Precision Automation: Redefining Production Lines Lines

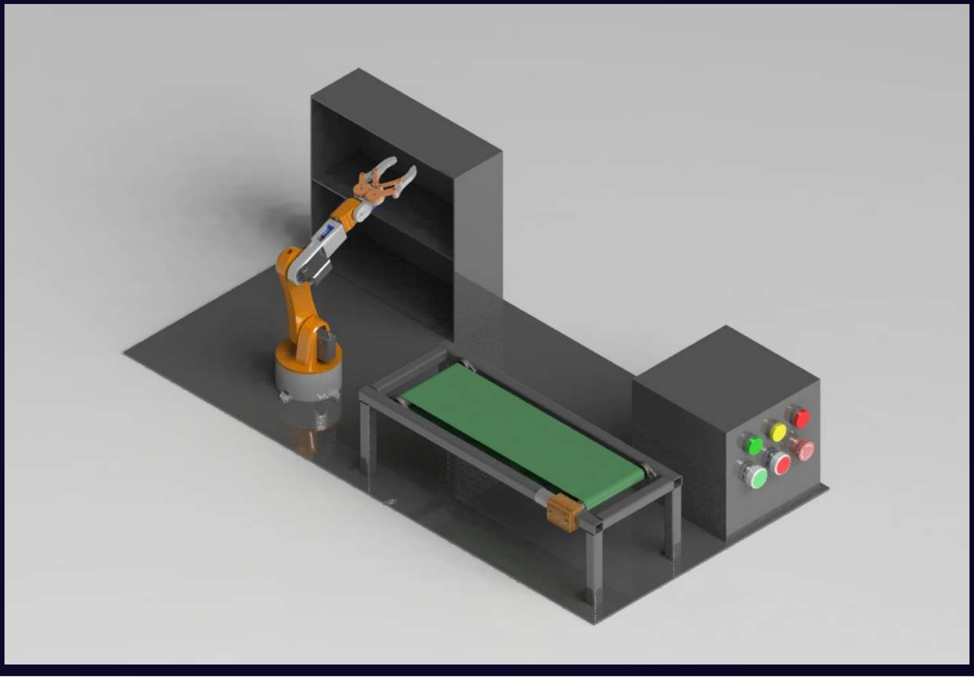
Lazy But Smart Bots| Robotics systems| 2025

Introduction & Motivation

The Challenge

In today's highly competitive manufacturing environment, conventional production lines struggle with rising operational costs, dependence on manual labor, and inconsistent sorting accuracy. These limitations increase the risk of human error and reduce overall efficiency. As a result, there is a growing need for an automated, reliable, and cost-effective production system capable of ensuring continuous operation and consistent product classification without human intervention.

Our project presents an affordable and scalable automation solution that combines sensor-based decision making with robotic manipulation, enabling accurate height-based sorting without the complexity of full-scale industrial robotics.



Project Team Structure

Team Division & Responsibilities

To ensure efficient project execution and balanced workload distribution, the team was divided into specialized sub-teams. This approach allowed tasks to be clearly allocated, reduced individual workload, and improved overall productivity and coordination throughout the project development process.

Mechanical Team

Design Team (SolidWorks)

Electrical Team

Programming Team

Mechanical Team

Kinematic Modeling of the Robotic Arm

1. System Description

- The project presents the complete mechanical design and analysis of a 5-DOF robotic arm developed for sorting and pick-and-place applications.
- The robot is designed to manipulate objects and place them in predefined locations based on sorting criteria such as size or length.

2. System Overview

- Manipulator Type: Serial robotic arm
- Degrees of Freedom: 5
- Joint Type: All joints are revolute
- Application: Sorting and pick-and-place operations

3. Joint Configuration

The robotic arm consists of five rotational joints:

J1: Base (waist) rotation

J2: Shoulder lift

J3: Elbow motion

J4: Wrist pitchJ5: Gripper rotation

This configuration provides sufficient flexibility and reach for accurate sorting tasks.

