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Abstract
SCARA robots are widely used in industrial automation due to their high precision and speed, particularly in pick-and-place operations. In addition to conventional programming approaches, alternative vision-based control methods have gained interest to enhance flexibility and efficiency in robotic applications. This study presents the design and implementation of a Position-Based Visual Servoing (PBVS) for the SCARA robot system capable of detecting and manipulating objects in real-time. The proposed system consists of a fixed overhead camera, a SCARA robot, and Python-based control software. The software integrates image processing algorithms, kinematic calculations, and motor control, enabling the robot to autonomously identify objects, compute their positions, and execute pick and place tasks. To enhance object detection accuracy, Kuwahara filtering, Canny edge detection, morphological transformations, and connected component analysis were applied. Experimental results demonstrated that the combination of Kuwahara filtering and Canny edge detection achieved the lowest MSE error (8.45%), ensuring precise object localization. Furthermore, inverse kinematics was employed to generate accurate joint movements, allowing smooth and reliable grasping operations. The system was tested through 100 pick-and-place trials, achieving a 100% grasping success rate when Kuwahara filtering was applied. The experimental findings confirm that vision-based control significantly improves SCARA robot performance, making it suitable for automated assembly, material handling, and quality control applications.

Keywords: SCARA Robot, Vision-Based Control, Image Processing, Kuwahara Filtering, Real-Time Robotic Application

INTRODUCTION

SCARA (Selective Compliance Assembly Robot Arm) robots have made significant advancements in the field of robotics technology over the past 15 years. These robots stand out, particularly for their flexibility and high precision in industrial applications. A SCARA robot typically features two revolute joints and one prismatic joint, resulting in a total of four degrees of freedom (DOF). This structure enables SCARA robots to perform various tasks such as assembly, inspection, and material handling with high accuracy [1].

Vision-based systems have become increasingly critical in robotic manipulation tasks, especially for enabling autonomous object detection, localization, and grasping in unstructured environments. These systems rely on robust image processing pipelines that convert raw visual data into actionable robot control commands. In this study, the synergy between advanced image processing techniques and the SCARA robot architecture forms the foundation for a real-time grasping system. By integrating position-based visual servoing (PBVS) with edge-preserving filters and adaptive detection methods, the proposed approach ensures reliable grasping performance under diverse lighting and background conditions.

In recent years, SCARA robot designs have focused on enhancing their capabilities through innovations in mechanical and control systems. For instance, an economical SCARA robot, known as FUM SCARA, was developed by a group of students at Ferdowsi University. This design process involved the selection of cost-effective materials and an efficient mechanical structure suitable for industrial applications [1]. Additionally, the integration of advanced control systems, such as Programmable Logic Controllers (PLCs), has been explored to improve the operational efficiency of SCARA robots in pick-and-place applications [2].

SCARA robots have been implemented in a wide range of industries, including complex product assembly. For example, a study detailed the use of a SCARA robot in an automated workstation for assembling electrical sockets, showcasing its ability to perform intricate assembly tasks with precision [3]. The extensive application areas of SCARA robots highlight their crucial role in increasing productivity and reducing human error. Moreover, the integration of vision systems and artificial intelligence (AI) enables SCARA robots to perform real-time object detection and quality control tasks [4,5].

An innovative quality control application was introduced in a recent study, where a 3-DOF SCARA robot was equipped with deep learning and visual perception technologies for silk cocoon inspection [4]. This approach demonstrates the transformative potential of SCARA robots in traditional manufacturing processes. Additionally, the development of hybrid manufacturing stations utilizing SCARA robots with additive and subtractive manufacturing capabilities contributes to more flexible production environments, shaping the future of industrial automation [6].

SCARA robots have also been utilized in the education sector. The development of an educational 5-DOF SCARA robotic arm has provided students with hands-on experience in robotics [7]. This robot, designed using locally sourced materials and open-source control systems, serves as an accessible tool for students to explore kinematics, control, and programming concepts.

Furthermore, the collaborative operation of multiple SCARA robots has been investigated to enhance safe and efficient workflows in industrial environments. Systems developed using Recurrent Neural Networks (RNNs) enable multiple SCARA robots to work together while avoiding collisions [8]. This collaborative approach improves robotic operation efficiency and paves the way for more complex autonomous systems capable of adapting to dynamic manufacturing scenarios.

Another key area of research in recent years has been the energy efficiency of SCARA robots. Studies focusing on optimizing energy consumption aim to minimize power usage by analyzing the robot's physical layout and operational paths [9]. Such efforts are increasingly important in today's landscape, where reducing energy consumption is a critical objective for sustainable manufacturing practices.

