods rises, automated systems that can manage a range of printing requirements and ensure accuracy and efficiency across several product lines are becoming increasingly crucial.

Additionally, the advancement of technology such as machine learning and image processing presents previously unusual opportunities for innovative industrial automation. By enhancing quality control protocols, optimizing batch processing operations, and maximizing resource utilization, firms will gain a competitive edge through the utilization of these technologies.

Therefore, the primary and main motivation behind this project was to develop an automated system for batch printing, verification, and sorting and use cutting edge technology to solve the problems faced by manufacturers.

1.1.1 Sustainable Development Goals

The design and development of an automated variable data printing, verification and sorting mechanism can contribute to several Sustainable Development Goals. Here are some examples:

Goal 3: Good Health and Well-being: Implementing AI algorithms for misprint detection supports by ensuring the accuracy and integrity of product information, which is important for consumers health and safety.

Goal 9: Industry, Innovation, and Infrastructure: This objective can contribute to sustainable development goals by promoting change in manufacturing processes and enhancing infrastructure for sustainable industrialization.

Goal 8: Decent Work and Economic Growth: Automated batch sorting aligns by improving efficiency in manufacturing processes and enhancing productivity, which can lead to economic growth and development

In summary, the design and development of an automated variable data printing, verification and sorting mechanism can contribute to several benefits, including Good Health and Well-being, Industry, Innovation and Infrastructure, and decent work and economic growth.

1.2 Literature Review:

Image processing Mechanism:

Real-time image processing is important for the advancement of mechatronics frameworks since it joins computer, electrical, and mechanical designing to further develop execution and value. [1] with regards to the mechatronics systems, this study offers a discerning rundown of the center thoughts, methods, and valuable uses of real-time image processing.

A fundamental component in the improvement of intelligent mechatronics frameworks is the reconciliation of picture handling and computer vision procedures. These frameworks can make very intelligent decisions and thus work on their insight, independent direction, and control abilities by utilizing visual contributions from pictures and videos.

Moreover, the paper features the significance of constant picture handling in mechatronics systems is following and movement examination. By computer vision algorithms, these frameworks can follow the movement of articles continuously, giving important data to control and dynamic inspirations.

The concentrate likewise investigates the real-time image processing and profound learning strategies, explicitly concerning Convolutional Neural Networks (CNNs). These high-level strategies set out new open doors for intelligent mechatronic systems by giving remarkable precision and flexibility in undertakings including object distinguishing proof and picture arrangement.

The down-to-earth troubles and factors, for example, memory needs, framework joining, and registering intricacy, that accompany trying ongoing image processing algorithms are likewise canvassed in this work. To guarantee productive execution in certifiable applications, execution improvement strategies, for example, equipment speed increase and algorithmic enhancements are covered.

All in all, the paper features the imperative job of ongoing picture handling in progressing mechatronics frameworks. By giving far far-reaching outline of the essential standards, procedures, and pragmatic applications, it underlines the significance of image processing methods.

Sorting Mechanism:

In today's sectors, automation is in demand, particularly in the packaging sector where sorting is crucial [2]. This literature study incorporates pneumatic systems into its analysis of the significance of automatic sorting machines in the packing industry in order to acquire low-cost automation solutions.

The packing sector has grown rapidly, driven by the need for precise and efficient sorting methods. Automation is the need of industries that were previously dependent on expensive human labor and simple packaging materials to meet the demands of production operations. The productivity of automatic sorting equipment has grown and labor expenses have decreased.

An important technical innovation is the sue of pneumatics in automatic sorting equipment. These devices provide a schematic carbon box according to size using direction control valve and pneumatic cylinders. In our project, “Batch Print Sortify: Automated Batch Marking, Verification, and Sorting System”, sorting will be done by using the same mechanism. Pneumatic systems make

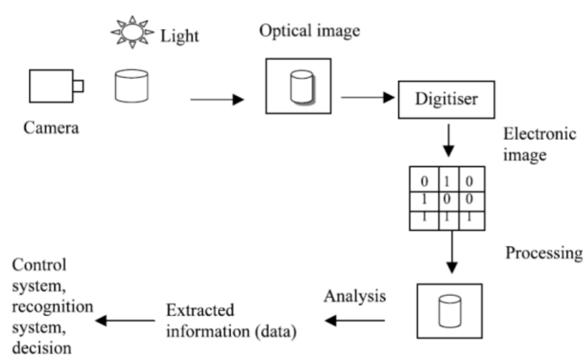


Figure 1.2 Computer Vision Technique [9]

sorting quick and accurate, which increases the efficiency. We want efficient and quick sorting system, so we will use the same pneumatic system sorting mechanism. Earlier studies on automatic sorting have looked into a variety of approaches and technology to help the packaging industry overcome their issues and problems. Using image processing and microcontroller technology, one author proposed a color-sorting robot that provides a quick and effective sorting mechanism. The other author showed how image processing techniques may be used to quantify packed box volumes. And the other author demonstrated the use of sensor technology in automation by integrating infrared sensors for material detection and sorting. Also, a Raspberry Pi to do barcode-based sorting was done to meet the industry standards.

In conclusion, automatic sorting machines, which offer high efficiency and productivity, represent an important advancement in the packaging industry. The integration of pneumatic systems enables efficient sorting operations, for enhanced production processes.

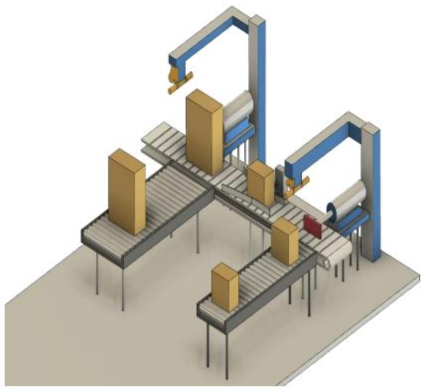


Figure 1.3 Prototype of sorting Mechanism [10]

Printing Mechanism:

Due to the necessity for modified treatment and the drawbacks of conventional mass production methods, the pharmaceutical industry has been immense growth over the last 20 years. Thermal inkjet printing (TIJP) [2] is one type of inkjet printing technique that has shown potential in the on- demand manufacturing of customized pharmaceuticals for patients. This study of the literature looks at the advantages and disadvantages of using TIJP and inkjet technology.

Medical materials may be accurately and precisely placed onto surfaces using inkjet printing technology. Pharmaceutical applications benefit greatly from the low risk of contamination and waste of medical samples provided by printing processes. To accurately design materials, inkjet printers use piezoelectric or thermal process to release ink droplets. Inkjet printing has drawbacks, including ink compatibility problems and poorly adhering designs.

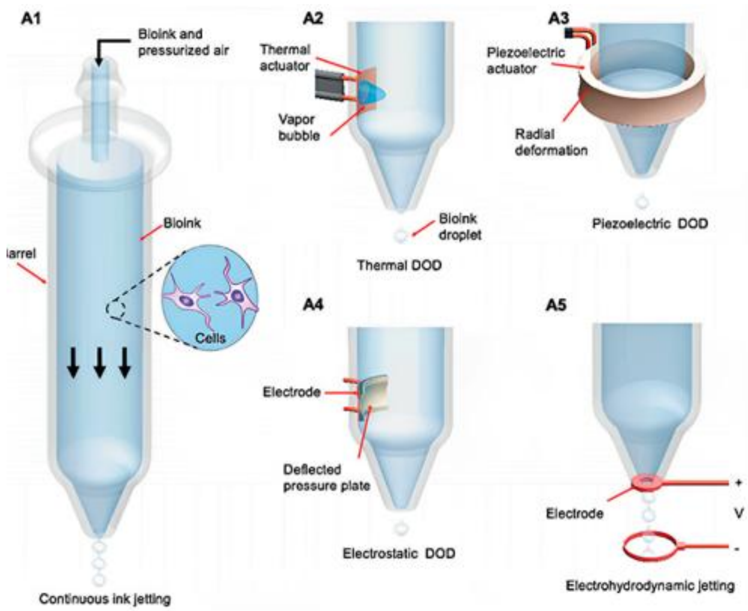


Figure 1.4 Classification of IJP technology [2]

TIJP, or thermal inkjet printing is a drop-on-demand, non-contact printing technology designed for digital data printing. TIJP printers create vapor bubbles with a thin- film resistive heater, which force ink droplets through nozzles and on the surfaces. TIJP printers provide a wide range of printing applications.

Based on the concept of droplet emission, TIJP printers are divided into three configurations: rear, roof and side shooter. With differences in droplet discharge angles and nucleation orientations, each variety has unique benefits and uses.

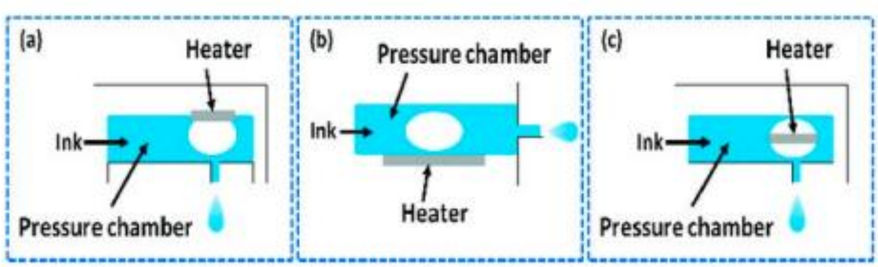


Figure 1.5 (a) Roof shooter, (b) side shooter, and (c) back shooter system [2]

Despite the benefits of TIJP and inkjet technologies, there are a few drawbacks, including issues with ink compatibility, the coffee ring effect and nozzle occlusion. To address these issues, researchers have suggested a few techniques, such as modifying printing settings, investigating substitute printing methods like screen printing and enhancing ink characteristics. These issues can be resolved using different techniques.

In conclusion, Inkjet and TIJP technologies have great potential to change the pharmaceutical manufacturing industry by producing on demand products. Even with drawbacks like ink incompatibility, continuous research and development efforts aims to improve the potential and dependability of these printing methods.

1.3 Problem Statement:

Batch printing, verification and sorting mechanisms on a conveyer are three different tasks which are usually not performed at the same time. There are manual errors and no real time feedback for verifying that batch number and expiry dates are printed correctly or not. This process altogether is not that efficient in workflow management. This project proposes the solution for doing all three tasks together automatically with accuracy in printing batch numbers and expiry dates as well as sorting them by verification through image processing at the same time, increasing efficiency of workflow and quality control by providing real time data of errors in printing.

1.4 Objectives of the Project:

The objectives of the project are to:

1. Design a system for variable data printing and verification
2. Implement an AI based solution for misprint detection
3. Design and implement an automated pneumatic batch number misprint, sorting mechanism

1.5 Cost Analysis:

Table 1.1 Cost Analysis

Name	Quantity	Cost
Printer	1	55000
Pneumatic cylinder	1	2200
Solenoid valve 5/2	1	1500
Proximity sensors	2	2000
Air compressor	1	9000
Raspberry pi	1	29000
Raspberry pi Kit	1	13000
Adjustable stand material	1	4000
Miscellaneous Charges		15000

Total:	126,700/-

1.6 Timeline of the Project:

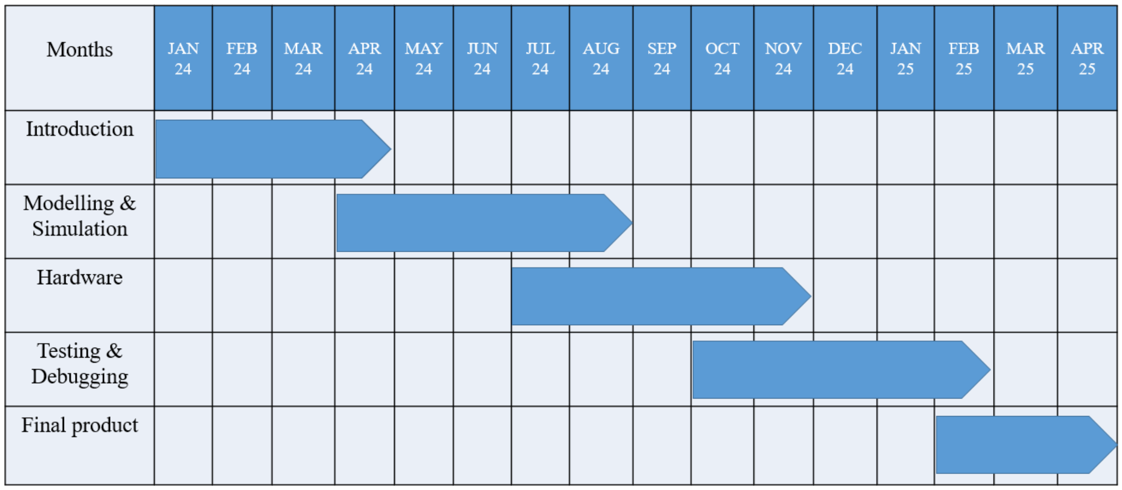


Figure 1.6 Timeline of the project

1.7 Work Division:

Table 1.2 Work Division

Work Division	Muhammad Junaid	Abdullah Ilyas	Izza Nadeem
Literature Review	-	-	✓
Calculations	✓	-	-
Methodology	✓	✓	✓
Components Selection	-	✓	-
Mathematical Modelling	-	-	✓
CAD Modelling	-	✓	✓
Software & Coding	✓	-	-
Electrical System	✓	✓	-
Mechanical System	-	✓	✓
Testing & debugging	✓	✓	✓
Reports Writing	-	✓	✓
Presentation Organization	-	✓	✓

1.8 Organization of Report:

The opening section this document acts as a fundamental component, the context, importance and goals of the research. It presents background details to provide a comprehensive understanding of the batch number printing and sorting, in alignment with existing literature and core ideas. A precise problem statement is given to clarify the issue and its resolution. The study's scope and constraints are delineated to establish its boundaries and set reasonable expectations. The chapter wraps up with a breakdown of work distribution, cost assessment, and project timeline.

