

Inspection of Silk Cocoons using the 3-DOF SCARA Robot for Quality Control

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Research Article

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ABSTRACT

In the dynamic landscape of silk production, integrating advanced robotics and artificial intelligence has emerged as a pivotal innovation. This paper delves into the application of a 3-Degree-of-Freedom (3DOF) SCARA Robot with a gripper, incorporating cutting-edge technologies such as deep learning, vision detection, and object detection. The aim is to revolutionize traditional pick-and-place operations with silk cocoons. Creating a seamless synergy between mechanical precision and intelligent automation strives to revolutionize standard pick-and-place operations with silk cocoons. Exploring the interaction of robotics and artificial intelligence can enhance efficiency, precision and overall silk production quality. In the delicate artistry of silk cocoon handling, the practical implications, solutions to challenges, and valuable insights to advance the use of advanced technologies.

Keywords: Deep learning; 3DOF SCARA Robot; YOLOv5; 3D modelling

INTRODUCTION

In the mesmerizing world of silk production, picture a 3-degree-of-freedom SCARA Robot as the star performer, elegantly wielding its robotic gripper to choreograph flawless pick-and-place maneuvers with silk cocoons. This captivating research paper unravels the groundbreaking fusion of deep learning, vision detection, and object detection technologies, weaving a transformative spell over silk industry applications.

Deep learning is at the core of this groundbreaking innovation, endowing the SCARA Robot with adaptive intelligence. The pivotal role played by object detection algorithms allows the robot to not only recognize but also locate and manipulate silk cocoons seamlessly, setting a new standard for accuracy. The robotic gripper is an extension of this technological fusion. Envision a scenario where the finesse of silk cocoon manipulation is entrusted to a robotic gripper, skillfully guided by the wisdom of deep learning algorithms. In this technological symphony, vision detection takes center stage, serving as the main lead that empowers the SCARA Robot to pick and place the silk cocoons with precision beyond conventional methods. This research paper meticulously unravels the layers of this integrated marvel, delving into the mechanical intricacies of the 3DOF SCARA Robot and the inner workings of deep learning models and vision detection algorithms. The spotlight extends to the practical application of object detection in the silk industry, shedding light on how this technological ensemble reshapes the landscape of silk cocoon handling.

As the narrative unfolds, the story goes beyond just machines; it's about mixing new ideas with old ones. Imagine the 3DOF SCARA Robot, like a boss, using its gripper to handle silk smoothly. It's like a fancy teamwork of smart learning and sharp vision, making the robot a pro at placing things just right. Incorporating a 3DOF SCARA Robot, a gripper, and the YOLO v5 algorithm is a pivotal advancement with far-reaching implications in robotics and silk industry applications. With YOLO v5's object detection capabilities, the SCARA Robot experiences a significant boost in efficiency, enhancing its speed and precision when identifying silk cocoons in pick-and-place operations. YOLO v5 is its real-time adaptability, enabling the SCARA Robot to respond swiftly to dynamic changes in the silk cocoon environment and ensuring a seamless workflow in varied production settings. Moreover, the streamlined architecture of YOLO v5 simplifies the integration process, providing a user-friendly solution for researchers and practitioners seeking advanced object detection without unnecessary complexity.

The precision achieved in silk cocoon handling is noteworthy, thanks to the accuracy of YOLO v5, aligning perfectly with the delicate nature of silk fibers, not only enhances the overall efficiency of the SCARA Robot but also minimizes the risk of damage during the handling process. Beyond efficiency and precision, the integration represents a significant stride in the automation of pick-and-place operations. The SCARA Robot, guided by YOLO v5, emerges as a more intelligent and reliable component in silk production, marking a transformative leap in applying cutting-edge technologies in traditional manufacturing practices.

MATERIALS AND METHODS

Precision and efficiency are paramount in the intricate world of silk industry applications. Imagine a realm where a meticulously designed 3-degree-of-freedom SCARA Robot seamlessly concentrates the delicate movement of pick-and-place operations, revolutionizing how silk-related tasks are accomplished. This research paper delves into the intricacies of the design process, unraveling the threads of innovation woven into creating a robotic marvel tailored to the unique demands of the silk industry.