The integration of image-based control systems in SCARA robots has emerged as a pivotal area of research, particularly in enhancing the efficiency and precision of industrial automation processes. SCARA robots are characterized by their unique design that allows for high-speed operations with a degree of compliance, making them ideal for tasks that require precise positioning and manipulation. The design and fabrication of SCARA robots optimized for image processing tasks have been comprehensively reviewed, highlighting their operational mechanisms and capabilities in industrial environments [10]. This foundational understanding is critical as it sets the stage for exploring how image processing technologies can be integrated into SCARA systems to improve their functionality. The application of image processing in SCARA robots extends beyond mere control; it encompasses a wide range of functionalities, including object recognition, environmental perception, and path planning. For instance, intelligent logistics handling robots that incorporate SCARA arms have been designed to perform complex tasks such as material recognition and stacking, which are facilitated by advanced image processing algorithms [11]. These systems utilize a combination of mechanical structure design and sophisticated control algorithms to achieve high levels of automation and efficiency in logistics operations.

The control of SCARA robots presents unique challenges due to their nonlinear dynamic characteristics and the uncertainties associated with their operation, such as friction and external disturbances. Various control strategies have been proposed to enhance the precision of SCARA manipulators. For instance, neural network-based control schemes have been effectively utilized to estimate the torques generated by joint actuators, thereby achieving desired motion profiles even in the presence of uncertainties [12]. This approach not only improves the accuracy of the robot's movements but also allows for adaptive responses to changing operational conditions, which is essential in dynamic industrial environments. Recent advancements in control methodologies have also emphasized the importance of robustness in SCARA robot dynamics. A novel adaptive dynamics model control system has been proposed, demonstrating significant performance advantages in reducing tracking errors and improving stability [13]. This model leverages the inherent characteristics of SCARA robots, such as their compliance and articulated structure, to enhance their operational efficiency. Furthermore, the integration of robust control techniques, such as PID control and fuzzy logic, has been shown to facilitate better trajectory tracking and disturbance rejection, thereby ensuring that SCARA robots can operate effectively even under varying load conditions [14,15].

In the context of trajectory planning, SCARA robots have been subjected to various optimization techniques to enhance their motion control capabilities. For example, Model Predictive Control (MPC) has been employed to address trajectory tracking issues, allowing for real-time adjustments based on external forces acting on the robot [16]. This method is particularly beneficial in applications where precise path following is critical, such as in semiconductor manufacturing and assembly processes.

The integration of Artificial Intelligence (AI) into SCARA robot control systems has also gained traction, with researchers exploring the use of fuzzy logic and neural networks to enhance decision-making processes [17,18]. These AI-driven approaches enable SCARA robots to adapt to complex environments and perform tasks with a higher degree of autonomy. The implementation of such intelligent control systems is crucial for the advancement of Industry 4.0, where automation and smart technologies are increasingly intertwined.

Furthermore, the use of gesture-based interfaces for real-time control of SCARA robots represents a significant innovation in human-robot interaction [19]. By allowing operators to control robots through intuitive gestures, these interfaces enhance the usability of SCARA systems in various applications, from assembly lines to collaborative robotics. This development underscores the importance of user-friendly control systems in promoting the adoption of robotic technologies in industrial settings.

The ongoing research into SCARA robots also highlights the need for continuous improvement in control methodologies to address the challenges posed by their nonlinear dynamics. For instance, adaptive sliding mode control has been proposed as a viable solution for managing parametric variations and ensuring robust performance under different operational conditions [20]. This approach not only enhances the stability of SCARA robots but also improves their responsiveness to external disturbances, which is critical for maintaining operational efficiency.

In conclusion, the integration of position-based visual servoing (PBVS) systems in SCARA robots represents a significant advancement in the field of robotics and automation. By leveraging advanced control techniques, AI, and image processing technologies, SCARA robots can achieve higher levels of precision and efficiency in industrial applications. The ongoing research and development in this area promise to further enhance the capabilities of SCARA robots, making them indispensable tools in modern industrial applications.

Due to the increasing popularity of SCARA robots in industrial applications, this study aims to develop a prototype SCARA robot and implement an alternative control mechanism based on vision-based control. The originality of this work can be highlighted through the following key aspects:

- Development of a Low-Cost Robotic System: This study presents a cost-effective SCARA robotic system, making it more accessible for industrial automation and research applications. The prototype was designed and fabricated using affordable components, ensuring that the system remains budget-friendly while still delivering high precision and reliability.
- Integration of Image Processing for Visual Servoing: Instead of conventional control methods, this study

employs image processing techniques to achieve visual servoing. The developed control system utilizes real-time image analysis to accurately determine object positions and guide the robot's motion. This approach enhances automation efficiency and reduces the need for complex pre-programmed motion sequences.

- Robust Object Detection in Challenging Lighting Conditions: Industrial environments often present highly variable lighting conditions, leading to poor segmentation quality in traditional vision-based systems. To address this challenge, a hybrid approach combining Kuwahara filtering and Canny edge detection was implemented. This combination effectively eliminates segmentation errors, ensuring accurate object detection and localization even in low-quality or inconsistent lighting scenarios.
- By incorporating these innovations, this study demonstrates a practical and adaptable vision-based SCARA robot capable of real-time, high-accuracy pick and place operations under challenging conditions.