2 Description

In the earlier chapter the problem was determined, the goals were set, a brief overview of the project was provided, and the project objective were created. Now we will extensively describe our project.

2.1 Description of the Project

The goal of this project is to create an automated system that can effectively print product expiration dates and batch number, and will identify errors using image processing and machine learning algorithms, and sort products according to printing specifications.

The system combines software algorithms for IP and ML with hardware elements including a conveyor belt, printers, sensors, cameras, and actuators. The development and improvement of AI algorithms for precise misprint detection- which use computer vision techniques to analyze printing material in real-time- is a primary focus.

2.2 Methodology

1. **Hardware Integration**:

Hardware will be integrated using the following mechanism:

- **Printing mechanism:**

The thermal inkjet printer will be used to print on boxes using optical sensors on conveyer belt. Resistors inside it heat up and causes the nearby ink droplets in the ink cartridge to evaporate and generate bubbles. A precise amount of ink is forced through the nozzle and onto the printing surface as the bubble expands. Fresh ink is taken out of the cartridge to replace the dropped droplet as the bubble bursts. Thousands of times a second, this process is repeated to produce prints.

- **Image Acquisition:**

Raspberry pi camera module is connected to Raspberry Pi hardware through a custom CSI interface. The sensor has 5-megapixel native resolution in still capture mode. In video mode it supports capture resolutions up to 1080p at 30 frames per second.

- **Sorting:**

  A pneumatic actuator will be used as a push mechanism for sorting misprinted objects. Sensors are placed before the actuator to detect object when it comes near actuator. Pneumatic actuators provide energy by compressed air, which then converts that into a linear motion to sort. Pneumatic actuators have a high velocity as well as acceleration. Valves are responsible for converting the compressed air to force.

2. **Software Development**:

   Machine learning and Image Processing algorithms will be used:

- **Real-Time Image Processing**:

  Develop image processing algorithms that can process captured images or video streams in real-time such as

- Machine learning algorithms can analyze patterns and anomalies in printed detect mis-printings. By using techniques like supervised learning, unsupervised learning, and deep learning, these algorithms can classify printed items as normal or misprinted based on learned patterns or deviations from expected distributions.
- Optical Character Recognition (OCR) converts characters in an image into characters that a machine or computer would recognize. OCR recognizes letters and numbers in images before converting information to files for storage. The difficulty of optical character recognition is solved by OCR

2.3 List of products:

We will need a combination of hardware and software components for an automated batch printing, verification, and sorting mechanism. Here is a list of the products:

1. Conveyor Belt System:

Conveyor belts to move products through the printing, verification and sorting stages.

Figure 2.1 Conveyor Belt [11]

2. Printer:

- Printer capable of printing batch numbers and expiry dates on products.
- Compatibility with the conveyor belt system for synchronized printing.

Figure 2.2 Batch Printer [3]

3. Sensors and Cameras:

- Barcode scanners for detecting product presence and orientation on conveyor belt.
- Cameras for capturing images pf the printed information and quality inspection sensors to detect misprinting or errors.

Figure 2.3 Raspberry Pi camera module [4]

Figure 2.4 Sensor [5]

4. Computer Vision and Image Processing Hardware:

- Embedded systems for processing images and running AI algorithms.
- High performance computers for processing images and running AI algorithms.

5. AI Algorithms and Software:

- Misprints can be detected by machine learning algorithms.
- For errors detection and for analyzing printed information image processing algorithms will be used.
- Software for controlling and integrating the printing, verification and sorting processes.

6. Microcontrollers:

- Motors, sensors, and actuators can be controlled by using microcontrollers.
- Integration with the conveyor belt and other hardware components.

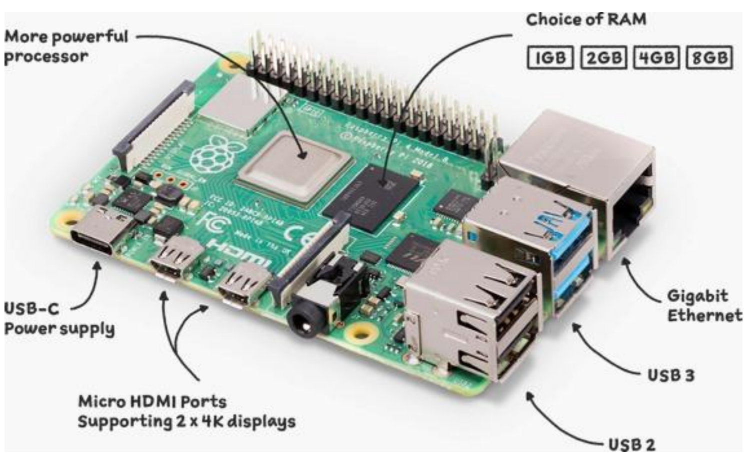


Figure 2.5 Microcontroller [6]

7. Mechanical Components:

- Mounting frames, brackets, and mechanical assemblies to support and position the printers, cameras, sensors, and other components.

Figure 2.6 Frame

- Actuators or pneumatic systems for automated sorting mechanisms.

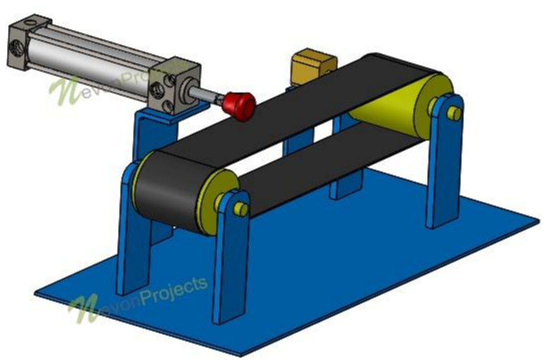


Figure 2.7 Push actuator [7]

8. Safety Components:

- Safety components such as emergency stop button, safety interlocks, and guarding to ensure safe operation

2.3.1 Block Diagram

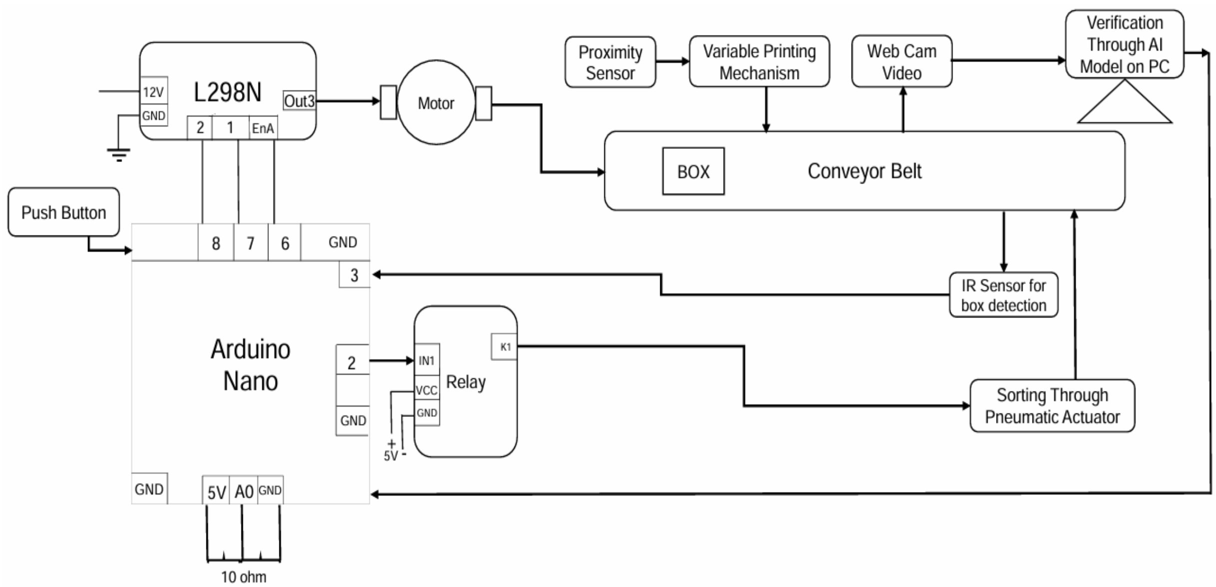


Figure 2.8 Block Diagram

Block Diagram Explanation:

1. **Push Button**: Initiates the operation manually.
2. **Arduino Nano**: The central microcontroller controlling all operations such as motor control, sensor input, and actuator signals.
3. **Conveyor Belt**: Moves items forward for sorting and printing.
4. **Motor and L298N Motor Driver**: The motor runs the conveyor belt. L298N drives the motor, with connections for power (12V, 5V, GND) and control (IN1, ENA, OUT3).
5. **Proximity Sensor**: Detects incoming Box on the conveyor.
6. **Pneumatic Actuator**: Sorts Boxes based on classification, pushes selected items off the conveyor.
7. **Variable Printing Mechanism**: Used to print data Batch Number and Expiry Dates on the Boxes.
8. **Web Cam for Verification**: Used for verification of Printed Batch Number.
9. **IR Sensor**: Detects presence of a box at the receiving end.
10. **Relay Module**: Controls high-power component, actuator through Arduino.

2.3.2 Flowchart:

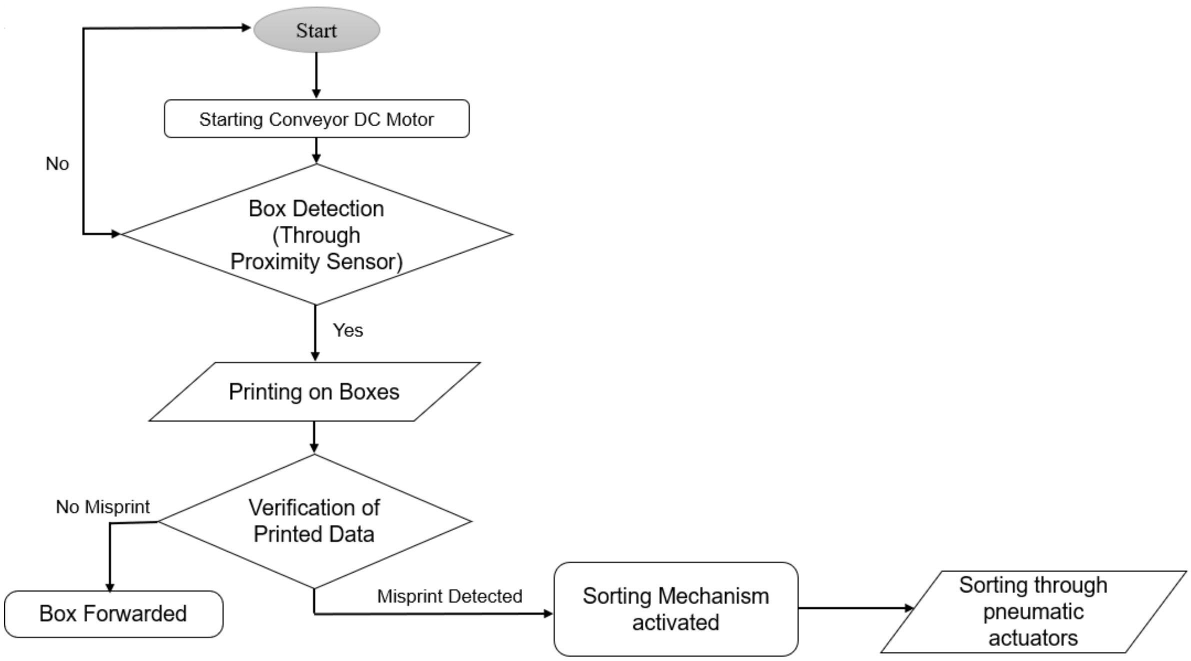


Figure 2.9 Flowchart

3 Modeling and Simulation

This section's main goal is to develop a virtual model for evaluating the suggested automated batch printing, sorting, and verification system. By simulating the dynamic interactions between hardware elements including actuators, sensors, and conveyor belts, such models seek to predict system behavior under a range of operating circumstances.

