

# Automated QR Code Recognition and Sorting Using OpenCV and SCARA

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**Abstract** - In the rapidly evolving domain of Industry 4.0 logistics, manual material handling remains a critical bottleneck characterized by high error rates and operational inefficiencies. Addressing this challenge, this research presents the design and implementation of a cost-effective, automated sorting system that integrates machine vision with a custom-fabricated SCARA robot. The primary objective was to engineer an autonomous work-cell capable of identifying and palletizing products based on barcode data, thereby mitigating reliance on manual labor. The methodology employs a robust distributed control architecture, decoupling high-level processing from real-time actuation. A laptop utilizing a custom Python- OpenCV pipeline performs real-time image acquisition and QR code decoding via a webcam to determine sorting logic. These commands are transmitted via serial protocol to an Arduino Uno equipped with a CNC shield, which functions as the deterministic controller for the 4-DOF SCARA robot's inverse kinematics. Experimental validation confirms that the system achieves high sorting accuracy and reliable mechanical execution, successfully bridging the gap between complex industrial requirements and accessible technology. In conclusion, this project demonstrates a scalable, economically viable solution for intelligent material handling, offering immediate applications in warehousing, e-commerce and fulfillment, and small-scale manufacturing lines.

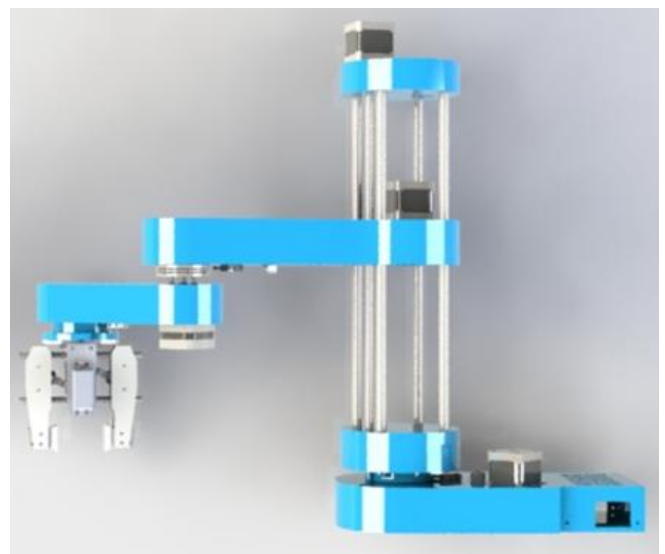
**Key Words:** SCARA robot, computer vision, QR code recognition, distributed control, industrial automation

## 1.INTRODUCTION

The evolution of modern manufacturing and logistics, in line with Industry 4.0, is defined by a fundamental shift towards intelligent and automated material handling (AMH) systems. This paradigm focuses on creating scalable, high-precision sorting cells that form critical links in an autonomous supply chain. Central to this evolution is the Selective Compliance Articulated Robot Arm (SCARA), a kinematic configuration featuring three rotary joints and one prismatic joint. The SCARA design is mathematically optimized for planar tasks, offering inherent rigidity in the vertical direction while remaining selectively compliant in the horizontal plane. By integrating Computer Vision (CV) via libraries such as OpenCV, the sorting process is transformed from a basic physical action into a smart, data-driven operation capable of dynamic decision-making.

While automated sorting is a staple of large-scale industry, current high-end solutions often rely on expensive, proprietary vision systems and industrial robots that regularly cost between Rs. 6,00,000 and Rs. 20,00,000. Manual material handling remains a significant bottleneck for smaller enterprises, characterized by high error rates, fatigue, and ergonomic hazards such as repetitive strain injuries. Furthermore, a critical technical challenge exists in managing the computational

conflict between non-deterministic high-level vision processing and deterministic real-time motor control. Attempting to run complex image processing and time-critical robotic actuation on a single processor often leads to microsecond-level timing failures and catastrophic mechanical sequences. There is a distinct research gap in developing accessible, low-cost architectures that effectively decouple these tasks, particularly when utilizing high-density data carriers like QR codes for stationary work-cell sorting.



**Fig -1:** SCARA robot

The primary objective of this research is to design and implement a cost-effective, autonomous sorting work-cell by integrating a custom-fabricated SCARA robot with a QR-code-based vision system. The methodology focuses on the complete mechanical design, kinematic analysis, and physical fabrication of the robotic manipulator using 3D-printed joints and high-carbon steel rods to minimize capital expenditure. A core goal is the establishment of a robust distributed control architecture, utilizing a laptop as a high-level supervisor for OpenCV-based image acquisition and an Arduino Uno with a CNC Shield as a dedicated real-time controller. By decoding QR code data in real-time, the system will autonomously execute precise pick-and-place sequences, validating the feasibility of using open-source tools and custom hardware to solve tangible industrial challenges.