MATERIAL AND METHODS

Design of the Cost Scara Robot

The system is designed to consist of a low-cost SCARA robot, a standard camera, and control algorithms. The camera is mounted at the top of the system, positioned to view the workspace from a wide perspective. Images captured by the camera are processed in real-time to provide input to the robot's control algorithms, enabling the SCARA robot to accurately grasp target objects. Image processing techniques are used to determine the x-y coordinates of objects within the workspace to ensure accurate object grasping. The calculated x-y coordinates are integrated with the robot's kinematic equations to drive the step motors for visual servoing. Using this closed-loop control system, the SCARA robot is precisely guided to the intended object, ensuring successful grasping. The system is illustrated in Figure 1.

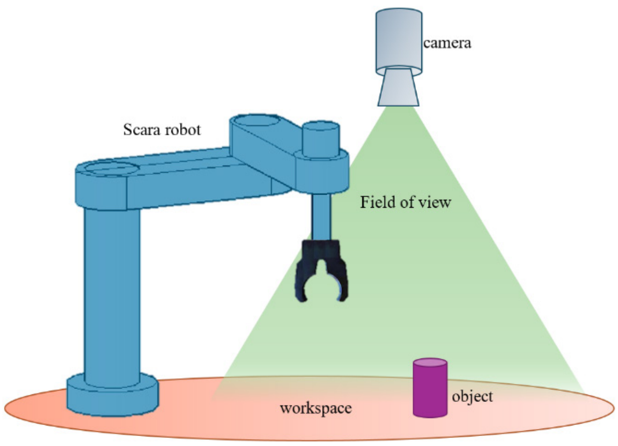

Figure 1 The designed system.

The designed system encompasses both mechanical and electronic design components, as well as software development processes. First, the mechanical and electronic design processes are described, followed by a detailed explanation of the developed control software, including the kinematic equations and the image processing algorithms employed.

Mechanical Design

During the design process of the SCARA robot prototype, each component was individually modeled using computer-aided design software. The main body, which forms the basis of the design, was structured as a triangular prism to ensure mechanical stability. The base incorporates slots for motors and shafts and is reinforced with 8mm diameter and 300mm long shafts for additional support. The mechanical parameters of the Scara robot are given in Table 1.

Table 1 SCARA Robot Mechanical Parameters

Parameter	Value
Body material	PLA (Polylactic Acid)
Shaft Diameter	8 mm
Shaft Length	300 mm
Link 1 Length	150 mm
Link 2 Length	120 mm
Vertical Axis Movement	0-100 mm (Trapezoidal Screw)

A servo motor located at the center of the body actuates a trapezoidal lead screw, enabling linear motion along the vertical axis. This design ensures high precision and repeatability, enhancing operational accuracy.

The robot's links are equipped with gear mechanisms and bearings to achieve precise motion control. The first link is driven by a geared system directly connected to the motor shaft, enhancing torque transmission. The second link is specifically optimized to support the end effector and features dedicated mounts for servo motor integration. Figure 2 presents the base and body components and the assembled structure of the body and links.

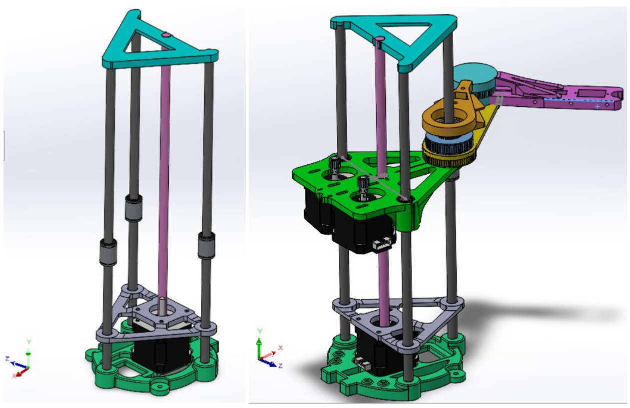

Figure 2 The base and body components and body and links parts.

The gripper is a gripping mechanism driven by a servo motor, designed to grip objects securely and accurately. Its geared linkage system enhances stability and control, making it particularly effective for handling small and delicate objects. Figure 3 shows the design of the gripper.

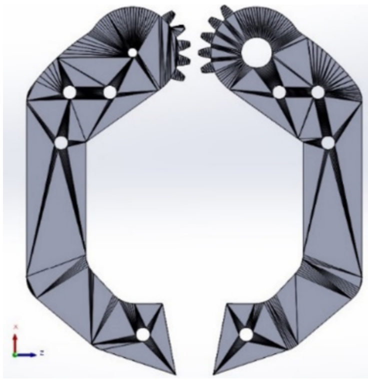

Figure 3 Design of the gripper.