Mechanical Team

Mechanical Design Summary

The robotic arm is analyzed under quasi-static operating conditions with rigid links and negligible friction, assuming a fixed base and vertical gravitational loading. The mechanical design has been validated through CAD-based analysis and torque calculations, demonstrating that the arm is lightweight, stable, and well-suited for sorting applications.

5. Motor Selection & Weight Optimization

- Motor types: MG995 and SG90.
- Rated torque: 13 kg·cm @ 6V.
- Safety factor ≈ 1.36.
- ABS material and hollow links reduce arm mass.
- Lower mass improves stability and efficiency.

6. Material Selection

- The robotic arm is manufactured using ABS plastic.
- Low density reduces inertia and motor load.
- Adequate mechanical strength for sorting tasks.
- Easy manufacturing using 3D printing.
- Electrical insulation and vibration damping.
- ABS Properties: Density ≈ 1040 kg/m³, Tensile strength ≈ 40 MPa, Elastic modulus ≈ 2–2.5 GPa.

7. Link Structure

Each link is treated as a rigid body connecting two consecutive joints:

- L1: Waist link
- L2: Upper arm
- L3: Forearm
- L4: Wrist link

The base is excluded from motion analysis since it is fixed.

4. Gripper, Load & Torque Analysis

- Gripper treated as an independent mechanical unit.
- Payload mass: 0.05 kg.
- Worst-case loading when arm is fully extended.
- Design ensures safe joint operation.
- Total required torque ≈ 9.52 kg·cm.

Kinematic Modeling of the Robotic Arm (DH Method)

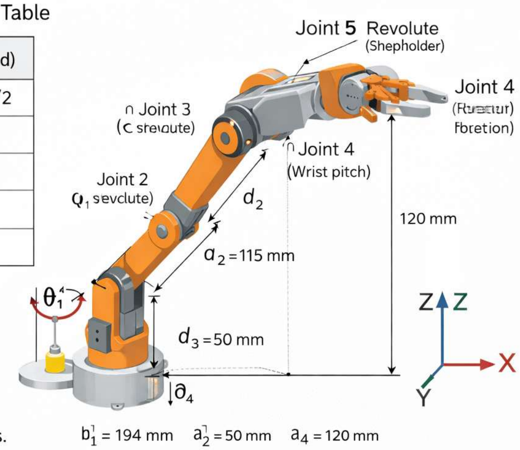
Denavit–Hartenberg (DH) Parameter Table

Joint	θ_1	d_2 (mm)	α_1 (mm)	α_1 (rad)
1	θ_1	194	0	$+\pi/2$
2	θ_2	0	115	0
3	θ_3	0	50	0
4	θ_4	0	120	0
5	θ_5	0	0	0