As navigating through the paper, the unrevealed motivation behind developing this specialized SCARA Robot is that there are challenges posed by the silk industry, and a compelling need for a robotic solution. The journey continues with a detailed examination of the robot's kinematics and dynamics, unraveling the mathematical tapestry that enables it to execute precise pick-and-place maneuvers. In the intricate tapestry of silk industry applications, this research paper serves as a guiding thread, shedding light on the transformative potential of a 3DOF SCARA Robot. Get ready to embark on a voyage through innovation, where the fusion of robotics and silk industry intricacies converges to redefine the future of pick-and-place operations.

In today's industries, robotic arms are crucial in automating routine tasks. The SCARA (Selective Compliance Articulated Robot Arm) is a popular choice, widely deployed on production lines, notably in semiconductor factories, for precise wafer handling. Its integration has become essential in the ever-evolving landscape of newly automated factories ^[1]. Intelligent manufacturing isn't limited to developed nations; it's gaining momentum in India and contributing significantly to GDP growth. The sector's Compound Annual Growth Rate (CAGR) of 7.32% from FY12 to FY17 indicates a trajectory towards achieving 25% GDP growth by 2022 ^[2]. The SCARA Robot, widely used in pick-and-place applications, elevates production

efficiency by enhancing product quality, accuracy, and precision, all while cutting costs. While costly for educational institutions, creating smaller-scale SCARA Robots presents valuable learning prospects. The SCARA's reliability, repetitive accuracy, and adaptability to challenging environments make it optimal for tasks like handling light payloads and diverse applications in assembly lines ^[3].

The SCARA's reliability, repetitive accuracy, and adaptability to challenging environments make it optimal for tasks like handling light payloads and diverse applications in assembly lines. As industrial sectors grow, increased automation is essential for meeting productivity targets. The SCARA Robot, widely used in pick-and-place applications, elevates production efficiency by enhancing product quality, accuracy, and precision, all while cutting costs. While costly for educational institutions, creating smaller-scale SCARA Robots presents valuable learning prospects. The SCARA's reliability, repetitive accuracy, and adaptability to challenging environments make it optimal for tasks like handling light payloads and diverse applications in assembly lines ^[4]. Robotic manipulators of various shapes and types play an integral role in industry, thanks to their broad applications. SCARA Robots, characterized by three revolutions and one prismatic Degree of Freedom (DOF), have gained popularity in packaging and assembly lines. Hiroshi Makino initially introduced this robot type in 1979 ^[5].

In ^[6], the authors presented the sorting robots driven by machine vision are crucial for efficient package handling on conveyors, reducing workloads. The robots integrate vision and motion control modules to identify and manipulate moving targets. The optimizing picking points for SCARA sorting manipulators proposes a high-speed picking-placing approach. By determining precise sorting points and adjusting conveyor belt velocity based on system density, the study demonstrates through simulations that optimal picking points reduce sorting time and energy consumption. The proposed control strategy, validated using the Robotics Toolbox for SCARA manipulators, enhances operational efficiency in real-time sorting operations. While longer processing times pose a drawback, the 3D camera's capacity to provide depth information proves invaluable, significantly improving overall performance in detection, classification, and localization ^[7]. Human-robot interaction improved assembly tasks. Safety in collaboration, guided by ISO 10218-1, focuses on monitoring separation distance and limiting robot speed, force, and power. The two crucial Human-Robot Collaboration (HRC) steps are danger evaluation and human detection ^[8].

With a mechatronic structure featuring linear actuators and motors, SCARA Robots enhance assembly precision, reduce time and costs, and perform linear movements in the X, Y, and Z axes. Typically mounted on pedestals, these robots replicate human arm motions with shoulder, elbow, wrist, and vertical movements, offering four degrees of freedom. Utilizing servo frameworks, machine vision, and straight modules, SCARA transforms into a flexible workstation, excelling in tasks such as dispensing and in-door gasket forming, ultimately contributing to streamlined and cost-effective production automation ^[9].