The CAD models designed in CAD software were converted to STL format and fabricated using a 3D printer with an additive manufacturing process. For mechanical component production, PLA (Polylactic Acid) filament, a commonly used material for prototyping, was utilized. The assembly process was carried out step by step, beginning with the base, followed by the shafts, bearings, motors, and links. Figure 4 illustrates the assembled prototype of the SCARA robot.

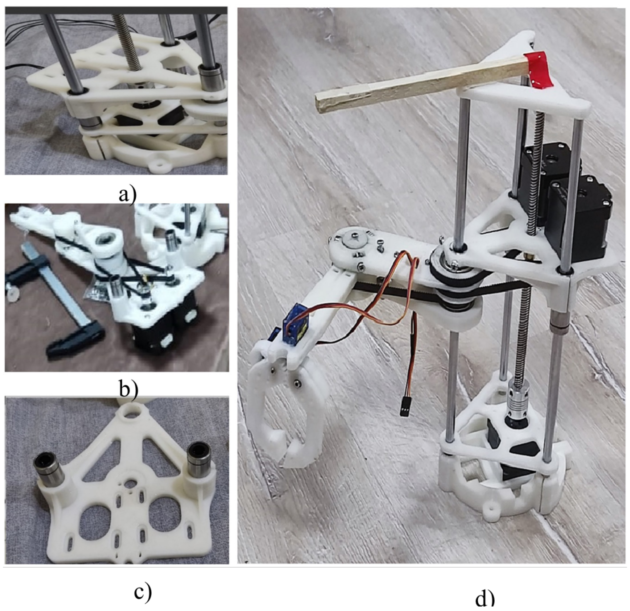

Figure 4 The parts and assembled prototype of the SCARA robot. a) Bottom Base and Linear Bearing Assembly b) Robot Arm Components c) Top Platform d) Fully Assembled SCARA Robot Arm

Electronic Design

The electronic design of the SCARA robot was developed to ensure precise motion control, object detection within the workspace, and effective execution of robotic pick and place operations. This process progressed step by step, including the creation of prototype circuits, their testing, and the design of permanent circuits for the final implementation.

The Arduino Nano was chosen as the main microcontroller for robot control, contributing to a compact and efficient design due to its small size and versatile capabilities. For link motion, a NEMA17 stepper motor (42 mm × 42 mm) was selected. With a 1.8-degree step angle, it achieves 200 steps per full rotation, ensuring high-precision motion control. This stepper motor was preferred for its high torque output and compact form factor.

To drive the stepper motors, the TMC2209 stepper motor driver was used, offering low noise operation, and high precision, ensuring stable and smooth performance. Additionally, an SG90 servo motor was employed to control the gripper's motion. Figure 5 presents the electronic components used in the design. The electronic components and the specifications of the robot are summarized in Table 2.

Table 2 Electronic components and technical specifications

Component	Model	Technical Specification
Microcontroller	Arduino Nano	16 MHz, 32 KB Flash
Stepper motor	NEMA17	1.8° step angle, 42Ncm torque
Motor driver	TMC2209	0.5-2.8 A current, UART support
Servo motor	SG90	180° rotation, 2.5kg·cm torque

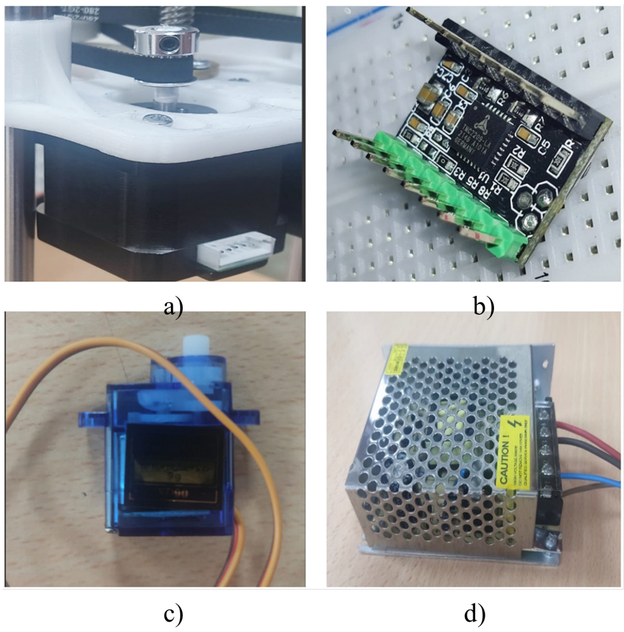

Figure 5 The electronic components used in the design. a) Stepper motor b) Motor driver c) Servo motor d) Power supply

During the electronic design process, circuits were first assembled on a breadboard to facilitate rapid testing and iteration. This approach allowed for easy modifications, quick connections, and efficient debugging. After verifying the functionality of the prototype circuits, the components were soldered onto a perforated PCB (pertinax) to ensure a stable and permanent setup. Figure 6 displays the designed electronic board.