Key elements of the simulation include:

- Actuator Dynamics: Visualizing of actuators' behavior for different forces and control signals.
- Stress and Deformation Analysis: Determining the extendibility of mechanical components under mixed loads.
- Performance Metrics: The critical indicators are Speed, accuracy in batch printing, error detection rates, and sorting efficiency.

By optimizing the system’s architecture, predictive modeling guarantees dependability and complies with the industry’s requirements. Iterative simulations explore improvements in accuracy, productivity, and algorithmic improvements in component designs and misprint detection. This systematic methodology provides quality control and workflow management with real-time insights, and guarantees the final implementation meets requirements in current manufacturing processes.

3.1 Mathematical Modeling

For the scope of our current project, “Automated Batch Printing, Verification, and Sorting System”, the practical side of the design has been the focus. This project's mathematical modelling is to serve as the basis for the automated batch printing and quality control system. The model attempts to approximate the interactions between the control procedures and the hardware of the system in order to achieve precision and efficiency.

Printing Mechanism

Thermal inkjet technology is used in the printing mechanism. The energy input (thermal pulse) and the subsequent fluid dynamics are analyzed in order to describe the droplet formation dynamics. Important variables include thermal input power, nozzle diameter, and ink pressure.

Misprint Detection Using Image Processing

This subsystem utilizes a Raspberry Pi Camera and AI and ML algorithms for misprint detection. It involves a Yolov5 model to get a region of interest by making a bounding box around expiry dates and OCR to read expiry dates with the given ROI provided by Yolov5.

Sorting Mechanism

Sorting is achieved through pneumatic actuators. The control signal's effect on actuator movement is modeled by: Air pressure dynamics and valve actuation characteristics.

3.1.1 Mathematical Model:

1. **Conveyor Belt Dynamics**

A conveyor belt system includes:

- A DC Motor

Known Data from the Motor

Rated Voltage: V =24

No-load Speed: N_0=142 rpm

(Assuming no-load speed at rated voltage)

Gear ratio can be inferred from model code but usually given in datasheet. We'll assume it is built-in.

Motor type: DC motor with gearhead (reduction gear)

Converting Speed to Angular Velocity

$$\omega_o = \frac{2\pi N_0}{60} = \frac{2\pi \times 142}{60} = 14.87\ rad/s$$

Basic DC Motor Model

For the electrical and mechanical parts:

Electrical:

$$V = L\frac{di}{dt} + Ri + K_e\omega \qquad (1)$$

Mechanical:

$$T = J\frac{d\omega}{dt} + B\omega + T_L \qquad (2)$$

Where,

V = Applied voltage

L = Armature inductance

R = Armature resistance

i = Armature current

K_e = Back EMF constant

ω= Angular velocity of the motor shaft

T = Torque output

J = Moment of inertia— includes motor rotor + gear + load reflected to shaft

$B\omega$ = Viscous friction coefficient

T_L = Load torque

Estimating Motor Constants

We estimate based on motor speed and voltage:

Back EMF constant K_e:

$$K_e = \frac{V}{\omega_0} = \frac{24}{14.87} = 1.61V.s/rad$$

Torque constant K_t

For DC motors, $K_t \approx K_e$ in SI units:

$$K_t \approx 1.61\text{Nm/A}$$

Armature resistance R and inductance L:

Typical values for small geared DC motors:

R ≈ 10–20 Ω (assumed 12 Ω for calculation)

L ≈ 1 mH = 0.001 H (often negligible in low-frequency)

Moment of inertia J and friction

J is small, depends on rotor and gear mass (e.g., $10^{-5}$to 10^{-4}kg·m^2)

B is friction coefficient (small, needs experimental or manufacturer data)

For modeling, these can be adjusted after system identification.

Mathematical Model:

Electrical dynamics:

$$V(t) = L\frac{di(t)}{dt} + Ri(t) + K_e\omega(t) \qquad (3)$$

Mechanical dynamics:

$$K_t i(t) = J\frac{d\omega}{dt} + B\omega(t) + T_L(t) \qquad (4)$$

Transfer Function

Ignoring load torque T_L =0 for simplicity, and taking Laplace transform:

$$V(s) = LsI(s) + RI(s) + K_e\Omega(s) \qquad (5)$$

$$K_t I(s) = Js\Omega(s) + B\Omega(s) \qquad (6)$$

Substituting for $I(s)$:

$$I(s) = \frac{Js + B}{K_t}\,\Omega(s)$$

Plugging into electrical equation:

$$V(s) = (Ls + R)\frac{Js + B}{K_t}\,\Omega(s) + K_e\Omega(s)$$

Rearranged:

$$\frac{\Omega(s)}{V(s)} = \frac{K_t}{LJs^2 + (LB + RJ)s + RB + K_e K_t} \qquad (7)$$

2. Pneumatic Sorting Actuator

Piston length (L):75 mm 0.075m (used for volume estimation but doesn't affect the dynamics directly).

Piston bore (D_b): 32 mm= 0.032 m

Maximum pressure (P_{max}): 0.9 MPa= 900,000 Pa

Piston Area (A_p)

The piston cross-sectional area is given by:

$$A_p = \frac{\pi {D_b}^2}{4} \tag{8}$$

Substituting D_b=0.032 m:

$$A_p = \frac{\pi\ (0.032)^2}{4} = 8.042 * 10^{-4} m^2$$

Compute Force

The maximum force exerted by the actuator is:

$$F_{max} = P_{max} * A_p$$

Putting P_{max}= 900,000 Pa and A_p = 8.042 x $10^{-4} m^2$

$$F_{max} = 900{,}000 \text{ x } 8.042\ x\ 10^{-4} = 723.78N$$

Default Parameters

To complete the model, we assign typical values:

Piston Mass (M_a) $= 2kg$

Damping Coefficient (B_a) $= 50Ns/m$

Spring Stiffness (K_a) = 500 N/m

Flow Resistance (R_t) = 100 Pa / (m^3/s)

Formula Derivation:

Pressure is converted into linear displacement by the pneumatic actuator. Its dynamics are governed by:

$$F_p(t) = M_a \frac{d^2x(t)}{dt^2} + B_a \frac{dx(t)}{dt} + K_a x(t) \tag{9}$$

Where:

$F_p(t)$: Force from the pressure difference.

M_a: Mass of the actuator and load.

B_a: Damping coefficient.

K_a: Stiffness coefficient.

$x(t)$: Displacement of the piston.

Force from Pressure

The force $F_p(t)$ is taken by the pressure difference across the piston:

$$F_p(t) = (P_1 - P_2)A_p$$

$$(P_1 - P_2)A_p = M_a \frac{d^2x(t)}{dt^2} + B_a \frac{dx(t)}{dt} + K_a x(t) \qquad (10)$$

Pressure Dynamics

The pressure P_1 in the chamber is related to the input flow $Q(t)$ and the rate of change of piston volume:

$$Q(t) = \frac{dV}{dt} + \frac{P_1}{R_t}$$

Where:

$V = A_p x(t) + V_0$: Chamber volume.

R_t: Flow resistance.

Taking the derivative of volume:

$$\frac{dV}{dt} = A_p \frac{dx(t)}{dt}$$

Substitute:

$$Q(t) = A_p \frac{dx(t)}{dt} + \frac{P_1}{R_t}$$

Rearranging for P_1:

$$P_1 = R_t(Q(t) - A_p \frac{dx(t)}{dt})$$

Putting P_1 and P_2 back into the force equation:

$$A^2{}_p R_t\big(Q_1(t) - Q_2(t)\big) - A^2{}_p R_t \frac{dx(t)}{dt} = M_a \frac{d^2x(t)}{dt^2} + B_a \frac{dx(t)}{dt} + K_a x(t)$$

Taking Laplace transform:

$$A^2{}_p R_t\big(Q_1(s) - Q_2(s)\big) - A^2{}_p R_t s\, X(s) = M_a s^2 X(s) + B_a s X(s) + K_a X(s)$$

Rearranging:

$$X(s)(M_a s^2 + B_a s + K_a + A^2{}_p R_t s) = A^2{}_p R_t\big(Q_1(s) - Q_2(s)\big) \qquad (11)$$

Transfer Function:

$$G_{actuator}(s) = \frac{X(s)}{Q_1(s) - Q_2(s)} = \frac{A^2{}_p R_t}{M_a s^2 + (B_a + A^2{}_p R_t)s + K_a}$$

Substituting values:

$$G_{actuator}(s) = \frac{(8.042\ x\ 10^{-4})^2.100}{2s^2 + (50 + 6.47 * 10^{-5})s + 500}$$

$$G_{actuator}(s) = \frac{0.01}{0.78s^2+50.01s+500}$$

3.1.2 MATLAB/ SIMULINK model:

Explanation:

The designed Simulink model captures the processes of the conveyor belt dynamics, and actuator dynamics for sorting in the Automated Batch Printing, Verification, and Sorting System. Transfer functions obtained from the mathematical analysis are used to represent each system, ensuring an accurate simulation of the system's dynamic behavior.

3.1.2.1 Simulink Model:

1. Conveyor belt (DC Motor):

This Simulink model simulates a roller throttle system to control the velocity of a DC motor connected to a supercapacitor load. The voltage input block feeds a constant DC supply voltage to the motor block, which acts as a DC motor. Given input, it outputs the angular speed (w) and the armature current (i). These signals correspond to the rotation speed of the shaft and the current in the windings of the motor. The behavior of the motor is controlled by describing how its physical properties, including armature resistance, inductance, back EMF constant, torque constant, moment of inertia, and viscous friction, result in the voltage being converted into motion and current flow. The digital output shows the angular velocity of the Motor, the current, and the input voltage are tied after being volumed by a mux block, going to a scope where its dynamic response is real-time. Moreover, the angular velocity feedback loop to the input mux is available for monitoring or controlling motor speed in a more complex system. All in all, this model offers essential analysis of the DC motor transient-state and steady-state operation under a constant voltage supply, which is used as a raw material for other improvement features such as load torque, type of control to feed the DC motor, and the change from angular to linear velocity for conveyor applications.

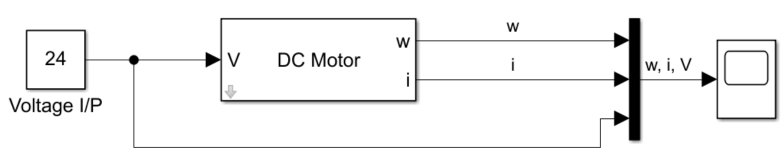


Figure 3.1 Simulink Model of DC Motor

2. Pneumatic Actuator:

- **Pulse Input:**

The following figure shows a Simulink model of a control system for a pneumatic actuator, which is actuated by the pulse input signal. The model starts with the pulse generator block, which generates a square wave signal periodically and is used to represent a switching or control input to the actuator system. This pulse signal acts as a system input and flows into a transfer function block describing the dynamics of the pneumatic actuator. represents a second-order linear system whose second-order linear system parameters: actuator natural frequency, damping, and gain form the transfer function that embodies how the actuator the responds to input changeover time. This transfer function $\frac{0.01}{0.78s^2+50.01s+500}$ block output represents the actuator pneumatic response that can be used for a scope block in order to have it to see the result of its action. Such an arrangement can be used to visualize the transient and steady state response of the actuator to the discrete pulse input and to study system stability, responsiveness, and control properties at practical operation conditions. On the whole, this model provides a simple yet efficient model for testing and optimizing pneumatic actuator dynamics to repetitive control action.

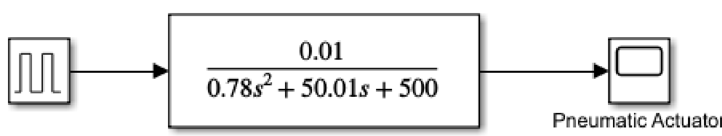


Figure 3.2 Simulink model pulse input

- **Step Input:**

This Simulink model represents a control system for a pneumatic actuator driven by a step input signal. The model starts with a step block, which provides a sudden change in input simulating a quick command or switch from an off to an on state. This step input feeds into a transfer function block representing the dynamics of the pneumatic actuator, described by the transfer function $\frac{0.01}{0.78s^2+50.01s+500}$. This second-order transfer function captures the actuator's response characteristics, including its inertia, damping, and gain, dictating how the actuator output evolves over time following the step input. The output of the transfer function block, representing the actuator's position or pressure response, is then routed to a scope block for visualization. This setup allows the observation and analysis of the actuator's transient and steady-state behavior in response to sudden input changes, which is essential for understanding system stability, responsiveness, and control performance in pneumatic systems.