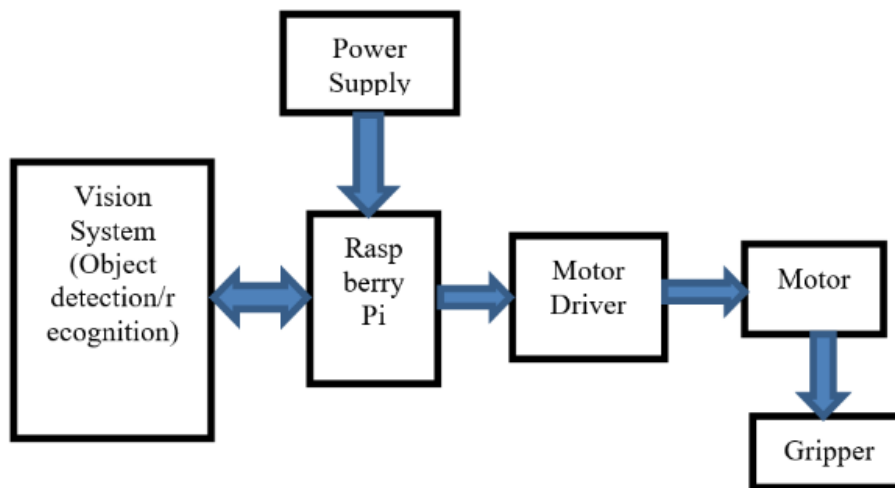
Inspection and quality control serve as vital for both client happiness and production. In order to achieve industry 4.0 criteria, machine vision-based strategies are being implemented more and more in smart production systems. This paper explores the problems, requirements, norms, challenges and present advancements in the field of intelligent machine vision-based quality control methods ^[10]. The study addresses the transition from traditional to intelligent quality control methods, focusing the difficulties relating to system integration, security, and human-robot interaction. It also covers the procedure of applying the Haar Cascade Classifier on cement surfaces of walls for surface defect detection, which is an essential QC application in current manufacturing ^[11].

The methodology encompasses designing the robot's mechanical structure and custom gripper for silk cocoon handling, followed by calibration, testing, and incorporating vision sensors. Deep learning models, trained with a silk cocoon dataset, and vision and object detection algorithms contribute to accurate identification during pick-and-place operations. Iterative testing and optimization ensure seamless collaboration, addressing challenges such as cocoon variability and proposing solutions to enhance system robustness. Real-time vision and object detection technologies offer crucial insights for accurate perception and localization of silk cocoons within the robot's workspace. The seamless collaboration between the gripper and advanced technologies demonstrates the potential to marry tradition with innovation in silk production, showcasing a transformation path for the industry. Fusing a 3DOF SCARA Robot with a gripper and the YOLO v5 algorithm is a pivotal advancement in robotics and silk industry applications. Leveraging YOLO v5's object detection capabilities enhances the SCARA Robot's speed and precision in identifying silk cocoons during pick-and-place operations, significantly boosting overall efficiency. YOLO v5's real-time adaptability ensures the SCARA Robot's swift response to dynamic changes in the silk cocoon environment, streamlining workflows. The algorithm's streamlined architecture simplifies integration, offering a user-friendly solution for advanced object detection.

Block diagram of 3 degree of SCARA Robot

A block diagram is a graphical representation of a system that showcases major components and their interconnections. These block diagrams are often used to represent complex systems and processes in a clear and concise manner. Figure 1 shows the block diagram of 3DOF SCARA Robot. The camera captures images of the robot's surroundings, which are then sent to the Raspberry Pi. The Raspberry Pi runs YOLO v5, a real-time object detection and recognition software. YOLO v5 identifies and locates objects of interest in the images, such as silk cocoons. The Raspberry Pi then sends signals to the motor driver, which controls the robot's gripper. The gripper picks up the silk cocoons and moves them to the desired location.

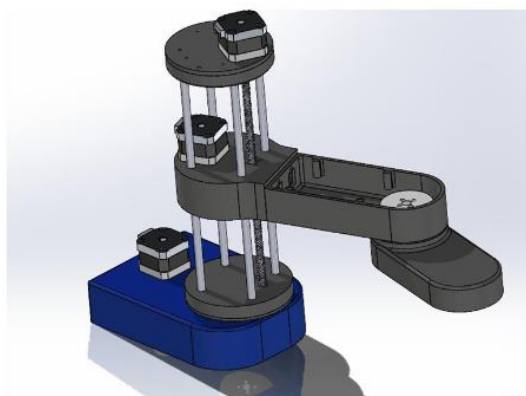
Figure 1. Block diagram of 3DOF SCARA Robot.



Design and implementation

The first thing for the SCARA Robot project is what it needs to do, such as how much weight it can handle, how far it can reach, and how accurate and speedy it should be. These requirements become our blueprint for designing the robot. The basic structure outlining the main arm and end-effector is shown in the Figure 2. This involves thinking about the overall shape, dimensions, and joints needed for movement. Utilizing solid-works software and designed the parts how they will fit together. It involves creating features like mounting holes, slots, and tabs to make assembly a breeze. Then, finalized the design and exported the CAD model to a format compatible with 3D printers, such as STL (Stereo-Lithography). The 3D printable files loaded into the 3D printer kick-start the printing process. Assembly begins with putting together the base, followed by the arm, links, pulleys, belts, actuators, joint connections, and the end-effector. After completing the assembly verified the movement of functionality of each joint, ensuring all components are securely connected and working as intended. It's a meticulous process to ensure the SCARA Robot is ready to perform its designated tasks with precision and efficiency.