The scope of this research is constrained to the development of a stationary robotic sorting cell; it does not include automated material conveyance or proximity-based arrival sensing. The system is specifically designed to handle lightweight payloads suitable for e-commerce fulfillment and small-scale manufacturing. Technical boundaries include the use of NEMA 17 stepper motors for primary axes and a metal-gear servo motor for end-effector actuation. Perception is limited to top-down 2D image acquisition of QR codes within a fixed focal range via a high-definition webcam. Furthermore, as this custom-built SCARA lacks inherent force-torque

sensors, the operational scope assumes a controlled environment requiring standard industrial safety measures, such as physical guarding, to prevent hazardous human-robot interaction.

## 2. METHODOLOGY

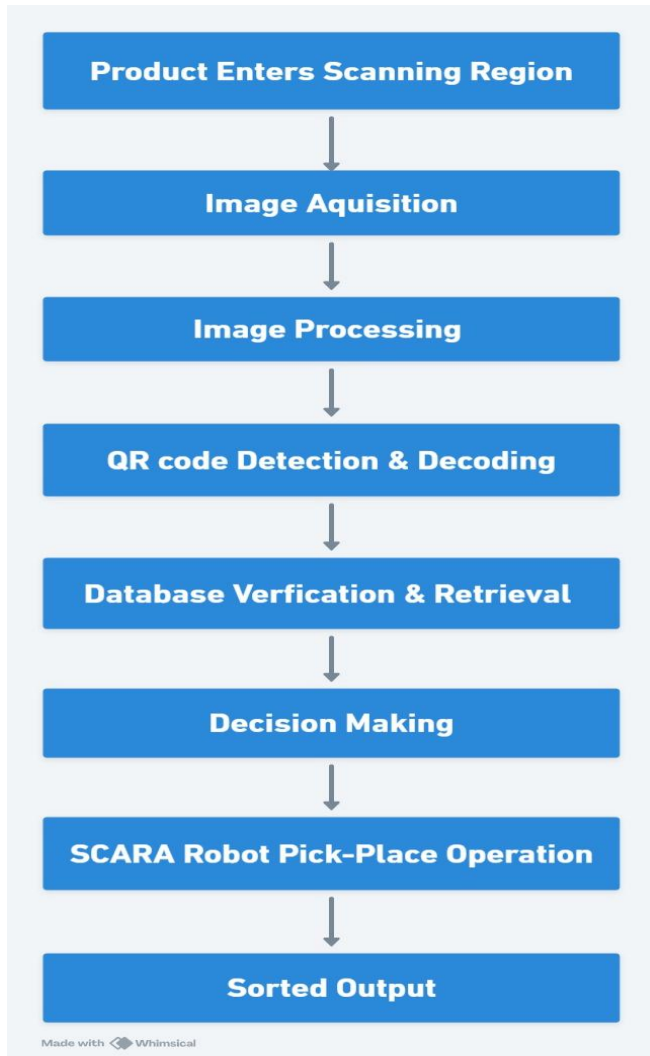


Fig -2: Flowchart

The methodology of the proposed system focuses on the development of an automated product identification and sorting system using QR code recognition integrated with a SCARA robotic manipulator. The system follows a structured workflow that combines computer vision techniques, database management, and robotic control to perform accurate product classification and sorting. The overall methodology involves multiple stages, including image acquisition, image processing, QR code detection and decoding, database verification, decision making, and robotic pick-and-place operations. Each stage plays a significant role in ensuring reliable and efficient system performance.

The process begins with the placement of a product within the scanning region of the system. A camera is positioned above the scanning area to capture the image of the QR code printed on the product surface. When the product enters the scanning zone, the camera captures a high-resolution image that contains the QR code information. The captured image is transmitted to the processing unit, where it becomes the input for the computer vision algorithms. The camera setup is

carefully arranged to maintain proper focus, lighting conditions, and viewing angles in order to ensure accurate image capture and minimize errors during the detection stage.

Once the image is acquired, it undergoes an image preprocessing stage. The primary purpose of preprocessing is to enhance the image quality and prepare it for reliable QR code detection. In this stage, the captured image is first resized to a standardized resolution to ensure consistent processing speed and performance. The image is then converted into grayscale format, which simplifies the image data by reducing the color channels and focusing on intensity variations. Additional filtering techniques are applied to remove noise and improve image clarity. Contrast enhancement may also be performed to highlight the QR code patterns and improve the visibility of the code structure. These preprocessing operations significantly improve the effectiveness of the subsequent detection algorithms.