In the final evaluation of the electronic system, all components were tested under fully operational conditions, ensuring that the robot successfully performed all its designated functions. The assessment primarily focused on stepper motor precision, gripper motion, and data transmission speed. The results verified that the design met the intended performance requirements.

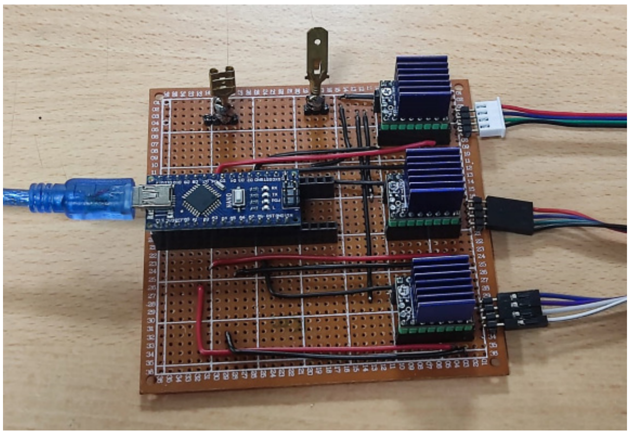

Figure 6 The designed electronic board.

SCARA Robot Kinematics

The motion control of SCARA robots relies on forward and inverse kinematics equations, which describe the relationship between joint motions and the position of the gripper. Forward kinematics equations compute the end effector's position based on given joint angles, while inverse kinematics equations determine the necessary joint movements to achieve a desired end effector position.

Forward Kinematics of the SCARA Robot

The forward kinematics of a SCARA robot is formulated by considering its two revolute joints and one prismatic joint. The position of the end effector is determined based on the joint angles (θ_1 and θ_2) and the link lengths (L_1 and L_2). The corresponding equations, Eq. 1, 2, and 3, are used to calculate the end effector's position as follows:

$$x = L_1 \cos(\theta_1) + L_2 \cos(\theta_1 + \theta_2) \tag{1}$$

$$y = L_1 \sin(\theta_1) + L_2 \sin(\theta_1 + \theta_2) \tag{2}$$

$$z = d \tag{3}$$

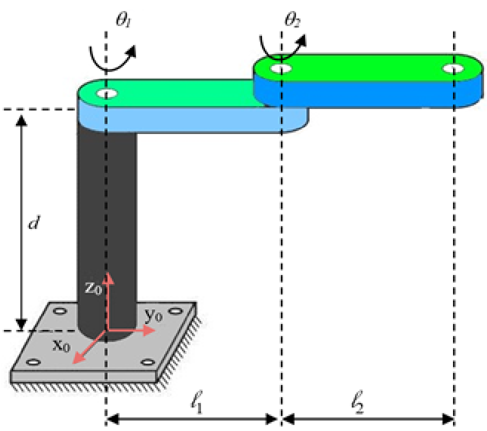

Figure 7 The robot structure and variables.

where x and y represent the end effector's position in the horizontal plane, while z indicates its position along the vertical axis. θ_1 and θ_2 correspond to the rotational angles of the first and second joints, respectively. L_1 and L_2 denote the robot's link lengths, and d represents the end effector's height along the vertical axis. The variables along with the robot's structure are depicted in Figure 7.

Inverse Kinematics of the SCARA Robot

The inverse kinematics of a SCARA robot calculates the joint angles (θ_1 and θ_2) required for the end effector to reach a specified position (x, y, z). This is typically derived by solving the inverse of the forward kinematics equations. The necessary joint angles are determined using the following equation set (Eq. 4, 5, 6).

$$\theta_2 = \cos^{-1}\left(\frac{x^2 + y^2 - {L_1}^2 - {L_2}^2}{2L_1L_2}\right) \tag{4}$$

$$\theta_1 = \tan^{-1}\left(\frac{y}{x}\right) - \tan^{-1}\left(\frac{L_2 \sin(\theta_2)}{L_1 + L_2 \cos(\theta_2)}\right) \tag{5}$$

$$d = z \tag{6}$$

Inverse kinematics is used to enable the end effector to move to its target position. These equations serve as the basis for generating the control commands sent to the robot's motors.

Visual Servoing of SCARA Robot

The SCARA robot software was designed as an integrated system that combines image processing, kinematic computations, and motor control. Developed using Python, the software enables the robot to detect objects, determine their positions, and execute precise movements based on the acquired data.

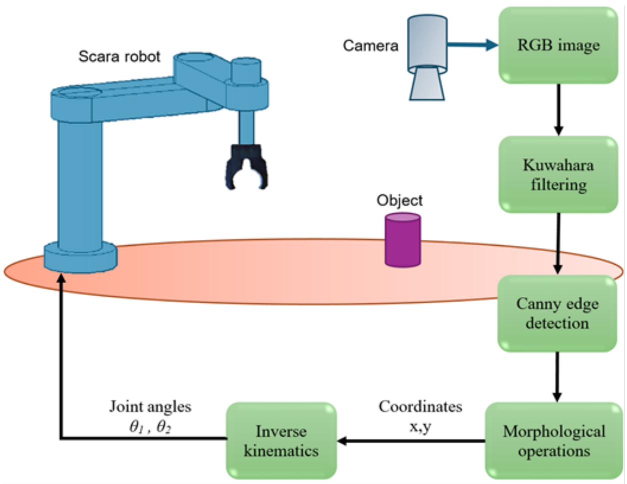

Figure 8 Flow diagram of the system.