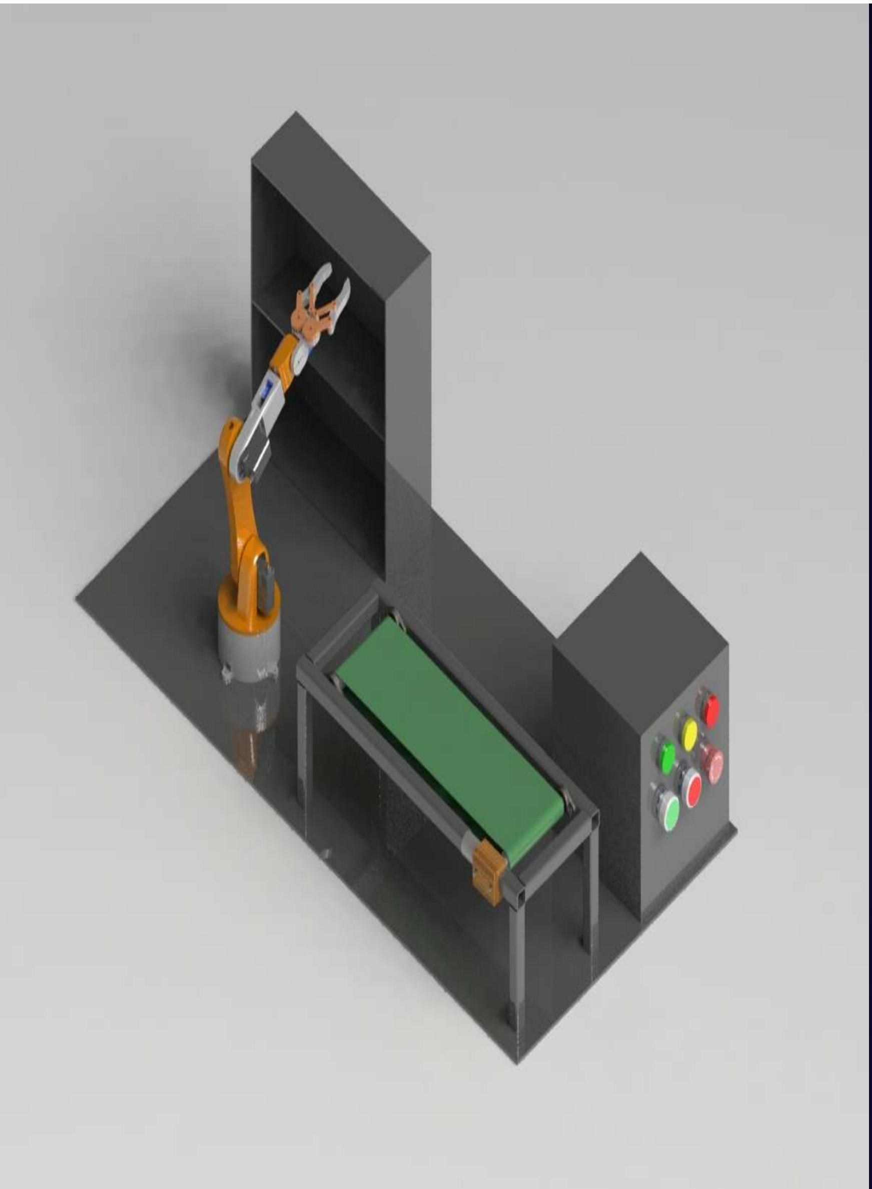
The kinematic model of the robotic arm is developed using the standard Denavit–Hartenberg (DH) convention.

The robot consists of five revolute joints, providing five degrees of freedom suitable for sorting and pick-and-place applications.

All DH parameters were extracted directly from the mechanical CAD design, ensuring accurate representation of the physical geometry,



DH frame assignment and joint configuration of the 5-DOF robotic arm.



Design Team (SolidWorks)

SolidWorks Design Details

The system was fully modeled using SolidWorks to ensure accurate dimensions, proper component placement, and realistic visualization before fabrication. The design includes the conveyor belt frame, robotic arm base, product handling area, and control panel housing. Special attention was given to structural stability, component alignment, and ease of assembly. This 3D model helped in identifying potential mechanical issues early and ensured seamless integration between mechanical, electrical, and control components.

1. Storage Shelf (Product Rack)

- Designed to store sorted products based on height classification.
- Multiple levels to accommodate different product sizes.
- Positioned within the robotic arm’s working envelope to ensure accurate placement.
- Designed with sufficient clearance to avoid collision during arm movement.

2. Control Box (Electrical Enclosure)

Houses electrical components such as power supply, Arduino controller, and motor drivers.

Designed for easy access and maintenance.

Front panel includes control buttons and indicator lights for system operation and status monitoring.

Provides protection for electronic components from dust and mechanical damage.

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3. Robotic Arm Assembly

- Mounted on a stable base to ensure vibration-free operation.
- Designed with adequate degrees of freedom to reach the conveyor and storage shelf.
- End-effector (gripper) designed to securely pick and place products.
- Motion range and positioning verified through SolidWorks assembly simulation.

4. Conveyor Belt (Production Line)

Acts as the main transport system for products.

Frame designed to provide structural rigidity and smooth belt motion.