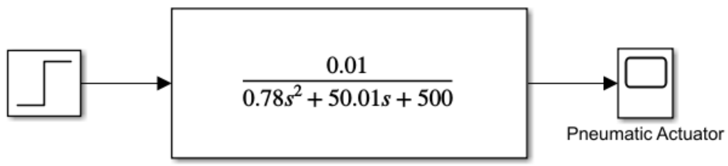


Figure 3.3 Simulink model step input

3.2 Simulation Results

1. Conveyor belt (DC Motor):

The simulation graph shows a realistic motor response where the angular velocity (yellow curve) quickly rises from zero, oscillates briefly due to system inertia and damping, and then settles around 15 rad/s, which aligns well with the motor's rated speed of approximately 142 rpm at 24 V. The current (blue curve) exhibits a typical startup surge before stabilizing near zero, reflecting minimal current draw at no load, while the input voltage (orange curve) remains steady at 24 V. Overall, the results indicate the motor accelerates smoothly to its expected speed with appropriate transient behavior, validating the model's accuracy under the given parameters.

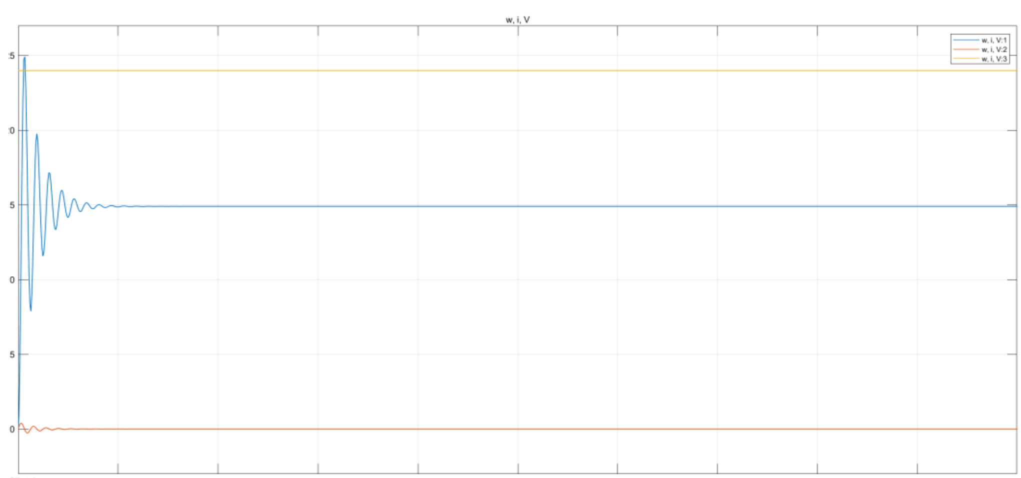


Figure 3.4 Response of DC Motor

3.2.1 Pneumatic Actuator:

- **Pulse Response:**

Output response of the pneumatic actuator against a step input signal held constant for 5 seconds before a return to zero, and with a comparison to a simulation graph. Initially, the actuator response rises rapidly from 0 to 2×10^{5} , indicating a fast-dynamic response of the actuator to the input step. The output then levels off and stays constant at this value for approximately 4 s, suggesting the actuator stays at the same position or pressure during the applied input in the first phase. Another step input is taken out at about 5 seconds, and the actuator output rapidly decreases back to zero, showing that the actuator has recovered. The solution exhibits a fast up and down with no oscillations, which is a classic second-order system with overdamping response. The fact that the output is very small means the system gain or sensitivity is low, as we would expect for an accurate or well-damped pneumatic actuator system.

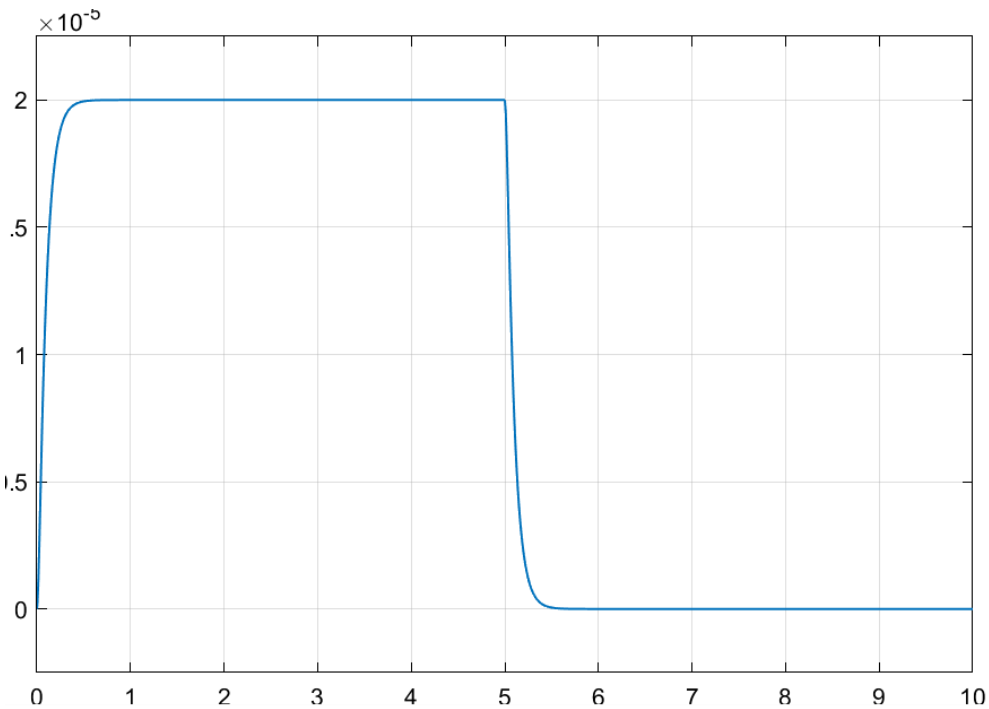


Figure 3.5 Pulse Response of DC Motor

- **Step Input:**

The simulation graph shows the response of the pneumatic actuator to a step input signal over a period of 10 seconds. The output starts at zero and quickly rises to a peak value near 20 microunits (around 2×10^{-5}) shortly after the step input is applied. This rise indicates the actuator's initial reaction to the input change. Following this peak, the output rapidly declines back toward zero and remains near zero for the remainder of the simulation time. This behavior suggests a highly damped or low-gain system where the actuator responds briefly but does not sustain displacement or pressure. The transient response is very fast, with the actuator output settling back quickly, implying either a very stiff system, high damping, or low system gain represented by the transfer function. Overall, the simulation depicts a pneumatic actuator with a rapid but very small amplitude transient output that does not maintain any significant steady-state response to the step input.

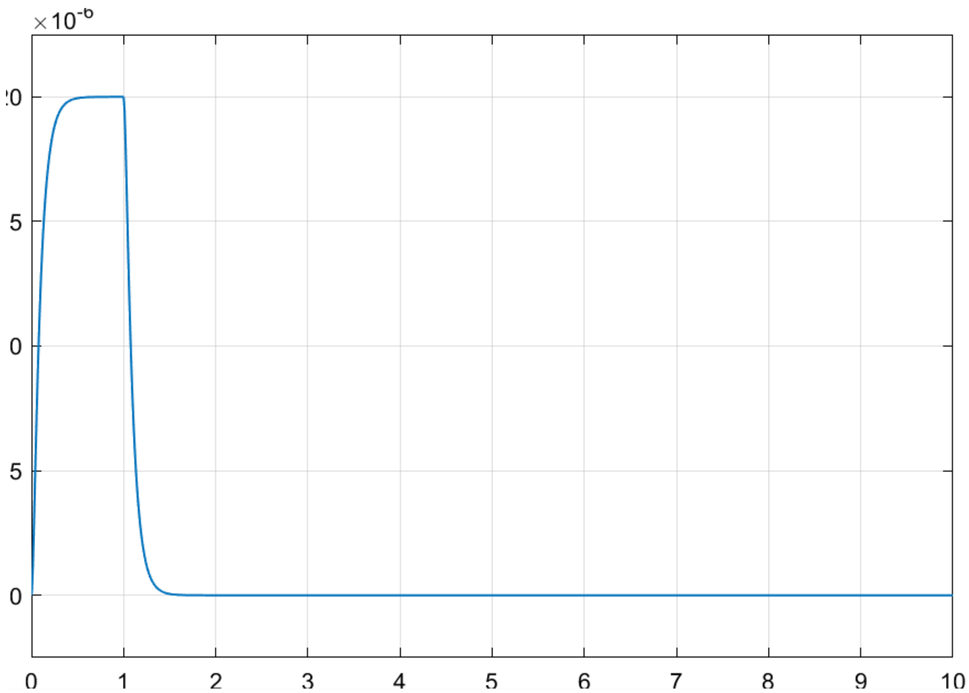


Figure 3.6 Figure 8 Step response of Pneumatic Actuator

3.3 CAD Modeling

An "Automated Batch Printing, Detection, and Sorting System" for effective labelling and sorting in industrial processes is represented by the CAD model. For accurate batch number labelling, the system uses a conveyor belt with a black frame and green belt to carry boxes beneath a printer positioned on a rod. Following printing, a camera is placed before the pneumatic actuator in order to analyze the printed data on the moving boxes and identify any misprints. The pneumatic actuator receives signals from the detecting system and pushes boxes that are flawed or incorrectly printed off the belt to sort them. The integration of the printer, camera, and pneumatic actuator provides a seamless, accurate, and efficient workflow, making it ideal for industries like logistics, warehousing, and manufacturing.

3.3.1 Conveyor Belt

The CAD model is a basic conveyor system showing intended use for automated batch printing and sorting. Because it is probably made of a strong material, the conveyor's rectangular frame gives the structural reliability and durability that it needs. A green conveyor belt goes smoothly on two rollers at the front and back of the frame.

The objects to be processed are represented by a box on the conveyor belt. These objects could go via a printing device that prints batch numbers. The tension of the belt can be controlled or a drive system can be connected for operation, as shown by the provision for a motor or tension adjustment mechanism on one side of the conveyor frame. Because of its durability and simplicity, the conveyor may be integrated with other parts, such a camera to detect misprints or a pneumatic actuator to sort misprinted boxes, fulfilling the needs of an automated batch processing system.

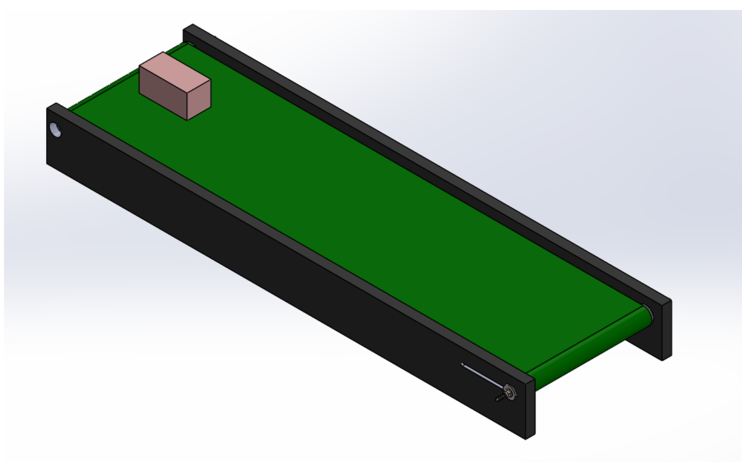


Figure 3.7 Conveyor Belt

3.3.2 Pneumatic Actuator

The CAD model represents a pneumatic actuator, an integral part of automation systems. That it has a piston linear mechanism, has a body like a cylinder, and when pressurized air is introduced; it causes the piston to move linearly. Because of apertures for air entry and exit at the ends of the cylinder, the motion of the piston may be controlled.

A capacity to fit to a threaded rod or a clevis mount at one end allows the actuator to be attached to the conveyor frame or another fixed structure. But on the other side of the actuator, usually when it is working, a piston rod stretches or shrinks (retracts), and to push, pull or hold objects. This actuator design in particular is likely to be used in an automated sorting system, which successfully pushes misprinted boxes off the conveyor, when the camera detects them. Its sturdy construction with efficient design shows that its able to withstand repeated operations in an industrial space.

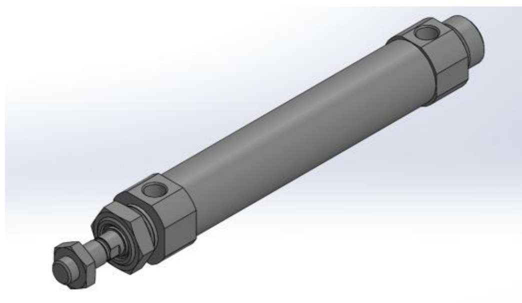


Figure 3.8 Pneumatic Actuator

3.3.3 Complete Assembly

The complete assembly of automated batch printing, verification, and sorting system is represented by this CAD model. The proposed system consists of a conveyor belt mechanism to convey boxes, a printer to print batch numbers, a camera for quality check and a pneumatic actuator for sorting.