After preprocessing, the system proceeds to the QR code detection and decoding stage. Computer vision algorithms implemented using the OpenCV library are utilized to locate the QR code region within the processed image. The detection algorithm identifies the QR code by analyzing its distinct square shape and alignment patterns. Once the QR code is successfully detected, the decoding algorithm extracts the encoded information embedded within the QR code. This information typically represents a unique product identifier that is associated with a specific product record in the system database. The decoded data is then transferred to the next stage of the system for verification and classification.

Following the decoding process, the extracted QR code information is compared with the records stored in the product database. The database acts as a centralized storage system that maintains detailed information about different products. This information may include product identification numbers, product names, product categories, and predefined sorting locations. The system searches the database for a matching entry corresponding to the decoded QR code data. Once a match is found, the relevant product information is retrieved and used to determine the appropriate sorting destination for the product. This database-driven approach allows the system to manage multiple product categories efficiently and enables flexible expansion by simply updating the database.

The next stage of the methodology involves decision making and control signal generation. The processing unit acts as the central controller that coordinates the interaction between the vision system and the robotic manipulator. Based on the product information retrieved from the database, the controller determines the sorting category and generates the necessary control commands for the SCARA robot. These commands include positional coordinates for the pick location, movement trajectory, and the target bin location where the product must be placed. The control system ensures proper synchronization between the detection system and the robot to maintain smooth system operation.

Once the control commands are generated, the SCARA robot performs the pick-and-place operation. The robot moves to the location of the identified product using predefined motion trajectories. A suitable end effector, such as a mechanical gripper or suction-based mechanism, is used to pick the product securely. After picking the item, the robot moves toward the designated sorting bin corresponding to the product category determined earlier. The robot then places the product into the appropriate bin with high precision. SCARA robots are particularly suitable for such tasks due to their high speed,

repeatability, and positional accuracy in industrial automation applications.

The final stage of the methodology is the automated sorting and output process. After the product is placed in the appropriate bin, the system prepares for the next product entering the scanning region. The continuous execution of these steps allows the system to handle multiple products sequentially with minimal human involvement. The integration of QR code recognition and robotic manipulation enables efficient product handling, reduces sorting errors, and improves operational productivity.

Overall, the proposed methodology demonstrates a systematic approach to integrating computer vision technology with robotic automation for intelligent product sorting. The combination of image processing techniques, database-based decision making, and robotic control enables the system to perform real-time identification and sorting tasks with high accuracy and efficiency. This methodology can be effectively applied in various industrial environments, including automated warehouses, manufacturing industries, logistics centers, and smart production systems where fast and reliable product classification is required.

### 3. FORWARD AND INVERSE KINEMATICS

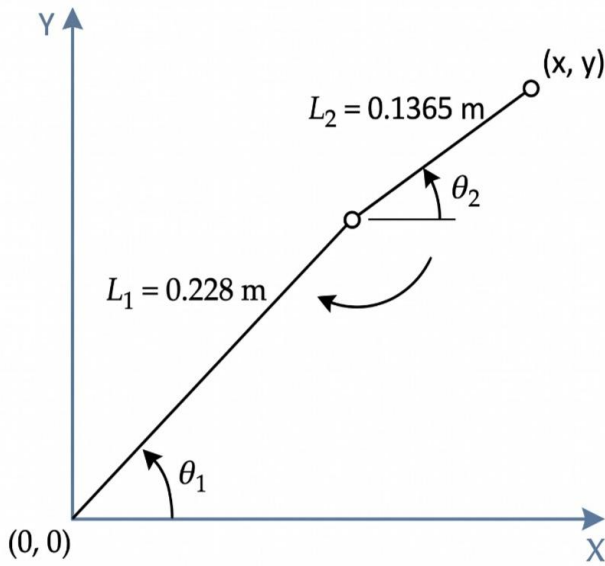


Fig.-3: Planar kinematics

#### A. Coordinate Definition

$$(x, y, z, \phi)$$

- $x$ : horizontal projection along X-axis
- $y$ : horizontal projection along Y-axis
- $z$ : vertical position of end-effector
- $\phi$ : orientation of end-effector about Z-axis

#### B. Robot Parameters

$$L_1, L_2, d_0, d_3$$

- $L_1$ : length of first arm link
- $L_2$ : length of second arm link

- $d_0$ : base height reference
- $d_3$ : vertical prismatic joint displacement
- $\theta_1$ : rotation of first angle
- $\theta_2$ : rotation of second angle
- $\theta_4$ : wrist rotation
- $k_1$ : horizontal component of second link
- $k_2$ : vertical component of second link