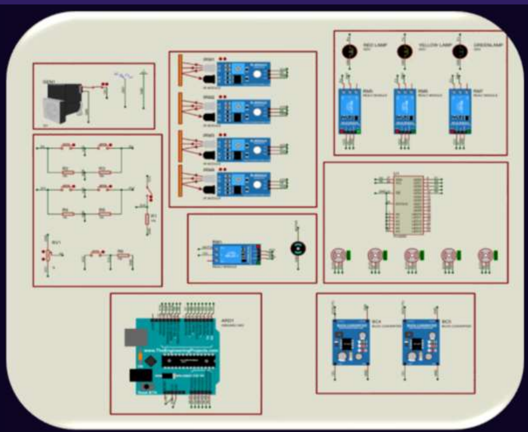
Belt dimensions selected to match product size and sensor placement.

Allows consistent product spacing for accurate IR sensor detection.

Electrical Team

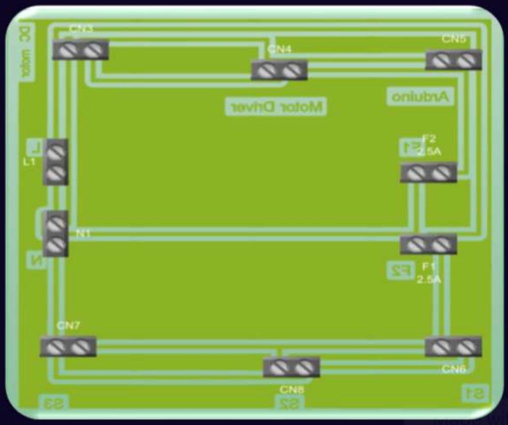
Electrical System – Diagram Integration

- As shown in the electrical diagram, all sensors, actuators, and indicators are connected directly to the Arduino controller, allowing full software-based control of the system.
- IR modules are interfaced with the Arduino to provide real-time product height detection signals.
- Relay modules are used to safely switch high-power devices such as lamps and motors under controller commands.
- Indicator lamps (Red, Yellow, Green) display the system status and sorting state.
- Servo motors controlling the robotic arm are driven through the controller with appropriate power regulation.



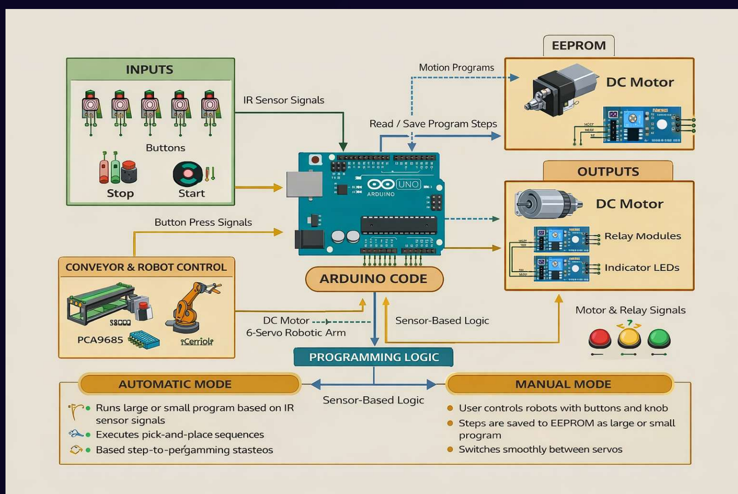
Electrical System – Diagram Integration

- The 12V / 10A power supply feeds the system as illustrated.
- Buck converters step down the voltage to suitable levels for logic and sensors.
- A custom-designed PCB is used to unify all ground connections, improving signal stability.
- Fuses integrated into the PCB provide protection against overcurrent and short circuits.



Programming Team

Control & Programming



1. Libraries & System Setup

- The system uses the PCA9685 servo driver to control multiple servo motors accurately via I2C communication.
- EEPROM is used to save robot motion programs permanently, so movements are not lost after power-off.