The boxes are then placed on the conveyor belt, and moved beneath the printer equipment. Fixed to rods above the conveyor, the printer is positioned so that after the conveyor has started running it can write batch numbers or other required information onto the moving boxes. As the boxes move down the conveyor, they go through the inspection section, a camera assures any errors or defects. The camera, positioned above the conveyor, works so that by continuously examining the printed patterns, the quality is ensured.

If there is a misprint or the sheet has some defect, the pneumatic actuator on the end of the conveyor will be activated. The defective box is pushed off the conveyor, such that only the properly printed boxes move to the next step of the process, as the actuator extends its piston rod to actuate. Due to its ease of the accurate printing, inspection, and sorting processes, this simplified design is preferred on the automated manufacturing lines. Its flexible structure and strong construction turn the system into a dependable, efficient system, easy to keep.

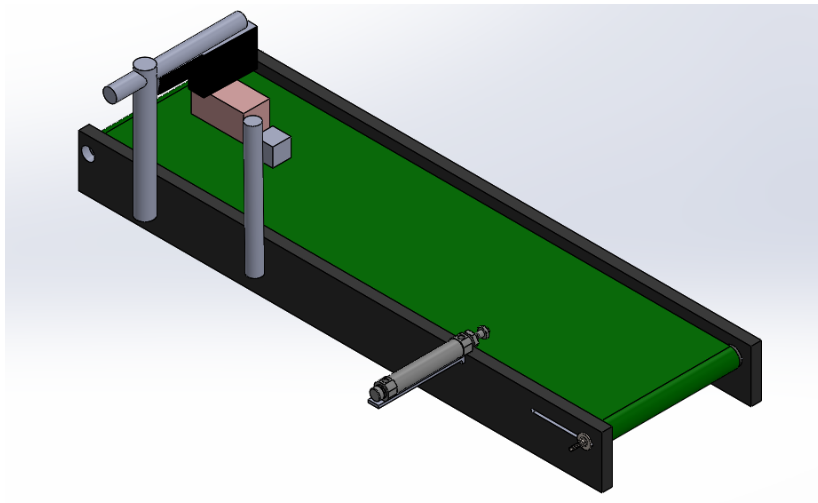


Figure 3.9 Conveyor Assembly

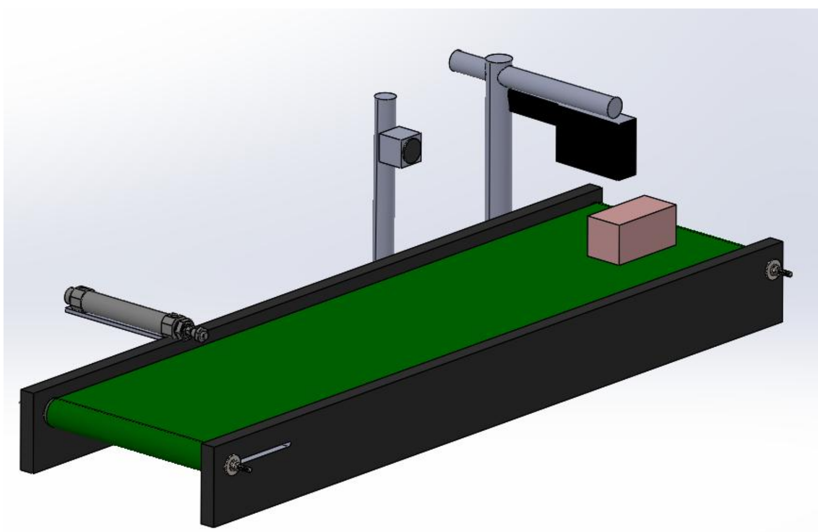
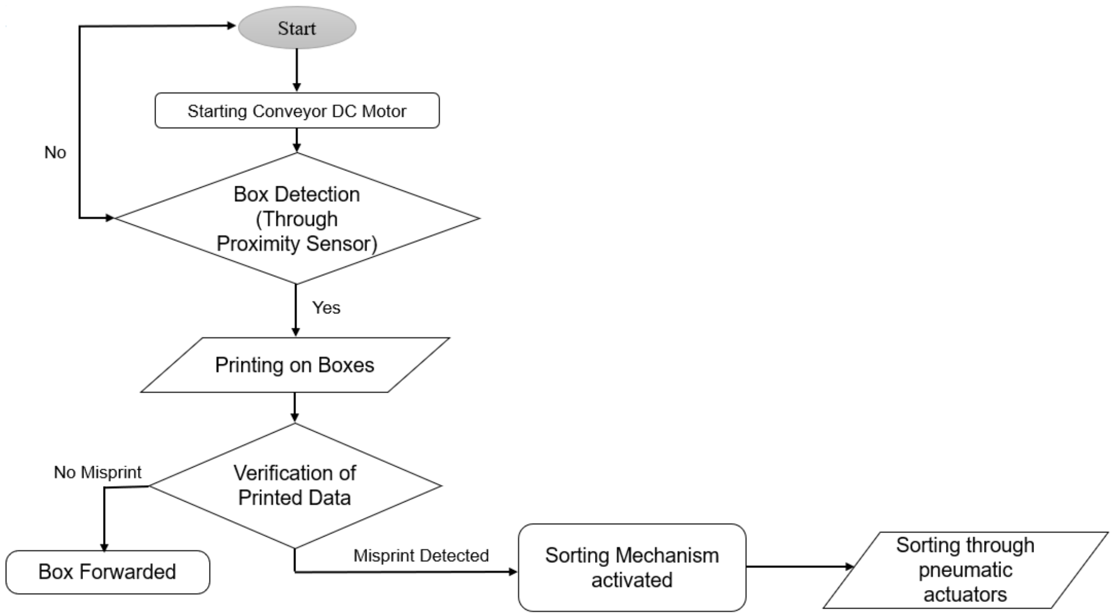


Figure 3.10 Conveyor Assembly

3.4 Algorithms

In our final year project, this section talks about the algorithms used for object localization and expiry date detection. The project uses state of the art machine learning techniques such as the YOLOv5 object detection model and Optical Character Recognition (OCR) to quickly detect and kindly extract expiry date from medicine and grocery items, and make a decision on whether the misprint is detected.

3.4.1 Flowchart



3.4.2 Algorithms Details

1 YOLOv5 for Object Localization

- **Introduction to YOLOv5**

You Only Look Once, Version 5 (YOLOv5) is an object detection algorithm that is very fast, and very accurate. It works by predicting bounding boxes and class probabilities of objects regarding a grid(cell) of an image. It is lightweight architecture and ease of deployment make it a key advantage of YOLOv5.

- **Implementation**
  1. **Dataset Preparation**: Own dataset was augmented with custom images of medicine boxes to train model using own dataset.
  2. **Preprocessing:** We resized the images, and formatted annotations in YOLO's required format.
  3. **Training:** Transfer learning was also used to fine tune the model, utilizing pre trained weights.

4. **Inference:** A webcam was used to deploy the trained object detection model to detect and localize objects in real time.

- **Workflow**

1. Input images or video frames are passed to the YOLOv5 model.
2. The model outputs bounding boxes and class probabilities for detected objects.
3. Bounding boxes corresponding to medicine boxes are cropped for further processing.

2 Optical Character Recognition (OCR) for Expiry Date Detection

- **Introduction to OCR**

OCR technology is used to convert text within images into machine-readable text. This capability is integral to detecting and extracting expiry dates from medicine boxes.

- **Implementation**

Text Region Localization**: Using the bounding boxes from YOLOv5, the regions likely to contain expiry dates are isolated.

Text Extraction: OCR tools such as Tesseract are applied to extract text from the localized regions.

Post-Processing:

Text cleaning to remove unwanted characters.

Regular expressions to extract valid date formats

- **Workflow**

1. Cropped image regions are passed to the OCR module.
2. Text data is extracted and processed to isolate expiry dates.
3. Detected expiry dates are validated and checked for any misprints or errors.

3 Integration Workflow

The integration of YOLOv5 and OCR ensures seamless object localization and text extraction. The combined workflow is as follows:

1. The webcam captures live images or video streams.
2. YOLOv5 localizes objects of interest (medicine boxes) and outputs bounding boxes.
3. The OCR module processes the localized regions to extract expiry dates.
4. The results are displayed in real-time, highlighting detected objects and expiry dates

4 Experimental Setup

Our project's experimental setup consists of an automated system that can effectively print boxes in batches, identify misprints, and reject defects on a conveyor belt. The following essential elements make up the setup:

Conveyor Belt System: The motor-powered conveyor belt makes it easier for boxes to move smoothly through the system's multiple stages. The boxes can be precisely positioned beneath the printer, camera, and pneumatic actuator thanks to the belt's consistent motion.

Batch Printer: A high resolution inkjet printer is fixed in an adjustable support structure above a conveyor belt. In other words, the printer is responsible for printing labels or batch numbers on the outside of the moving boxes. The alignment of each box will ensure it will print accurately and with reliability.

Camera for Misprint Detection: A high speed camera is placed immediately after the printer to check the printed text or design on each box. This camera includes an image processing system that inspects the printed output against predefined criteria. If something has a flaw or it's a mistake we reject it.

Pneumatic Actuator: At the end of the conveyor belt there is a pneumatic actuator. This actuator is regulated by the system through the feedback from the camera. If it spots a mistake, the actuator pushes a box off the conveyor and into a designated rejection box very quickly. Boxes free of defects proceed on the conveyor for further processing.

Control Unit: A central control unit coordinates the whole system, including the conveyor belt, printer, camera and pneumatic actuator. It guarantees excellent operational efficiency, real time decision making, and a seamless workflow.

However, the elements may be adaptively sewed into the experimental setting, thus assuring crisp printing, accurate determination, and effective snubbing of blemished boxes. Made for companies that need to batch code and QC their manufacturing lines, this system provides accuracy and authorization to increase efficiency.

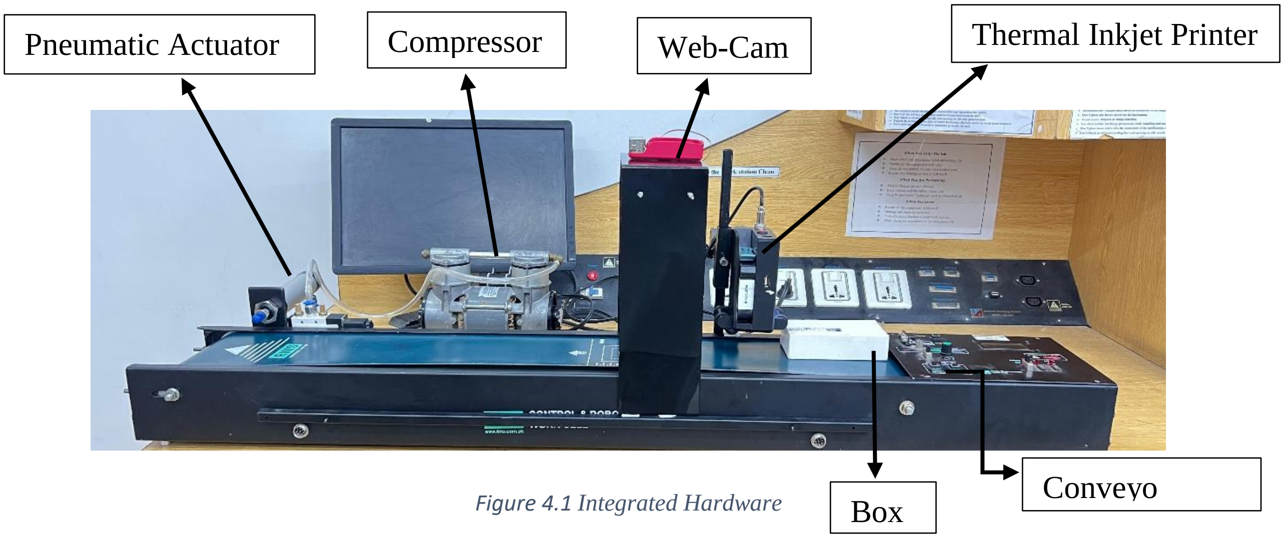


Figure 4.1 Integrated Hardware

4.1 Hardware Description

The automated batch printing, verification, and sorting hardware setup consists of a conveyor belt for moving boxes, a printer for affixing batch numbers, a camera system for identifying misprints, and a pneumatic actuator for separating misprints from good items. The DC motor is used to power the conveyor belt to move smoothly and consistently, for the boxes under the printer and camera. The printer can accurately mark because it has a high-resolution inkjet mechanism. A high-speed camera follows the printer, placed thoughtfully to examine and confirm the printed batch numbers. If a misprint or other problem occurs, then the pneumatic actuator, which is operated by a compressor and controlled by a solenoid valve, is triggered to push the defective boxes off the conveyor belt. It is integrated system that ensures uninterrupted operation, accurate printing and provides fast faulty item classification.