#### C. Forward Kinematics

##### 1) Position in X, Y, Z direction

$$x = L_1 \cos \theta_1 + L_2 \cos (\theta_1 + \theta_2) \quad (1)$$

$$y = L_1 \sin \theta_1 + L_2 \sin (\theta_1 + \theta_2) \quad (2)$$

$$z = d_0 - d_3 \quad (3)$$

##### 2) End effector orientation

$$\phi = \theta_1 + \theta_2 + \theta_4 \quad (4)$$

#### D. Inverse Kinematics

##### 1) Planar distance

$$r = \sqrt{x^2 + y^2} \quad (5)$$

##### 2) Workspace condition

$$|L_1 - L_2| \leq r \leq L_1 + L_2 \quad (6)$$

##### 3) Joint angle $\theta_2$

$$\cos \theta_2 = \frac{r^2 - L_1^2 - L_2^2}{2L_1 L_2} \quad (7)$$

##### 4) Auxiliary variables

$$k_1 = L_1 + L_2 \cos \theta_2 \quad (8)$$

$$k_2 = L_2 \sin \theta_2 \quad (9)$$

##### 5) Joint angle $\theta_1$

$$\theta_1 = \text{atan2}(y, x) - \text{atan2}(k_2, k_1) \quad (10)$$

#### E. Final Joint Variables

$$q = (\theta_1, \theta_2, d_3, \theta_4) \quad (11)$$

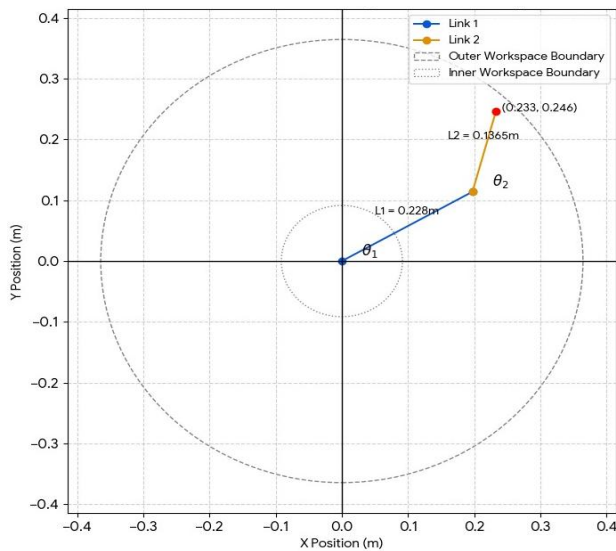


Fig -4: Kinematic configuration and workspace

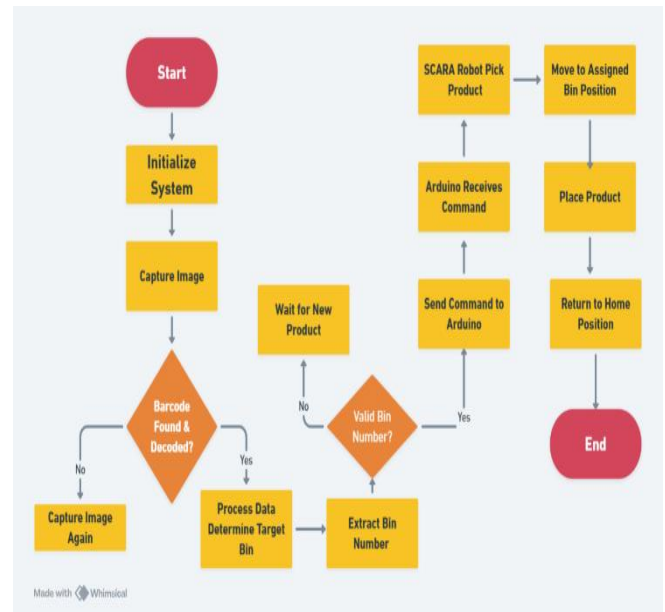


Fig -5: Block diagram

#### 4. SYSTEM ARCHITECTURE

The proposed system architecture is developed to automate the process of product identification and sorting using QR code recognition integrated with a SCARA robotic manipulator. The system combines computer vision techniques, data management, and robotic control to perform efficient and accurate sorting operations with minimal human intervention. The architecture consists of several interconnected modules that work together to capture product information, process visual data, identify products, and perform robotic manipulation for sorting. This integrated approach enables real-time product classification and improves operational efficiency in industrial environments such as warehouses, packaging units, and logistics centers.

The first stage of the system is the image acquisition module, which is responsible for capturing the visual data of the QR code attached to the product. A camera is positioned above the scanning area where the product is placed or transported. When a product enters the scanning region, the camera captures an image containing the QR code printed on the product surface. The captured image is then transmitted to the processing unit for further analysis. Proper illumination and camera positioning are maintained to ensure that the captured image has sufficient clarity and minimal distortion. High-quality image acquisition is essential because it directly affects the accuracy of QR code detection and decoding.