Figure 2. CAD model of SCARA Robot.



This project's system requirements highlight three crucial components: three stepper motors with a torque rating of 0.4 Ncm, three TB6600 micro step drivers to control the stepper motors, and a Raspberry Pi as the central processor with 40 GPIO pins. Two Nema17 motors are designated to actuate the system's two links, each under the control of a TB6600 microstep driver. The lead screw is set in motion by a motor, and power is supplied through a 12 V adapter, with jumper wires linking the components. The TB6600 micro step drivers govern the Nema17 stepper motors for precise control, ensuring accurate movement. The Raspberry Pi, with its 40 GPIO pins, takes the lead as the central controller. It connects the direction and pulse pins of the stepper and DC motor driver pins, showcasing its role in coordinating movements. Careful power design is integral to the system.

The Raspberry Pi draws power from a stable 3.3 V supply via a power bank. On the other hand, the stepper motors and drives are powered by a 12 V DC adapter with a current output of 1.5 A. Noteworthy is the strategic operation of the Nema17 motors at a maximum of 1 A, achieved by setting the motor drivers to an existing current range between 0.7 and 1.0 A. This optimization ensures optimal performance while effectively managing current consumption. The project incorporates a camera component. This camera integrates seamlessly into the Raspberry Pi system, enhancing its capabilities by providing visual input. This addition opens up possibilities for applications requiring visual feedback, further enriching the functionality of the robotic system.

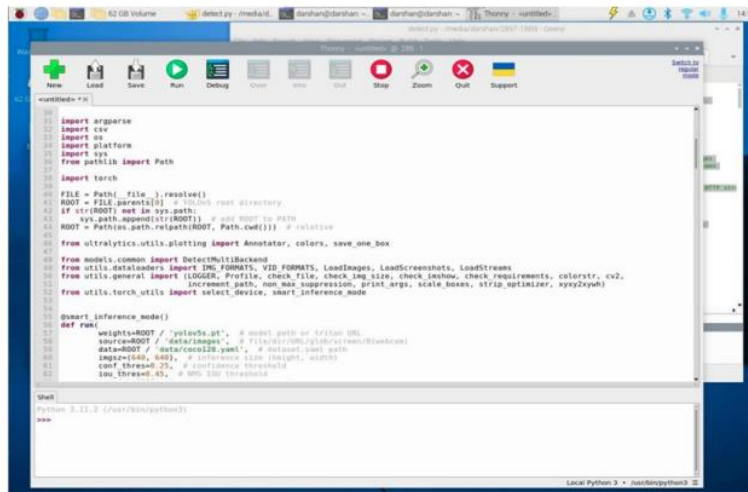
Matlab is a powerful tool for system simulation and visualization in the context of the 3-DOF SCARA Robot for cocoon picking. The simulation environment allows engineers to model the entire system, including the robot and vision system. Matlab's capabilities enable the visualization of robot movements, vision system outputs, and gripper control, providing a comprehensive understanding of system behavior. System simulation: Engineers can simulate various scenarios to test the performance of the cocoon-picking system under different conditions. It includes assessing the robot's movements, the accuracy of the vision system in detecting cocoons, and the control of the gripper during picking. Data analysis and optimization: Matlab's advanced data analysis tools come into play for processing and analyzing collected data. Metrics such as cocoon detection accuracy, picking time, and overall system efficiency can be evaluated. Furthermore, optimization algorithms within Matlab can fine-tune system parameters, improving performance and efficiency in the cocoon-picking process.

Solid-works plays a crucial role in the mechanical design and simulation of the 3-DOF SCARA Robot for cocoon picking. Its versatile functionalities contribute to different aspects of the design process. 3D modeling and design: Engineers can use solid-works for the creation of detailed 3D models of the SCARA Robot, ensuring mechanical integrity and structural coherence. Assembly and kinematics: The software facilitates the assembly of different components, allowing engineers to assess the kinematics of the robot, studying the motion and interactions of various parts in the assembly. Solid-works enables engineers to simulate the motion of the robot, providing insights into how it will behave in real-world scenarios. This aids in identifying any potential issues and refining the design for optimal performance. Visualization and documentation: Solid-works helps visualize the designed robot and creates comprehensive documentation. This documentation is crucial for understanding and communicating the design specifications.