Figure 4.2 Integrated Hardware

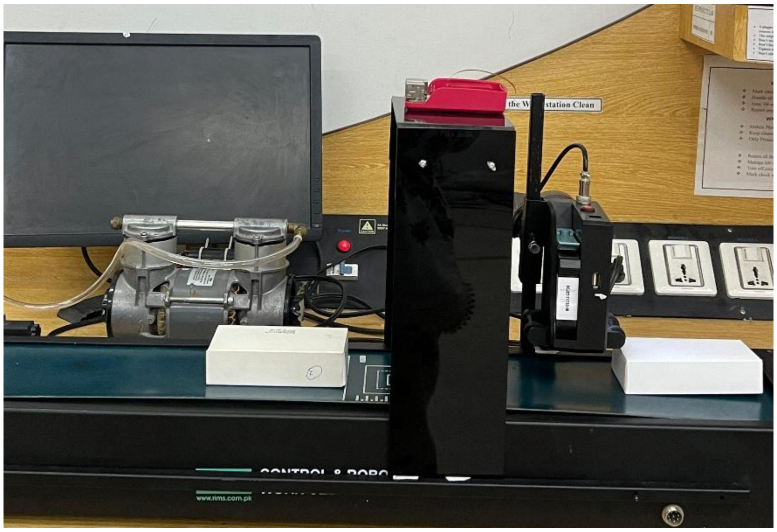


Figure 4.3 Integrated Hardware

4.2 Components

4.2.1 Air Compressor

An air compressor is the hardware component pictured, an essential part of the pneumatic actuator system employed by our automated batch verification and sorting system. This air compressor is used to run the pneumatic actuator which ejects defective or incorrectly printed boxes from the conveyor belt.

The air compressor dual piston is constructed to compress the air in the most efficient and minimal noise and vibration manner possible. Designed with a steel frame that will be reliable over long time periods when in use. The two cylinders deliver high airflow and pressure resulting in better performance and is suitable for industrial applications.

Figure 4.4 Air compressor

4.2.2 Printer

These images demonstrate a Inkjet Printer, a compact printer with a lot of versatility, that can mark and code on different surfaces. The simple touchscreen interface allows users to choose fonts, change sizes, set up settings and personalize batch numbers or barcodes. It does so because of its usage of inkjet technology to print high resolution prints which are suitable for industrial use like batch marking, labelling and expiration date printing. Due to its lightweight construction and layout it is easily carried and used even with prolonged use. It is also very versatile on many manufacturing lines as it can print on cardboard, plastic, and metal. Since it is versatile and mobile, it is an important tool for printing jobs which require on-the-go work in such sectors as packaging, logistics and manufacturing.

Figure 4.5 Printer

Figure 4.6 Printer

4.2.3 Solenoid Valve 5/2

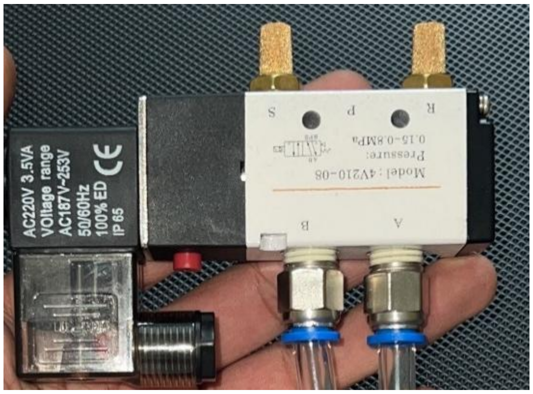


Figure 4.7 Solenoid Valve 5/2

In this image can be seen a solenoid valve, specifically made for pneumatic applications. It is a small valve to effectively manage flow of the fluid and gas as well as it can run on AC 220V input power. Suitable for an industrial pneumatic system, it allows the regulated release or blocking of air flow in the pressure range of 0.15–0.8 MPa. Both input and output connection ports are labeled "A" and "B"; and strong fittings hold the pneumatic tubing firmly in place. Equipped with IP65 protection certification with resistivity to low pressure water and dust the coil assembly allows for stable and quick switching. This solenoid valve is essential when it is a need to operate pneumatic devices such as cylinders and actuators.

4.2.4 Pneumatic Cylinder (Double-Acting)

In this image is Pneumatic Cylinder – commonly used in pneumatic systems for linear motion. With a bore diameter of 32mm and stroke length of 75mm, the cylinder is suitable for applications which entail moderate forces. The high strength and durability are maintained, but lightweight construction is assured, escapes Tomkins in the introduction to a colorful primer on the metals. A rated maximal pressure, generally about 1 MPa, can be held in this cylinder. It is made to work under compressed air. The safe air supply connections of the end fittings ensure reliable functioning. Small and with excellent performance, it makes it the ideal product when we talk about industrial automation for pushing systems, lifting mechanisms and conveyor belt actuation.

Figure 4.8 Pneumatic Actuator

4.2.5 Conveyor Belt

An image is shown of a conveyor belt system that is specifically identified by RIMS as part of the "Control & Robotics Work Cell" for industrial and automation applications. This conveyor belt is the fundamental component for moving objects of all sorts boxes, parts, or even finished goods from one site to another across the numerous production stages. Smooth, long lasting (yet adjusted for accuracy and dependable use), the belt surface. Such markings on the belt as alignment guides and measurement applications are made to the tolerance level to allow high precision applications like sorting, testing and printing. These guidelines, as the goods move along the conveyor, will make sure they fall in the right spot as they go. A strong, metal frame supports the proper dependable frame that drags the conveyor. The switches and indicators on the side control panel allow operation and observation of the conveyor. This control system allows the integration with sensors, actuators, and other automated work cell components so that an efficient and adaptable operation can be guaranteed. The smooth movement of items and support of additional parts such as cameras, printers and actuators make this conveyor ideal for applications such as continuous automated batch printing, verification and sorting.

Figure 4.9 Conveyor Belt

4.3 Schematic and PCB Design

4.3.1 Schematic Diagram

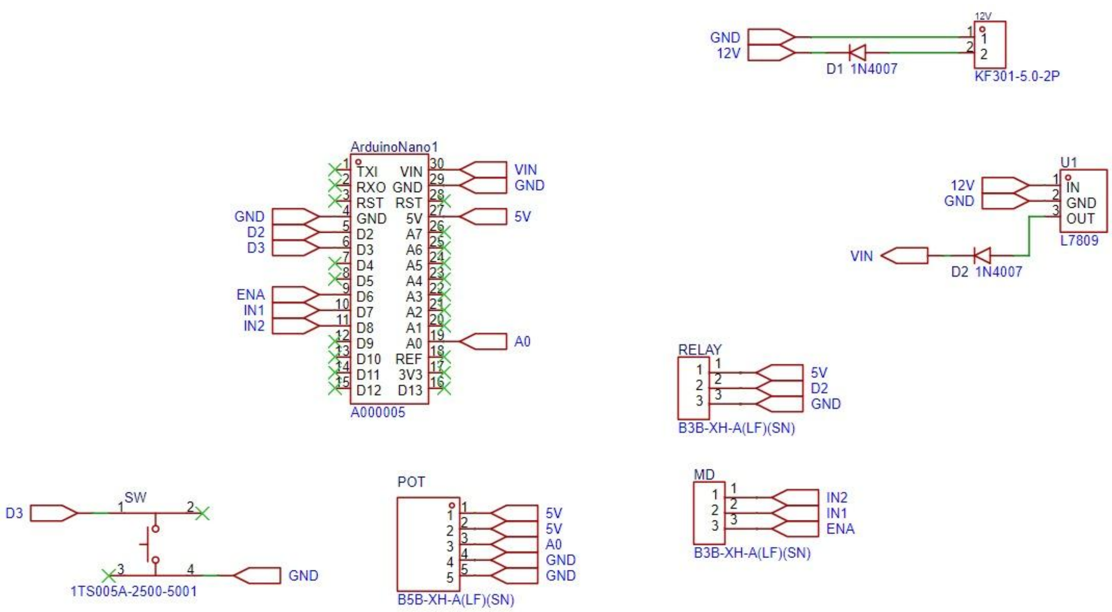


Figure 4.10 Schematic Diagram

4.3.2 PCB Design

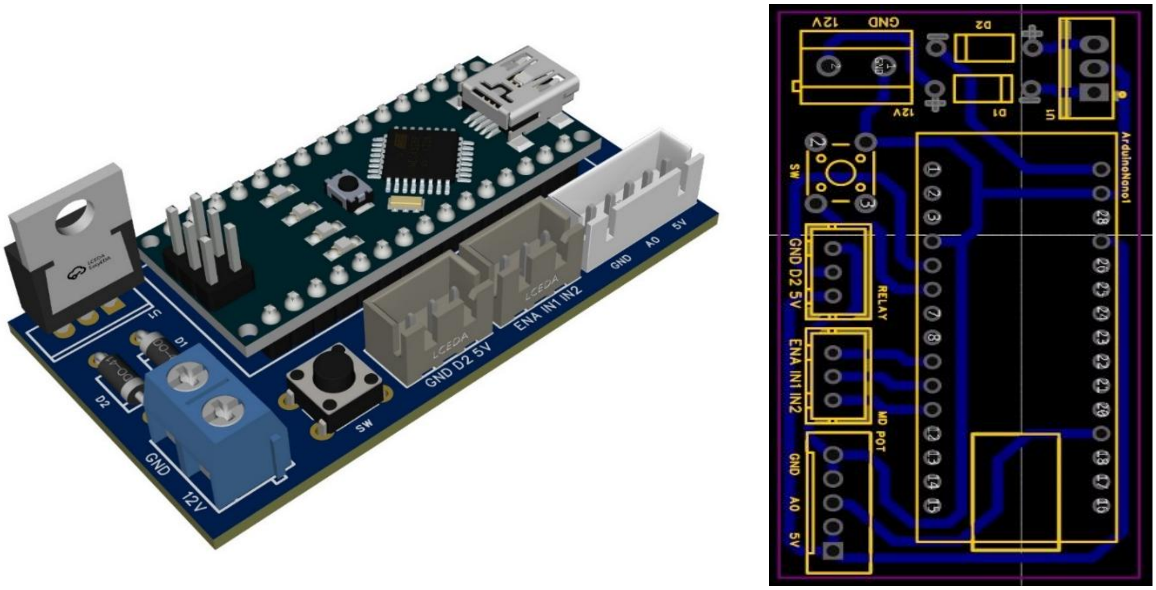


Figure 4.11 PCB Design

5 Results and Discussion

5.1 Results

This project, Automated Batch Number Print, Verification and Sorting System is the contribution to solve automation of the critical process of batch number printing, verification and sorting in the manufacturing. The successful adoption of such system has contributed to countless issues of the manufacturing industry solved, including minimizing manual tasks, ensuring greater precision, and optimizing business processes.

The system combines image processing, machine learning and pneumatic sorting in hit, delivering a full solution for the printing and control of batch number. With high resolution inkjet printer, the system attains accurate and reliable marking of batch numbers and expiry dates. Use of a Raspberry Pi camera allows the detection of any misprint of any inconsistency in printed information with real-time image processing. What is more, the product rejecting facility by means of air system can effectively reject those unqualified products even in the process of conveying so that the qualified products directly go to the further process.

All objectives were achieved:

Objective 1: Design a system for variable data printing and verification

Key Achievements:

- Successfully integrated a high-resolution thermal inkjet printer capable of accurately printing batch numbers and expiry dates on moving boxes.
- Integrated sensors and precise timing mechanisms ensured synchronized printing aligned with conveyor belt motion, maintaining consistent print quality.
- Developed an image acquisition setup using a Web camera module that captures real-time images of printed data for verification.
- The system reliably performed printing tasks with high precision, minimizing misalignment and print quality defects.