Once the image is captured, it undergoes an image pre-processing stage to enhance the quality of the visual data before performing QR code detection. In this stage, various image processing techniques are applied using computer vision libraries. The captured image is first resized to a suitable resolution and then converted into grayscale format to simplify the image data. Noise reduction techniques and filtering operations are applied to eliminate unwanted disturbances in the image. Additionally, contrast enhancement may be performed to improve the visibility of the QR code pattern. These pre-processing operations help in improving the reliability and accuracy of the QR code detection algorithm.

After preprocessing, the system performs QR code detection and decoding. The detection process identifies the QR code region within the image by recognizing its characteristic square patterns and alignment markers. Once the QR code is located, a decoding algorithm extracts the encoded information stored within it. The decoded information typically represents a unique product identifier that is associated with a specific product type or category. This decoded data is then forwarded to the system controller for further processing. Accurate decoding ensures that each product can be uniquely identified and categorized without manual input.

Following the decoding process, the extracted QR code information is compared with the records stored in a product database. The database contains detailed information about various products, including product identification numbers, product names, product categories, and predefined sorting locations. When the decoded QR code matches an entry in the database, the system retrieves the corresponding product details and determines the appropriate sorting location for that particular product. This database-driven approach enables flexible product management and allows new product categories to be added easily without significant modifications to the system.

The control processing unit acts as the central coordination component of the system. It receives the decoded QR code data and the corresponding product information from the database and determines the appropriate action for the robotic manipulator. Based on this information, the control unit generates motion commands and positional instructions for the SCARA robot. These instructions include the coordinates for the pick location, the target sorting bin, and the required movement path. The control unit ensures synchronization between the vision system and the robotic manipulator, enabling smooth and efficient operation of the entire sorting process.

The SCARA robot performs the physical manipulation required for sorting the products. SCARA robots are widely used in industrial automation due to their high precision, fast response time, and repeatability. Once the control unit sends the command, the robot moves toward the product location and picks the item using a suitable gripping mechanism such as a mechanical gripper or suction-based end effector. The robot

then transports the product to the designated sorting bin and places it at the correct location. The use of a SCARA robot significantly enhances the speed and accuracy of the sorting process compared to manual handling.

Finally, the sorted products are placed into predefined bins or compartments according to their category. Each bin corresponds to a specific product classification determined by the QR code data. This automated sorting mechanism reduces the possibility of human error, increases processing speed, and improves overall productivity. The proposed system demonstrates how the integration of computer vision technology and robotic automation can create an efficient and reliable solution for modern industrial sorting applications. Such systems can be widely applied in manufacturing industries, logistics facilities, warehouses, and smart production environments where fast and accurate product handling is required.

### 5. CIRCUIT DIAGRAM

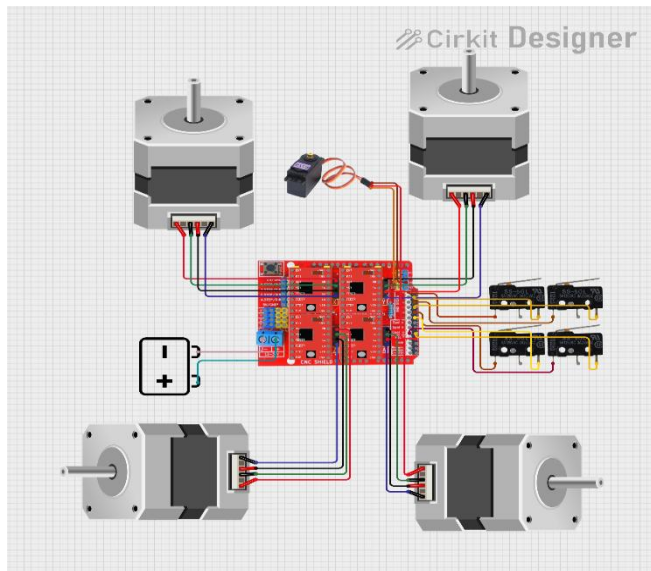


Fig -6: Circuit diagram

The circuit design of the proposed system is centered around the Arduino Uno, which acts as the primary control unit responsible for coordinating all hardware operations. The controller is interfaced with the CNC Shield V3, which provides a structured and compact interface for integrating motor drivers, switches, and actuators. The SCARA robotic arm is driven by four bidirectional stepper motors connected to the X, Y, Z, and A axes of the CNC Shield. Each motor is controlled through an A4988, which converts digital STEP and DIR signals into precise rotational motion. The use of stepper motors allows accurate position control without the need for complex feedback systems, while the drivers enable fine step resolution, improving motion smoothness and positioning accuracy. Heat sinks are attached to the driver modules to ensure efficient thermal dissipation and stable operation under continuous load conditions.