2. Input & Output Definition

- The system uses the PCA9685 servo driver to control multiple servo motors accurately via I2C communication.
- IR sensors detect product presence and determine its height.
- Push buttons are used for Start, Stop, mode selection, and saving positions.
- LED indicators (Red, Yellow, Green) show the current system status.
- A DC motor is used to drive the conveyor belt.
- EEPROM is used to save robot motion programs permanently, so movements are not lost after power-off.

3. Servo Control Logic

- The robotic arm consists of 6 servo motors, each controlled independently.
- Servo angles are converted into PWM signals using the PCA9685 driver for smooth and stable motion.

Programming Team

Control & Programming

4. Manual Mode (Teaching Mode)

- Each servo can be selected and controlled manually using a potentiometer.
- Servo positions are saved step-by-step into EEPROM.
- Two motion programs are stored:
  - One for large products
  - One for small products
- This allows easy reprogramming without changing the code.

6. Conveyor & Counting Logic

- The system counts products entering and leaving the conveyor.
- Separate counters are used for small and large products.
- This keeps the conveyor and robotic arm fully synchronized.

5. Automatic Mode

- The robotic arm moves automatically to a home position before starting.
- Product size is identified using IR sensors.
- The robot executes the corresponding program (large or small).
- Sorting is performed automatically without human intervention.

7. LED Indicators & Safety Control

- LEDs provide clear feedback on system status (Running, Waiting, Stopped).
- The conveyor motor stops automatically when required to ensure safety.
- The Stop button immediately halts the system and resets all counters.

8. System Reliability & Integration

- The control logic ensures smooth coordination between sensors, conveyor, and robotic arm.
- The software was developed in coordination with the Electrical and Mechanical Teams to achieve full system integration using a single controller.

Bill of Materials

Hardware Components Specification

No.	Component	Quantity	Function
1	Arduino Uno	1	Main controller for sensors, motors, and logic
2	PCA9685 Servo Driver	1	Controls multiple servo motors via I2C
3	Servo Motors	6	Robotic arm movement
4	IR Sensors	4	Product detection and height classification
5	DC Motor	1	Drives the conveyor belt
6	Relay Modules	4	Controls high-power devices
7	Red Indicator Lamp	1	Stop / Error indication
8	Yellow Indicator Lamp	1	System running / standby
9	Green Indicator Lamp	1	System ready / active
10	Push Buttons	6	Start, Stop, Save, Run, Mode selection
11	Potentiometer	1	Manual servo position control
12	Power Supply 12V 10A	1	Main power source
13	Buck Converters	2	Voltage step-down for logic and sensors
14	Custom PCB	2	Ground unification and wiring organization
15	Fuses	2	Circuit protection
16	Conveyor Belt	1	Product transportation
17	Robotic Arm Structure	1	Mechanical arm structure (ABS)
18	Control Box	1	Houses electrical components
19	Wiring & Connectors	As needed	Electrical connections

Lazy But Smart Bots

Num	Team	Team 1	Section	Notes
1	Programming Team	عبدالله جمال عبدالسلام ابوزيد	3	
2		نورهان مصطفي عبد الوهاب اسماعيل	5	
3		فاطمه وائل يوسف على	3	
4	Electrical Team	أحمد مجدي عبدالحميد محمد	1	
5		عمر هاني عبدالحميد حافظ	3	
6		احمد ياسر عبدالرشيد عبدالعليم	1	
7		عمرو أبو الخير عبدالحميد عبدالرازق	6	
8		عبدالحليم عبدالهادي الديب	1	
9	Mechanical Team	يوسف عرفان محمود إبراهيم	6	
10		رقية احمد سيف هلال	6	
11		ميرنا سيد احمد عبدالعزيز عويس	6	
12		نسرين يوسف بكري جوده عوض	5	
13	Mechanical Team	نورا ابراهيم ابراهيم على عبدالحليم	5	
14		محمد على حسن سليمان حسن	4	
15		يوسف محمد بكر ابو القمصان السودانى	6	
16		هاجر شريف عبدالعظيم عبدالخالق سالم	5	
17		كريمان اشرف عبدالعزيز عيسى	3	

Thanks