Figure 5.1 Achieved objective 1

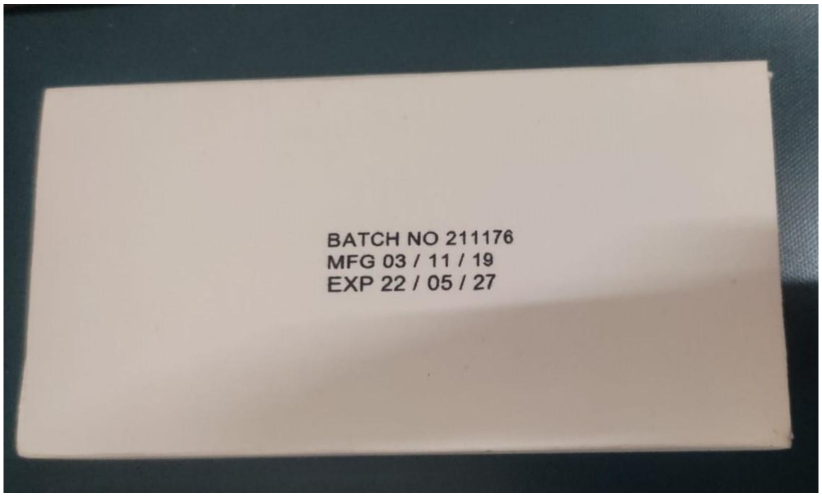


Figure 5.2 Printed Data

Figure 5.3 Printed Data of Different Size

Objective 2: Implement an AI based solution for misprint detection

Key Achievements:

- Developed and deployed an AI-based misprint detection system utilizing YOLOv5 for object localization and Optical Character Recognition (OCR) for text extraction.
- Achieved real-time image processing enabling rapid detection of printing errors or inconsistencies on each box.
- The PC based AI model was trained and fine-tuned on a custom dataset, improving accuracy and robustness in diverse printing conditions.
- The solution successfully identified misprints with high accuracy, reducing the need for manual inspection and improving overall quality control.

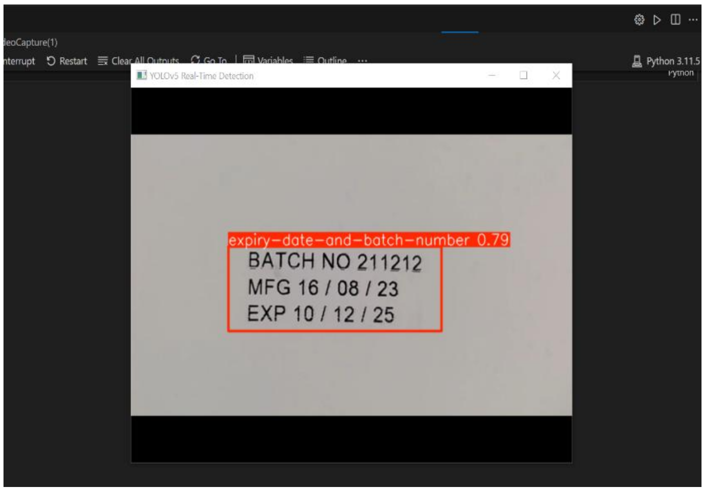


Figure 5.4 Misprint Detection

Figure 5.5 Half Print

Figure 5.6 Blur Print

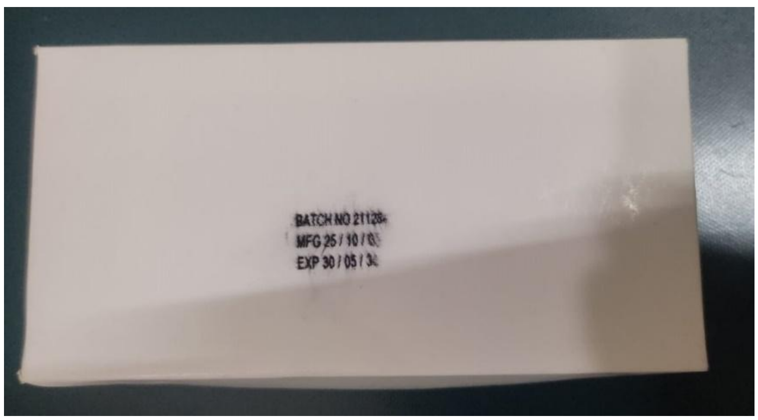


Figure 5.7 Ink Dissipation

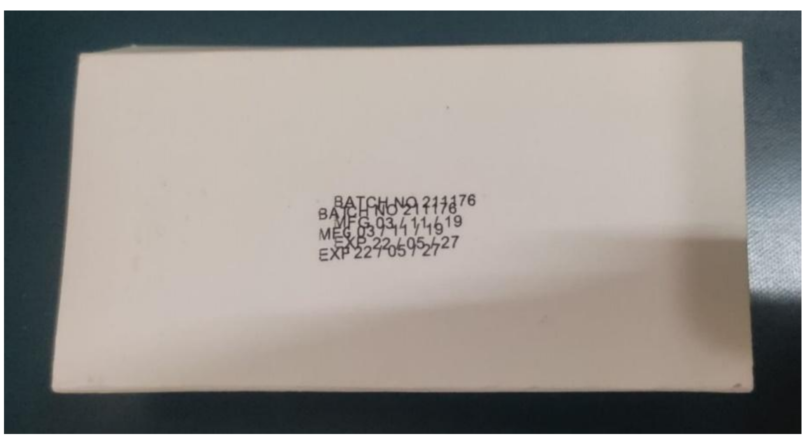


Figure 5.8 over Print

Testing Results:

During the testing phase, the YOLOv5-based misprint detection model was evaluated on a dataset comprising 28 images containing 25 instances of batch numbers. The system achieved a precision of 93.8%, recall of 89%, and a resulting F1 score of approximately 91.4%.
Based on the model's predictions:

- Out of 25 total boxes, the system correctly detected 22 boxes as true positives.
- There was 1 false positive, where a non-defective box was incorrectly flagged.
- 3 boxes were not detected (false negatives) due to factors such as low contrast or partial occlusion.

This indicates that **88%** of all boxes were correctly identified with minimal false positives, confirming the effectiveness of the object detection and OCR pipeline for batch number and misprint verification.

These results highlight the practical viability of the system for industrial batch number inspection tasks. However, the few undetected instances (false negatives) were primarily due to low image contrast, blur, or partial occlusions. This supports the recommendation for higher-quality industrial cameras and improved illumination to further enhance detection reliability.

Table 5.1 Analysis

Metric	Value
Total Images	28
Total Batch	25
Numbers	22
True Positives (TP)	1
False Positives (FP)	3
Precision	93.8%
Recall	89.0%
F1 Score	91.4%
Correct Detection	88%
Common Issues	Low contrast, blur, occlusion
Recommendations	Use better cameras & lighting

Objective 3: Design and implement an automated pneumatic batch number misprint sorting mechanism

Key Achievements:

- Made a pneumatic sorting mechanism integrated with the printing and PC based detection system, capable of automatically rejecting defective or misprinted boxes.
- The pneumatic actuator, controlled by a solenoid valve and sensor feedback, pushed misprinted boxes off the conveyor with precise timing.
- The sorting system operated continuously and reliably during extended testing, with no false rejects or mechanical failures.
- This automation significantly improved workflow efficiency by eliminating manual sorting and ensuring only correctly printed boxes proceed down the production line.

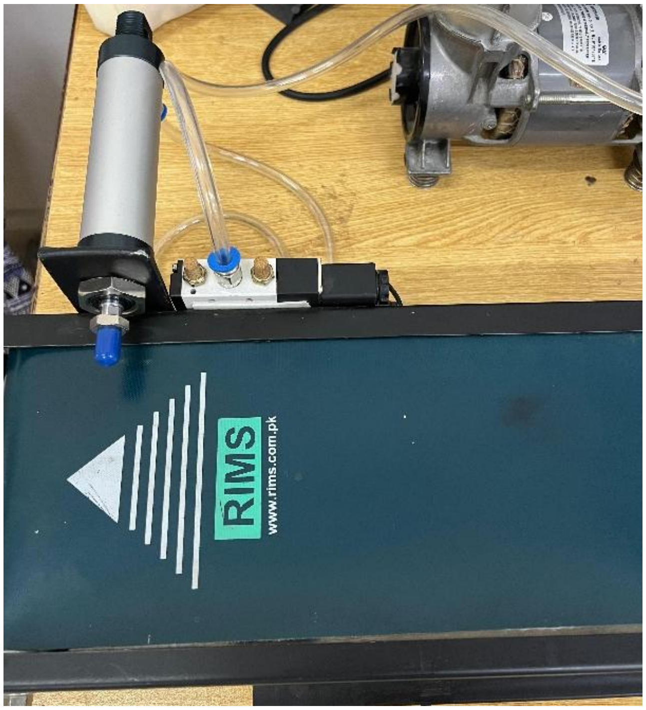


Figure 5.9 Pneumatic Hardware

5.2 Discussion

5.2.1 Integration Success

The hardware systems, including web camera, sensors, thermal inkjet printer and pneumatic actuator, could be well-integrated with their accurate and synchronous control. All component worked together to support each other for system stability and functionality. On the software side, YOLOv5 and OCR were used together to detect misprints in real time for quick processing. This successful integration of hardware and software produced a fully automated software loop with near-constant use and little hands-on time, excellent for high reliability and minimal user intervention for various testing strategies.

5.2.2 Performance vs. Manual Processes

The automated system also achieved a significant difference to the traditional manual batch verification process, which is generally longer per box. This is approximately five times the throughput. Further, it has eliminated the possibility of errors occurring out of tiredness or oversight. With a repeatable process on every cycle, quality was held steady, and the system proved to be a fit for high volume, tight turn-production requirements.

5.2.3 Operational Limitations

During the development and testing phases of the Batch-Print Sortify system, a Raspberry Pi 5 combined with its dedicated camera module was initially selected to perform real-time image acquisition and processing. This choice was motivated by the Raspberry Pi's low cost, compact footprint, and suitability for embedded automation tasks. However, practical deployment revealed notable operational limitations that impacted overall system performance.

A primary constraint was the limited processing power of the Raspberry Pi hardware. The real-time execution of computationally intensive tasks specifically the YOLOv5 object detection model and Optical Character Recognition (OCR) algorithms proved to be highly demanding for the Pi's CPU and limited RAM resources. As a result, the system experienced significantly reduced processing speed and a low frame rate (FPS) during continuous operation. This reduction in FPS led to observable latency in the detection pipeline, causing delays in identifying misprinted products and affecting the synchronization between detection and pneumatic sorting.

Furthermore, the Raspberry Pi camera module itself contributed to operational challenges. While suitable for prototyping, its image resolution, lens quality, and low-light performance were not sufficient to ensure accurate OCR, especially when print quality varied or ambient lighting conditions fluctuated.

To address these shortcomings within the available constraints, the processing tasks were offloaded to a PC processor, which provided improved computational capabilities and GPU support for faster model inference. Simultaneously, the Raspberry Pi camera module was replaced with a high-resolution mobile web camera, which delivered clearer images and superior focus and lighting adaptability. This interim solution enabled the team to complete functional testing and demonstrate proof-of-concept results with acceptable detection reliability.

The use of a laptop for processing is not viable for an industrial embedded system that requires compact, dedicated edge computing hardware. A web camera, although practical for prototyping, does not offer the ruggedness, fixed mounting precision, or continuous operational reliability required in industrial environments. Both substitutes limit the system’s scalability and hinder integration into a robust, production-grade deployment.

To overcome these limitations and fully transition the system to industrial standards, it is strongly recommended that the hardware be upgraded to include an NVIDIA Jetson platform (e.g., Jetson Xavier NX or Jetson Nano). These embedded AI modules are specifically designed for real-time edge processing and provide powerful GPU acceleration capable of handling advanced computer vision algorithms with high FPS and minimal latency.

Additionally, a dedicated industrial camera offering higher resolution, adjustable optics and focus, robust low-light capability, and industrial-grade connectivity (such as GigE Vision or USB3 Vision standards) is required. Such cameras ensure stable, repeatable image capture and are engineered for continuous operation under industrial conditions.

Integrating these advanced hardware components will resolve the current operational bottlenecks, enhance real-time detection accuracy, maintain consistent processing speeds, and ensure the entire system performs reliably in demanding manufacturing environments.

5.2.4 Opportunities for Enhancement

Several improvements have been suggested to overcome the limitations mentioned and to further increase system performance. If LEDs are permanently mounted around the camera, lighting quality becomes independent of ambient light. Moreover, by using a high-res camera or adopting a dual camera system, a 360° inspection can be realized, along with a larger range of product shapes and sizes. Utilizing a user-friendly interface would allow operators to view feedback in real-time, manually intervene when required, and access performance logs and data analytics at any time, enhancing the service they provide and process control in general.

5.3 Project Outcomes

5.3.1 Project Impact

The Batch-Print Sortify system proved highly effective and quantifiable in the automation of an inherently manual task of printing of batch numbers, verification, and sorting. By integrating thermal inkjet printing, on-the-fly image processing, and pneumatic actuation, the effort has resulted in a full solution to improve traceability and reduce human error. By integrating the system into the production line, misprinted products could be detected and rejected immediately, greatly enhancing production line efficiency and consistency. The smooth integration of hardware and software demonstrated that robust automation is attainable even with no more than modest means in small and medium-sized businesses.