To ensure accurate positioning and safe operation, four micro-switches are incorporated as end-stop devices, with one dedicated to each axis. These switches are connected to the CNC Shield’s end-stop inputs and are used for homing and limit detection. During initialization, the robotic arm moves until the switches are triggered, establishing a reference position for all joints. This prevents cumulative positioning

errors and protects the mechanical structure from overtravel. Additionally, the system ensures coordinated multi-axis movement by synchronizing control signals across all motors, enabling smooth and precise SCARA motion.

A servo motor is integrated into the circuit to control the gripper mechanism, operating through Pulse Width Modulation (PWM) signals generated by the microcontroller. This allows accurate control of the gripping action required for handling objects. The entire system is powered using an external DC power supply connected to the CNC Shield, which provides adequate current for motor operation. Regulated voltage levels are supplied to sensitive components such as the controller and servo motor to ensure stable performance. A common ground is maintained throughout the circuit to ensure proper signal referencing and minimize electrical noise. The overall circuit design, supported by the structured layout of the CNC Shield, reduces wiring complexity, improves reliability, and provides a scalable platform for integrating vision-based robotic control systems.

### 6. EXPERIMENTAL SETUP

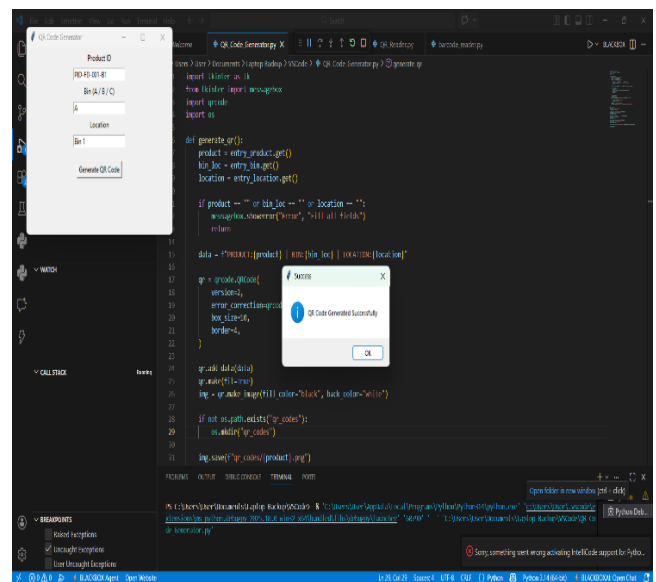


Fig - 7: QR code generation

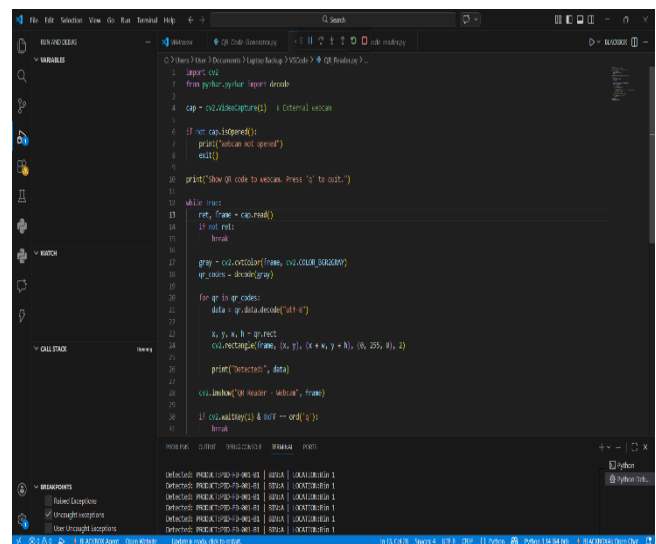


Fig -8: QR code recognition

The proposed QR code-based automated sorting system was experimentally evaluated to analyze its detection accuracy, processing speed, and robotic sorting performance. The vision module, implemented using OpenCV, successfully detected and decoded QR codes from captured images under controlled lighting conditions. The average QR code detection accuracy achieved during testing was approximately 95–98%, with an average processing time of 0.45–0.60 seconds per product. The SCARA robot demonstrated high positional accuracy and repeatability during pick-and-place operations, resulting in a sorting success rate of approximately 96–100%.

The experimental observations indicate that the integration of computer vision with robotic manipulation enables reliable real-time product identification and automated sorting. The system maintained stable performance across multiple trials and effectively reduced manual intervention in the sorting process. These results demonstrate that the proposed approach is suitable for industrial automation applications such as warehouse management, logistics sorting systems, and smart manufacturing environments, where high accuracy and operational efficiency are required.