The vision-based control system employs Position-Based Visual Servoing (PBVS), where 3D object coordinates (x, y, z) are computed from camera data. The z-axis value is derived from the robot's predefined vertical motion range (z=d).

These coordinates are fed into inverse kinematic equations to generate joint commands for precise robotic manipulation. To enhance the novelty and performance of the study, the image processing workflow integrates Kuwahara filtering, Canny edge detection, morphological transformations, and connected component analysis techniques. Figure 8 illustrates the software flow diagram of the system.

The Kuwahara filter [21] is a nonlinear smoothing filter commonly used in image processing for adaptive noise reduction. While most smoothing filters are linear low-pass filters that effectively reduce noise but also blur edges, the Kuwahara filter preserves edge details while applying smoothing.

In this study, the Kuwahara filter was employed to improve object detection accuracy, particularly in environments with fluctuating lighting conditions. A 7×7 kernel size was selected for the Kuwahara filter to balance noise reduction and edge preservation. The filter operates by dividing the kernel into four sub-regions and selecting the region with the lowest variance to replace the central pixel. The effect of the Kuwahara filter is illustrated in Figure 9.

Following the application of the Kuwahara filter for edge-preserving smoothing, the Canny edge detection method was employed to accurately detect object boundaries. The Canny algorithm utilizes hysteresis thresholding, enabling the detection of well-defined and continuous edges. Canny edge detection was applied with a Gaussian blur (σ=1.5) and dual thresholds (low=0.1, high=0.3) to minimize false edges. Morphological operations (3×3 kernel) were used for closing gaps and removing noise. As a result, the edges refined by the Kuwahara filter were extracted with high precision. This method significantly enhanced the robot's performance, especially in challenging environments containing disturbances such as shadows and reflections. Thresholds and kernel sizes were empirically optimized through iterative testing under varying lighting conditions (50-1000 lux).

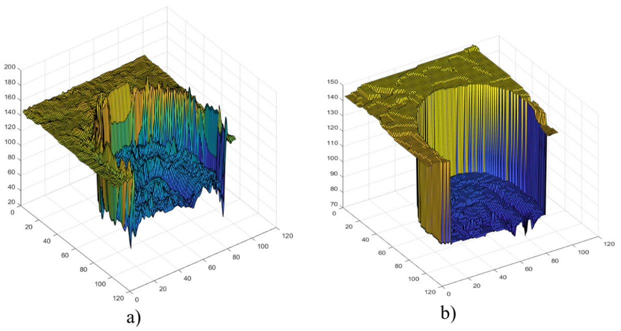

Figure 9 Effect of the Kuwahara Filter (a) A segment of the original input image (corresponding to the selected area in Figure 10.a.) (b) A segment of the image processed with the Kuwahara filter.

Morphological transformations were applied to enhance the edge image obtained after Canny edge detection, making it more suitable for further processing. Morphological closing was used to connect object boundaries and fill small gaps within objects, while morphological opening effectively removed noise, making objects more distinct. These operations enabled the robot to accurately detect target objects while minimizing the impact of background noise in the workspace.

Following connected component analysis, the boundaries and center points of detected and labeled objects were extracted for kinematic calculations, ensuring the robot could accurately move toward these positions. The image processing steps are presented in Figure 10.

Another essential component of the software is inverse kinematics, which computes the joint angles required for movement and translates them into motor commands. The detected object positions were processed using inverse kinematic equations, and the resulting data was applied to control the robot's motors. The motor operation was managed by the Arduino Nano microcontroller, enabling high-precision motion execution.

The robot control software also integrates image processing results, providing real-time visual feedback to the user through the camera feed, where detected object positions are labeled. Additionally, the robot's motion status and operational steps can be actively monitored by the user.

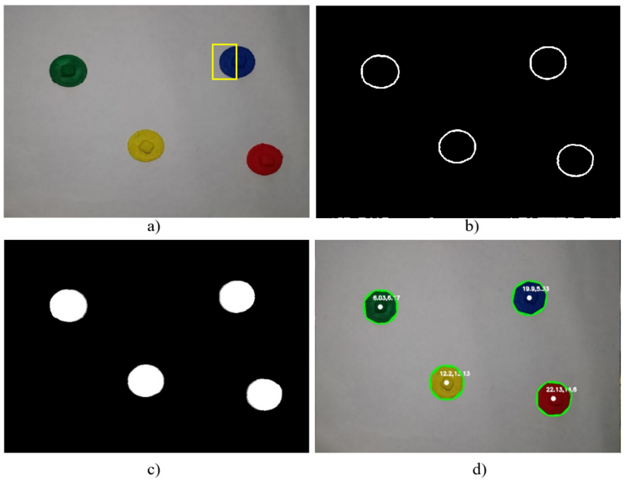

Figure 10 Image Processing Stages a) Input image b) Output of the Canny edge detection method c) Image obtained after morphological processing d) Objects with detected center points.