5.3.2 Industrial Relevance

The system fulfills a vital requirement in markets including pharma, food packaging, and consumer goods, where labeling accuracy is imperative to comply with regulations and ensure consumer safety. Manual checks, as traditionally done, are consuming and leave the possibility of missing defects, whereas this equipment offers uniform quality control at a high speed. Thanks to its modular design, it is relatively easy to extend and scale to meet the specific needs of different product lines, and it is also very cost-effective, with inexpensive microcontrollers, Raspberry Pi, and open-source tools being its main components something that is particularly appealing to industry, often working with very narrow margins.

5.3.3 Sustainable Development Contributions

This initiative has a direct contribution to several SDGs. Goal 3 (Good Health and Well-being) The solution is there to help consumers by verifying that the product labeled is the product received and reducing health risk through correctable lot and expiration date inaccuracies. Goal 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work Efficiency and productivity on the manufacturing line can contribute to being more competitive and cost-effective. Finally, SDG 9 (Industry, Innovation, and Infrastructure) is tackled with the aim of allowing smart systems and automation to enter conventional industries, thereby fostering innovation and sustainable industrialization.

6 Conclusions and Future Recommendations

6.1 Conclusions

The *Batch-Print Sortify* system has successfully demonstrated the feasibility and effectiveness of integrating automation, artificial intelligence (AI), and pneumatic sorting technologies in industrial batch verification and sorting processes. Key achievements include:

- **Enhanced Operational Efficiency**: With the help of technology, it managed to remove most manual operations, minimizing human errors and delivering higher throughput with standardized Quality Control.
- **Advanced Print Verification**: The introduction of PC based AI-based algorithms for OCR and object detection has made it easier to accurately score print quality in line with industry standards.
- **Scalable and Modular Design**: The system's architecture allows for easy adaptation to various production environments, making it suitable for diverse industries such as pharmaceuticals, food and beverage, and consumer goods.
- **Real-Time Data Processing**: Real-time integration for data analytics has enabled proactive, quality management and traceability, which allows quick action to potential issues.

These outcomes align with findings from recent studies highlighting the transformative impact of AI and automation in manufacturing processes.

6.1.1 Achievement of Objectives

The project successfully achieved all its core objectives, including the design and implementation of an automated system and integration of batch number printing, real-time verification using AI-based image processing on PC, and pneumatic sorting of misprinted products. The system effectively replaced manual inspection processes, reducing errors and increasing throughput.

6.1.2 System Efficiency

The project fully met all its core intentions and, as a result, has integrated an automatic device for printing batch numbers, real-time PC based verification of products with the use of AI-based image analysis, and pneumatic separation of defective items. The system virtually eliminated manual inspection activities, and helped decrease errors and increase yield.

6.1.3 Industrial Relevance and Scalability

The system has strong industrial relevance, particularly in the pharmaceutical, food, and consumer goods sectors. Its modularity and cost-effective design make it very flexible and scalable for use on different production lines, particularly in small and mid-sized companies seeking to automate their labelling and control operations.

6.2 Future Recommendations

6.2.1 Enhanced Camera

Higher resolution cameras, as well as fixed LED lighting, would improve the accuracy of OCR, specifically in changing conditions. It would make the system able to scan muddier or less crisp prints, as well.

6.2.1.1 Importance of High-Resolution Cameras

High-resolution cameras capture more pixels per inch, resulting in sharper images with finer details. OCR systems need this level of detail to correctly identify text in images and extract it. Fine detail of characters, such as serifs or small variations in font style, needs to be imaged accurately so that OCR algorithms can interpret them correctly. In the absence of such detail, OCR systems may have difficulty recognizing characters properly, causing errors in the extracted text and thus in the further processing of the data.

6.2.1.1.1 Key Benefits:

- **Detail and Precision:** High-resolution web cameras capture images with more pixels, resulting in finer details and higher image clarity.

- **Better Zooming Capabilities:** Both images have undergone zooming, less details are lost with a higher resolution image compared to a lower resolution image.
- **Better Analysis:** PC based AI and ML algorithms can analyze more efficiently on high-resolution web cameras, where they can read more subtle information.

6.2.1.2 Role of Fixed LED Lighting

Fixed LED lighting simplifies the light condition and avoids shadow and glare from background light that often degrades image quality. The lighting environment needs to be stable in OCR systems, and it should avoid the situation where the image quality will rather inconsistent when the conditions change, and accordingly, the text recognition accuracy will also be affected.

6.2.1.2.1 Key Benefits:

- **Consistent Illumination:** Fixed LED lighting provides uniform brightness, reducing shadows and highlights that can interfere with OCR accuracy.
- **Enhanced Contrast:** Good lighting provides enough contrast to allow the characters to stand out from the background.
- **Reduced Glare:** Our lights are designed to reduce glare to the minimum possible level and help reduce visual fatigue.

6.2.1.3 Combined Impact on OCR Accuracy

This combination of high-resolution cameras and fixed LED lighting provides an ideal platform for OCR systems. Such configurations have been demonstrated to result in major advancements in OCR accuracy, particularly under difficult conditions such as small and faded text and complex backgrounds.

6.2.2 Handling of Diverse Product Shapes

The current system is optimized for flat-surfaced boxes. Future designs should incorporate adjustable mounts and multi-angle cameras to accommodate cylindrical and irregular-shaped packages, broadening industrial applicability.

6.2.2.1 Multi-Angle Imaging Systems

A single camera system can also be problematic in the case of cylindrical and irregular-shaped packages that require all surfaces to be read for OCR purposes. This can be achieved by multi-camera systems located around the item. For example, the Cylindrical 360-degree OmniView Product Inspection System stitches images together from 4-5 separate cameras to create a continuous, unwrapped view of the surface of a cylindrical object.

6.2.2.2 Adjustable Mounting Systems

In order to be able to accommodate different product shapes, movable brackets are required. These mounts provide versatility to the camera positioning and the correct tilt for capturing images on complex surfaces. For instance, adjustable optical mounts may be worked to couple the optical elements to a cage system for the purpose of retaining and aligning for high precision imaging.

6.2.2.3 3D Vision Systems

More complex, or optically clear packaging may benefit from 3Dvision systems. These systems can capture the depth and contours of objects, permitting detailed inspection of labels and prints on textured objects. The Zivid 3D color cameras, for example, lever the structured light to generate high-definition 3D point clouds and perform accurate measurements or inspection of objects regardless of their shapes.

6.2.3 AI Model Expansion

More comprehensive datasets would be able to enhance the YOLOv5 model to better detect low-resolution or colored text. We would also like to look at both edge computing and FPGA-based acceleration for faster inference.

6.2.3.1 Dataset Augmentation and Diversity

Expanding and diversifying the training dataset is essential for improving model robustness. Incorporating a wide range of fonts, colors, backgrounds, and print qualities ensures that the model generalizes well across different scenarios. The original images can also be artificially scaled, translated, rotated, and color-jittered to expand the size and variations of the dataset, as well as to achieve better model performance.

6.2.3.2 Model Architecture Enhancements

Incorporating advanced architectural modifications can enhance YOLOv5's ability to detect small, incomplete, or embossed characters. For instance, integrating multi-scale residual attention mechanisms allows the model to focus on relevant features at different scales, improving detection accuracy for challenging print scenarios

6.2.3.3 Edge Computing and FPGA-Based Acceleration

Running YOLOv5 on edge devices featuring Field-Programmable Gate Arrays (FPGAs) can greatly reduce the inference latency and computational overhead. Recent FPGA-based accelerators have demonstrated fast and efficient operation using quantization methods with low-resolution bits, i.e.,4-bit quantization, with minimal degradation in accuracy.

6.2.3.4 Hardware-Software Co-Design Approaches

Implementing hardware-software co-design strategies can further optimize YOLOv5's performance on edge devices. Techniques like Tensor Train (TT) decomposition for model compression and the development of efficient hardware accelerators tailored for YOLOv5 can lead to significant improvements in execution time and resource utilization.

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Appendices

Python Code:

```
import serial
import time
import torch
import cv2
import numpy as np
import os
import sys
import warnings
warnings.filterwarnings("ignore")

# Load custom YOLOv5 model
path = r'C:\FYPN\yolov5'
sys.path.insert(0, path)

from utils.torch_utils import select_device
from utils.general import non_max_suppression
from models.common import DetectMultiBackend

device = select_device('')
model = DetectMultiBackend(r'C:\FYPN/bestfinal.pt', device=device)
model.eval()


cap = cv2.VideoCapture(1)
if not cap.isOpened():
print("Error: Could not open webcam.")
exit()

ser = serial.Serial('COM4', 115200)

# Thresholds
CONF_THRESHOLD = 0.5
PRINT_THRESHOLD = 5
# Counters
count_print = 0
count_misPrint = 0
count_no_detection = 0

while True:
ret, frame = cap.read()
if not ret:
print("Error: Failed to capture image.")
break
```

```
frame = cv2.resize(frame, (512, 512))  # width=512, height=512
img_tensor = torch.from_numpy(frame).permute(
2, 0, 1).float().div(255.0).unsqueeze(0).to(device)

with torch.no_grad():
pred = model(img_tensor)
pred = non_max_suppression(pred, conf_thres=0.5, iou_thres=0.45)


detected = False

for det in pred:
if det is not None and len(det):
for *xyxy, conf, cls in det:
class_id = int(cls.item())
confidence = float(conf.item())

if class_id == 0 and confidence > 0.5:
count_misPrint += 1
detected = True
break  # exit inner loop

elif class_id == 1 and confidence > CONF_THRESHOLD:
count_print += 1
detected = True
break  # exit inner loop

if detected:
break


if count_print >= PRINT_THRESHOLD:
print('0')  # Correct print
count_print = 0
count_misPrint = 0
count_no_detection = 0
ser.write(b'0')
time.sleep(10)

elif count_misPrint >= PRINT_THRESHOLD:
print('1')  # Misprint
count_misPrint = 0
count_print = 0
count_no_detection = 0
ser.write(b'1')
```

```
elif not detected:
count_no_detection += 1
if count_no_detection >= PRINT_THRESHOLD:
print('1')  # No detection after enough attempts
count_no_detection = 0
count_print = 0
count_misPrint = 0
time.sleep(2)
ser.write(b'1')
else:
# Reset no-detection counter if something was detected
count_no_detection = 0

if cv2.waitKey(1) & 0xFF == ord('q'):
break

cap.release()
ser.close()
cv2.destroyAllWindows()
```

Arduino Code:

```
const int RELAY_PIN = 2;    // Relay ki pin
const int TRIGGER_PIN = 3;  // sensor ya button ki pin

const int Pot = A0;

const uint8_t ENA_PIN = 6;  // PWM to L298 ENA
const uint8_t IN1_PIN = 7;  // L298 ki IN1 deni
const uint8_t IN2_PIN = 8;  // L298 KI IN2 deni


int RUN_SPEED = 255;        //speed kam ziyada
const bool RUN_FWD = true;  //forward ya reverse krne k liye

int PotValue = 0;

int Pwm = 0;

char Data;

bool SignalFromPi = false;
```

```
void setup() {
  Serial.begin(115200);

  pinMode(ENA_PIN, OUTPUT);
  pinMode(IN1_PIN, OUTPUT);
  pinMode(IN2_PIN, OUTPUT);
  pinMode(RELAY_PIN, OUTPUT);
  pinMode(TRIGGER_PIN, INPUT);
  digitalWrite(RELAY_PIN, LOW);
  digitalWrite(ENA_PIN, LOW);
  digitalWrite(IN1_PIN, LOW);
  digitalWrite(IN2_PIN, LOW);
}

void loop() {


  ///////////////For Serial

  while (Serial.available() > 0) {
    Data = Serial.read();
    Serial.println(Data);



    PotValue = analogRead(Pot);
    Pwm = map(PotValue, 0, 1024, 0, 255);

    analogWrite(ENA_PIN, Pwm);
    digitalWrite(IN1_PIN, HIGH);
    digitalWrite(IN2_PIN, LOW);
    if (Data == '0') {

      SignalFromPi = false;
      digitalWrite(RELAY_PIN, LOW);

    } else {
    }
    if (Data == '1') {

      SignalFromPi = true;

    } else {
    }
  }
```

```
  if (SignalFromPi == true) {
    if (digitalRead(TRIGGER_PIN) == LOW) {

      digitalWrite(RELAY_PIN, HIGH);
      delay(3000);

      digitalWrite(RELAY_PIN, LOW);

      SignalFromPi = false;
    }
  }
  else{

  }

  ///////// Motor Control

  PotValue = analogRead(Pot);
  Pwm = map(PotValue, 0, 1024, 0, 255);

  analogWrite(ENA_PIN, Pwm);
  digitalWrite(IN1_PIN, HIGH);
  digitalWrite(IN2_PIN, LOW);

  //Serial.println(Pwm);
}
```

GitHub Project Link:

https://github.com/mj70339/Fyp-Batch-number-and-expiry-date-printing-verification-

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