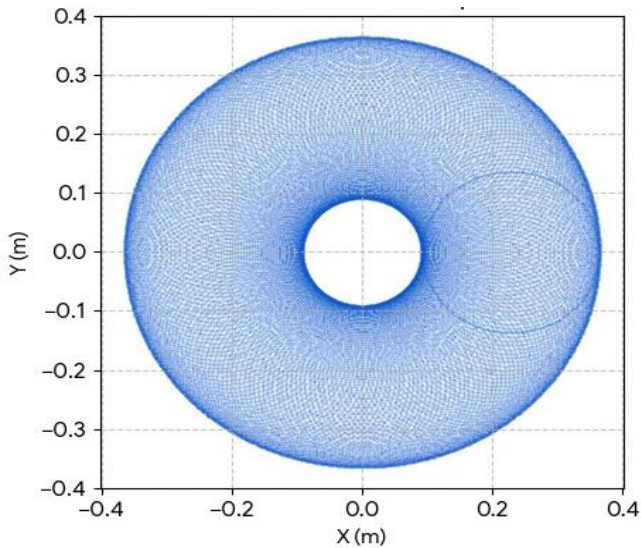


Fig -9: Scara robot workspace

The planar workspace of the 2-DOF SCARA robotic manipulator was mathematically modeled and visualized in Cartesian space to analyze its operational capability and mechanical constraints. Fig. 9. illustrates the resulting reachable region, which forms a distinct annular geometry. The analysis confirms that the robot's maximum extension creates an outer reach boundary at approximately 0.3645 m. Crucially, the central void in the visualization confirms the presence of an inner singularity radius at 0.0915 m, generated by the mechanical overlap of the primary and secondary links. By formally quantifying this functional area, we can rigorously define the sorting environment; all target QR codes and designated sorting bins must be geometrically placed within this non-singular, high-dexterity blue zone to ensure mathematical controllability. This workspace definition is fundamental for the subsequent development of Inverse Kinematic algorithms, as it establishes the boundary conditions for valid joint-angle calculations.

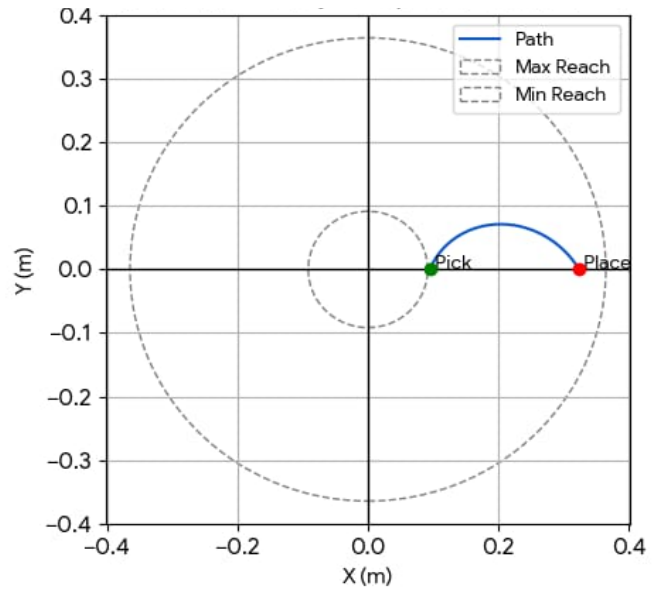


Fig -10: Pick and place trajectory of SCARA robot

The kinematic performance of the SCARA robotic manipulator was evaluated through a simulated pick-and-place trajectory executed between two predefined coordinates on the horizontal plane. The system was initialized at a "Pick" position of 0.0950 m, 0.0000 m and tasked to move to a "Place" position located at 0.3237 m, 0.0000 m. Although the target points are collinear along the X-axis, the trajectory was generated using linear interpolation in the joint space ( $\theta_1, \theta_2$ ), which resulted in a characteristic non-linear "arc" path within the Cartesian workspace. This curved end-effector trajectory is a direct consequence of the transcendental forward kinematic equations governing the two-link planar structure. The simulation confirmed that the entire motion profile remained strictly within the operational workspace boundaries, defined by a minimum reach (inner singularity) of 0.0915 m and a maximum reach (outer singularity) of 0.3645 m. These results demonstrate that while joint-space interpolation ensures computational efficiency and smooth motor transitions, the resulting workspace path must be carefully monitored to avoid collisions with peripheral obstacles during high-speed sorting operations.