While Easy-EDA primarily focuses on electronics design, it can be applied to the electronic control system of the cocoon-picking SCARA Robot. Schematic design and PCB layout: Easy-EDA facilitates schematic design and PCB layout, allowing engineers to design and prototype the electronic control system. This includes selecting components, creating schematics, and arranging them on a Printed Circuit Board (PCB). Simulation: Easy-EDA's simulation capabilities enable engineers to test the electronic control system virtually before implementation, ensuring functionality and identifying potential issues. Collaboration Features: The web-based nature of Easy-EDA allows collaboration among team members, streamlining the design and prototyping process for the electronic control system.

Thonny Python IDE is utilized to develop the software components and algorithms governing the operation of the cocoon-picking SCARA Robot. Code editing and debugging: It provides a user-friendly interface for writing, editing, and debugging Python code, streamlining the development process. Integration with libraries: This software supports integrating Python libraries, allowing engineers to leverage existing code and functionalities to develop the robot's control software. Data visualization: It includes features for data visualization, aiding in the analysis and debugging of the Python-based software component is shown in Figure 3.

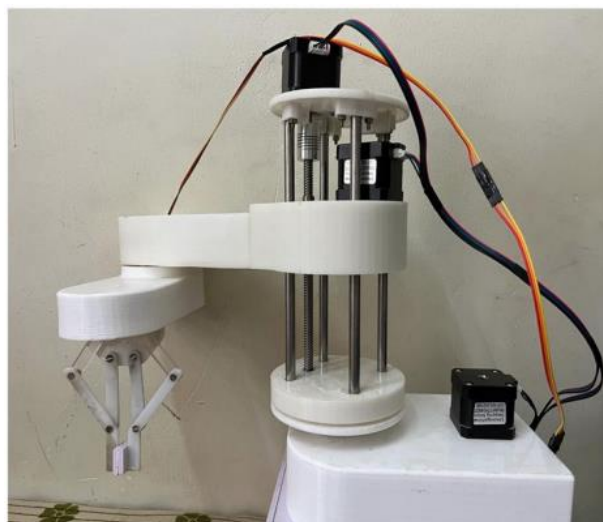
Figure 3. Analysis and debugging of the Python-based software component.



Hardware setup of the system

The architecture of a system provides a blueprint for its design and functionality for SCARA Robot. The SCARA Robot system architecture integrates electric energy signals and unsorted silk cocoons as inputs. The system incorporates a camera for detecting and analyzing silk cocoons. The camera's role is distinguishing between good and bad silk cocoons based on predetermined criteria. Upon identifying a bad cocoon, the system activates the SCARA Robot, which is equipped with a gripper mechanism is shown in Figure 4. The SCARA Robot, guided by its programmed instructions, precisely picks up the detected bad cocoon. The gripper's functionality lets the robot grasp and manipulate the targeted cocoons effectively. The SCARA Robot then carries out the sorting process, segregating the bad cocoons from the good ones. This automation enhances efficiency by automating the labor-intensive task of silk cocoon sorting. The system's architecture ensures seamless integration and coordination between the camera, robot, and gripper. Overall, the designed architecture optimizes the silk cocoon sorting process, improving accuracy and productivity.

Figure 4. Hardware setup of the SCARA Robot.



Control system of SCARA Robot

Implementing the YOLO (You Only Look Once) v5 algorithm for a 3DOF SCARA Robot for pick-and-place operations with silk cocoons in the Silk Industry presents a unique computer vision and robotics fusion. YOLO v5 is renowned for its real-time object detection capabilities, making it a promising tool for enhancing the precision and efficiency of the robotic system. In this application, the YOLO v5 algorithm can be adapted to recognize and locate silk cocoons within the robot's

workspace. The algorithm's ability to swiftly process images and identify objects in a single pass aligns seamlessly with the dynamic nature of silk production environments.

The workflow involves integrating a camera system with the SCARA Robot, capturing real-time images of the silk cocoon environment. The YOLO v5 would then process these images, providing the robot with accurate spatial information to execute precise pick-and-place maneuvers. This type streamlines the operation and contributes to the quality of silk production by minimizing the risk of damage to delicate silk fibers. Furthermore, the algorithm can be fine-tuned to accommodate variations in cocoon shapes and sizes, ensuring adaptability to the diverse characteristics of silk cocoons. The real-time feedback loop created by YOLO v5 enhances the robot's responsiveness, making it well-suited for the nuanced demands of silk cocoon handling.