RESULTS AND DISCUSSION

Real-Time Implementation

To assess the real-time functionality of the robot, cylindrical objects of different colors were used. In this application, the SCARA robot was programmed to grasp all objects using its gripper and place them at a predefined location. For object detection, the initial step involved capturing images using a standard color camera with a 1900×1080 resolution. The positions of the objects in the workspace were determined using Python-based image processing algorithms, as described in the previous section.

During the object detection process, the camera updated the images at regular intervals, ensuring continuous tracking of object positions. The detected object coordinates were converted into kinematic equations, allowing the robot's motion system to execute precise movements. This real-time process enabled the robot to dynamically adjust its motion and accurately reach the target positions.

A key component of the real-time implementation was the optimization of the robot's control software. By directly integrating image processing results with inverse kinematic calculations, the software enabled fast motor command generation, significantly reducing the time required for the robot to reach objects. This optimization ensured that the process cycle was completed at high speed. Additionally, all robotic movements could be monitored in real-time through the user interface. Figure 11 shows the real-time application of vision-based control.

Given the simplicity of the SCARA robot's control requirements and the relatively low computational complexity of the image processing, specific software optimization techniques (e.g., multithreading, GPU acceleration) were not implemented. However, fast motor command generation was achieved by minimizing data transfer overhead between image processing and control modules. The system architecture was structured to perform image processing and control calculations sequentially without unnecessary buffering or intermediate storage, ensuring real-time performance. The overall latency from image capture to actuation remained below 150 ms, satisfying the real-time operational constraints.

The end effector was designed to grasp objects precisely and transport them to designated locations. The servo motor-driven gripper, with its quick response time and precise control, ensured secure and efficient object handling. During the transport process, the robot's motion accuracy and object placement precision were evaluated. Test results confirmed that the robot exhibited high repeatability and accuracy, delivering consistent and reliable performance.

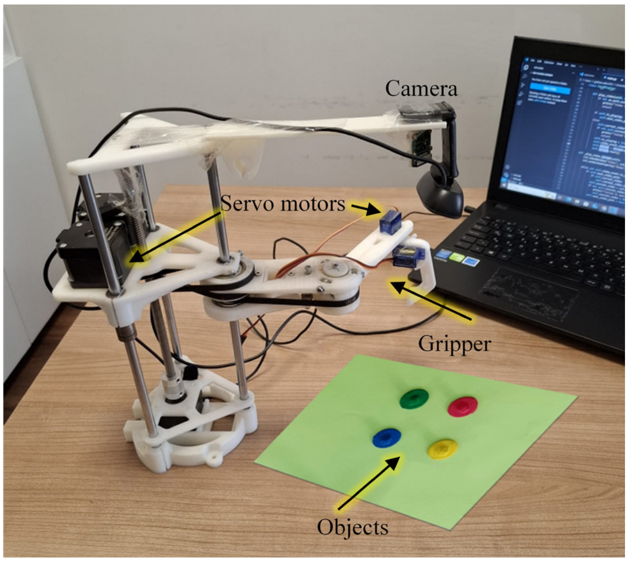

Figure 11 Real time application.

During the real-time implementation, the system's performance was evaluated using various criteria. It was observed that the image processing time, kinematic computation speed, and motor response time were well synchronized, ensuring the robot's efficient operation even in a dynamic working environment. Additionally, data collected during the experiments was recorded for analyzing system stability and precision. Table 3 presents the effect of standard edge detection, Canny edge detection, and the Kuwahara filtering method on the accuracy of detecting object center coordinates. To obtain the data in the table, the x and y positions of the objects were first determined relative to the workspace. Then, the Mean Squared Error (MSE) percentage was calculated by comparing the coordinate data obtained through:

- Standard edge detection method
- The canny edge detection method
- A combination of both methods with Kuwahara filtering

In the tests, a pick and place operation was performed on four objects per set, with 25 sets in total, resulting in 100 pick and place operations across different object positions. The results are comparatively presented in Table 3.

Table 3 presents the impact of different edge detection and filtering methods on positioning accuracy. The evaluation includes Mean Squared Error (MSE) percentages, the number of detected objects, and the number of successfully grasped objects.