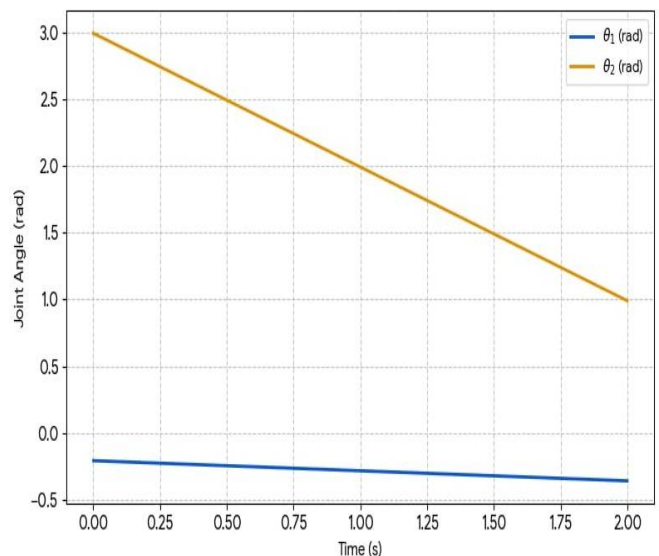
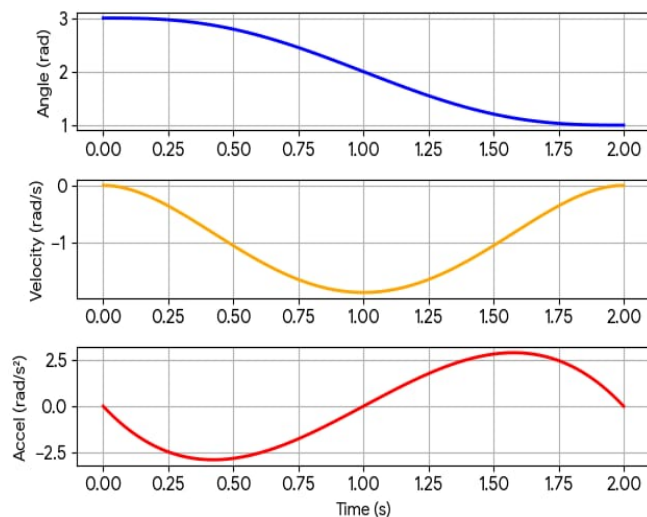


Fig -11: Joint space trajectory (theta vs time)

Fig. 11. Illustrates the motion of each joint of the SCARA robot over a 2-second interval. Since linear interpolation is used, both joint angles exhibit straight-line profiles, indicating constant velocities throughout the motion. It is observed that  $(\theta_1)$  has a very shallow negative slope, with a small variation of approximately  $(-0.15)$  rad, whereas  $(\theta_2)$  shows a much steeper negative slope, decreasing significantly from approximately  $(3.0)$  rad to  $(1.0)$  rad. This behavior indicates that, in a real SCARA robot, the second joint (elbow) performs most of the motion, while the first joint (shoulder) contributes only minor adjustments. Although this linear interpolation approach is mathematically simple and easy to implement, it introduces a critical limitation in practical systems. Specifically, the constant velocity profile results in instantaneous changes in velocity at the start ( $t = 0$ ) and end ( $t = 2$ ) of the motion, implying infinite acceleration at these points. This leads to undesirable effects such as jerk, vibration, and increased mechanical stress. To overcome this limitation and make the motion suitable for real-world robotic applications, advanced trajectory planning methods such as S-curve or quintic polynomial interpolation are commonly employed, as they ensure that both velocity and acceleration start and end at zero, resulting in smoother and more reliable robot operation.



**Fig -12:** Quintic smooth trajectory (Joint 2)

Fig. 12. Illustrates the dynamic response and kinematic profile of the SCARA manipulator's primary joint under a quintic polynomial trajectory. The figure depicts a smooth sigmoidal (S-curve) transition in angular position from the initial state of  $2.9966$  rad to a final state of  $0.9904$  rad over a  $2.0$  s duration. By utilizing a fifth-degree polynomial, the system effectively constrains the velocity to a continuous bell-shaped distribution, reaching a peak magnitude of  $1.8804$  rad/s the trajectory midpoint. Crucially, the acceleration profile demonstrates a smooth transition from zero, peaking at  $2.8957$  rad/s<sup>2</sup> before returning to a null state at the conclusion of the motion. This behavior indicates that the higher-order trajectory effectively eliminates the instantaneous jerk associated with linear interpolation, thereby minimizing mechanical stress on the NEMA 17 actuators and ensuring the high precision required for reliable QR code identification and object sorting.

## 7. CONCLUSION

The proposed system presents an automated product identification and sorting solution using QR code recognition integrated with a SCARA robotic manipulator. By combining

computer vision techniques with robotic automation, the system efficiently detects and decodes QR codes to identify products and determine their appropriate sorting locations. The integration of OpenCV-based image processing with a structured product database enables accurate product classification and decision-making.

The SCARA robot performs precise pick-and-place operations to sort the products into designated bins, improving sorting speed, accuracy, and operational efficiency. This automation approach reduces manual intervention and minimizes sorting errors in industrial environments. Overall, the developed system demonstrates an effective and scalable solution for applications in warehouse automation, logistics management, and smart manufacturing systems.

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