Integrating a 3-Degree-of-Freedom (3DOF) SCARA Robot for pick-and-place operations with silk cocoons, utilizing deep learning, vision detection, and object detection technologies, is not without its set of challenges. These hurdles, inherent in the complexity of silk industry applications, warrant careful consideration in the research paper such as cocoon variability, delicate handling, and real-time responsiveness. Challenges are achieving real-time responsiveness in vision and object detection is essential for dynamic silk production environments. Any delay in processing may impact the efficiency of pick-and-place operations. Ensuring that the system can process visual information swiftly and make real-time decisions is crucial for seamless integration into the silk production process.

Adaptability to environmental changes are interdisciplinary collaboration, implication, and cost considerations. Addressing these challenges in the research paper provides a comprehensive understanding of the intricacies involved. It paves the way for future advancements in seamlessly integrating SCARA Robots with deep learning and vision technologies in silk cocoon handling.

RESULTS AND DISCUSSION

Integrating the YOLO v5 algorithm into the 3-DOF SCARA Robot for silk cocoon pick-and-place operations represents a significant advancement in the intersection of computer vision and robotics. The real-time object detection capabilities of YOLO v5 contribute to the precision and efficiency of the robotic system in the silk industry. The workflow involves a seamless fusion of a camera system with the SCARA robot, capturing real-time images of the silk cocoon environment. The YOLO v5 algorithm processes these images with remarkable speed, providing the robot with accurate spatial information for executing precise pick-and-place maneuvers is shown in the Figure 5.

Figure 5. 3-DOF SCARA Robot.

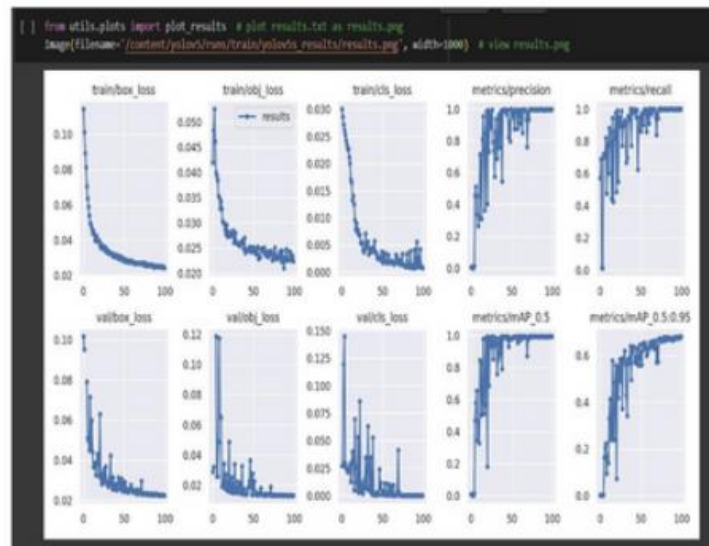


This integration streamlines the operation and enhances the quality of silk production by minimizing the risk of damage to delicate silk fibers. The adaptability of the YOLO v5 algorithm is a key feature, allowing it to be fine-tuned to accommodate variations in cocoon shapes and sizes. The integration of YOLO v5 into the 3-DOF SCARA Robot for silk cocoon handling demonstrates the synergy between computer vision and robotics and presents a practical solution is shown in the Figures 6 and 7.

Figure 6. Detection of silk cocoons.



Figure 7. Graphs obtained after training the data set.



CONCLUSION

Integrating the YOLO v5 algorithm into the 3DOF SCARA Robot for pick-and-place operations with silk cocoons represents a groundbreaking synergy of computer vision and robotics. This novel approach leverages YOLO v5's real-time object detection capabilities to enhance precision and efficiency in silk industry applications. By seamlessly incorporating a camera system, the SCARA Robot can dynamically respond to the silk cocoon environment, optimizing pick-and-place maneuvers and minimizing the risk of damage to delicate silk fibers. The adaptability of the algorithm to variations in cocoon shapes and sizes further underscores its suitability for the nuanced demands of silk cocoon handling. This research contributes not only to the field of robotics but also holds significant implications for improving the quality and efficiency of silk production processes.

AUTHOR CONTRIBUTION

First authors, second, third, fourth, fifth, and sixth authors wrote the all contents.

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