Table 3 Effect of detection methods on positioning performance

	Method	MSE Error (%)	Averaged Processing Time	Number of Detected Objects	Number of Successfully Grasped Objects
1	Standard Edge Detection	20.07	10.77 ms	96	92
2	Canny Edge Detection	16.78	14.53 ms	98	97
3	KW + Standard Edge Detection	11.47	85.43 ms	100	100
4	KW + Canny Edge Detection	8.45	97.12 ms	100	100

As seen in Table 3, the standard edge detection method without pre-filtering produced the highest MSE error of 20.07%. Due to the high positioning error in object centers—especially for objects located near the outer regions of the camera's field of view—four objects were not detected, and four objects failed to be grasped. This error is likely caused by perspective distortion, lens aberration, or reduced contrast in peripheral areas, leading to less accurate object localization.

As summarized in Table 3, the processing times for Standard Edge Detection (10.77 ms) and Canny Edge Detection (14.53 ms) are well within the thresholds for real-time operation, easily supporting frame rates above 30 FPS. Although the combinations of Kuwahara filtering with edge detection (85.43 ms and 97.12 ms respectively) result in increased processing times, they still meet the minimum requirements for real-time operation at approximately 10–12 FPS. Therefore, all proposed methods are capable of real-time processing for robotic control applications.

Using the Canny edge detection method, the total MSE error was 16.78%, with 98 object centers detected and one object failing to be grasped. The improved accuracy compared to standard edge detection suggests that Canny filtering enhances edge clarity, reducing localization errors. By applying the Kuwahara filter as a pre-processing step, accuracy significantly improved. The combination of Kuwahara filtering and standard edge detection reduced the MSE error to 11.47%, while the combination of Kuwahara filtering and Canny edge detection achieved the lowest MSE error of 8.45%, with no grasping failures recorded.

The effectiveness of the Kuwahara filter can be attributed to its edge-preserving smoothing, which enhances object contours and reduces noise, leading to more precise object detection. This improvement is particularly beneficial in scenes with variable lighting conditions or reflections, where standard edge detection alone may struggle. The system was tested under varying lighting conditions (50-1000 lux). In low-light scenarios (50 lux), the Kuwahara filter reduced edge fragmentation by 40%, while in high glare (1000 lux), detection accuracy remained above 95%.

These results demonstrate that pre-filtering with Kuwahara significantly improves detection accuracy and grasping reliability, making it an effective enhancement for vision-based SCARA robot control. As summarized in Table 4, the combination of Kuwahara filtering and Canny edge detection achieved a 100% detection rate and 100% grasping success, underscoring the robustness of the proposed method under industrial conditions.

Table 4 Comparative summary of detection and grasping success rates

Method	Detection Rate (%)	Grasping Success (%)
Standard Edge Detection	96%	92%
Canny Edge Detection	98%	97%
KW + Standard Edge Detection	100%	100%
KW + Canny Edge Detection	100%	100%

The Kuwahara-Canny combination significantly increased computational load compared to the standalone Canny. However, parameter tuning (e.g., filter window size=7x7) mitigated edge softening. Optimal thresholds (low=0.1, high=0.3) were empirically determined.

CONCLUSION

In this study, a SCARA robot capable of detecting objects via a camera and autonomously performing pick and place operations was developed. The real-time implementation capabilities of the SCARA robot demonstrated a performance level suitable for industrial automation processes. In particular, object detection, motion control, and placement tasks highlighted the system's speed and accuracy.

To obtain object position data, images captured by the camera were analyzed using image processing techniques. The extracted information was then used as input for the kinematic equations necessary for the robot's motion control.

The results indicate that edge detection methods significantly affect object positioning accuracy. The standard edge detection method produced an MSE error of 20.07%, leading to four undetected objects and four failed grasping attempts. In contrast, by integrating the Kuwahara filter, the lowest MSE error of 8.45% was achieved with no grasping failures recorded. These findings confirm that pre-filtering with Kuwahara improves object localization accuracy and enhances pick and place reliability.

During color object detection, light-colored objects—particularly yellow objects—exhibited poor edge localization, resulting in higher error values and, in some cases, failure to detect the object entirely. The Kuwahara filtering method significantly improved the detection of weak edge boundaries, leading to an 11.67% increase in object detection accuracy.

The integration of PBVS with Kuwahara filtering enabled 100% grasping success, demonstrating the efficacy of 3D position-driven control in industrial automation.

The real-time implementation tests, which included 100 pick and place operations, demonstrated that the system achieved 100% successful grasping when Kuwahara filtering was applied. Furthermore, the integration of optimized kinematic calculations and motor control algorithms ensured smooth and efficient motion execution, minimizing processing delays and improving task completion speed.

Overall, the developed vision-based SCARA robot provides a high-performance solution for automated object handling, with potential applications in industrial automation, material sorting, and precision assembly tasks. Future work will focus on further optimizing the image processing pipeline, improving grasping strategies for complex objects, and adapting the system for more diverse real-world industrial applications. The current system is limited to static environments. Dynamic obstacles or moving objects were not tested. Additionally, the gripper's payload capacity (max 200g) restricts handling heavier industrial components.

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