

Solution of a 4-Axis Selective Compliance Assembly Robot Arm (SCARA) for Picking & Placing an IC Component onto the PCB

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Abstract—The SCARA robot arm, known for its horizontal movement and accurate positioning, presents a versatile platform for assembly tasks in various industries, particularly in electronics manufacturing. The main goal is to get the forward kinematics equations required to precisely calculate the end-effector's location and orientation using the 4-axis SCARA robot arm's joint angles. The mathematical model explaining the link between the robot's joint variables and the position/orientation of the end-effector is developed by specifying the Denavit-Hartenberg (DH) parameters and using transformation matrices. The work intends to simulate and test the computed end-effector locations and orientations against experimental or simulated data using the obtained forward kinematics equations. The forward kinematics approach will be implemented using code developed as part of the project, enabling systematic investigation and testing of the pick-and-place capabilities of the SCARA robot. Additionally, it also provides a brief overview of the possible uses and consequences of using this SCARA-based solution for accurate and efficient assembly jobs in industrial settings. The incorporation of a graphical user interface (GUI) has the potential to enhance user engagement and aid in the real-time management and observation of the pick-and-place processes. By offering a methodical solution to the direct kinematics problem of a 4-axis SCARA robot arm for the purpose of picking and placing IC components onto PCBs, it advances robotic assembly technologies and highlights their potential to increase productivity and accuracy in manufacturing processes.

Index Terms—SCARA Robot, forward kinematics, 4-axis Robot Arm, PCB assembly, Graphical User Interface(GUI), end-effector positioning, Denavit-Hartenberg parameters, pick and place task, manufacturing efficiency, motion planning.

I. INTRODUCTION

One of the most crucial jobs in the industrial sector is pick and place, which is done by “Selective Compliance Assembly Robot Arm” (SCARA). One amazing quality of this kind of manipulator is its repeatability with rapid movement in a horizontal plane. The problem of attaining high-speed movement stability with lengthy linkages is the design challenge of SCARA [1]. Arms with shorter connections can move more steadily. Due to this requirement, the linkages should be regarded as restricted, and the operation area (workspace) should thus be

restricted [2]. In industrial automation, the 4-axis Selective Compliance Assembly Robot Arm (SCARA) is indispensable, especially for repetitive and accurate activities like choosing and inserting components onto Printed Circuit Boards (PCBs). Because of their speed, precision, and mechanical design, SCARA robots are very useful for assembling Integrated Circuit (IC) components onto PCBs [3].

II. OBJECTIVES

- To reduce mistake rates and guarantee high-quality assembly, make sure that IC components are placed precisely and accurately in the appropriate locations on the PCB [4].
- Boost production efficiency by using the fast and steady motions of the SCARA robot to do pick-and-place tasks quickly, which will enhance throughput and shorten cycle times [5].
- By automating the labour-intensive and repetitive activity of putting IC components, assembly line productivity may be increased overall [6].
- This frees up human operators to concentrate on more complicated or value-added procedures [7].
- By using SCARA robots to optimize the process, minimize material waste, rework, and improve resource utilization, production costs related to assembly may be reduced [8].
- Provide the SCARA robot the ability to handle a wide range of IC component sizes, shapes, and configurations to ensure that it can be easily reprogrammed or adjusted to diverse product designs [9].
- Make sure that IC components are placed on PCBs in a consistent and trustworthy manner to preserve consistency across manufacturing batches and lower the possibility of errors or failed products [10].
- To enhance productivity and expedite the assembly process, use effective pick-and-place techniques such as gripper design, trajectory planning, and optimal motion profiles [11].
- To enable real-time monitoring, feedback, and adaptive control, seamlessly link the SCARA robot with the current manufacturing systems, such as sensors, vision systems, and control interfaces [12].
- Enable safe and cooperative interactions between human operators and SCARA robots to use the skills of both human and robotic workers in cooperative work settings [13].

III. BLOCK DIAGRAMS

The Selective Compliant Assembly Robot Arm, also known as the Selective Compliant Articulated Robot Arm, is a benchmark design used to introduce students to the field of mechatronics design. This three-axis robot can move in the X, Y, and Z coordinates within of its work area. Because of its parallel-axis joint design, which makes the arm somewhat flexible in the X-Y direction but rigid in the 'Z' direction, SCARA robots are employed in assembly processes where inserting a part requires a single vertical motion as its final step. It's commonly referred to as “vertical assembly” In pick-and-place, assembly, and packaging applications, they are widely used. In example, the electronic printed circuit board sector employs a lot of SCARAS to install semiconductor integrated circuits (ICs) and other components on computer circuit boards. The block-diagram is shown in the Fig. 1.

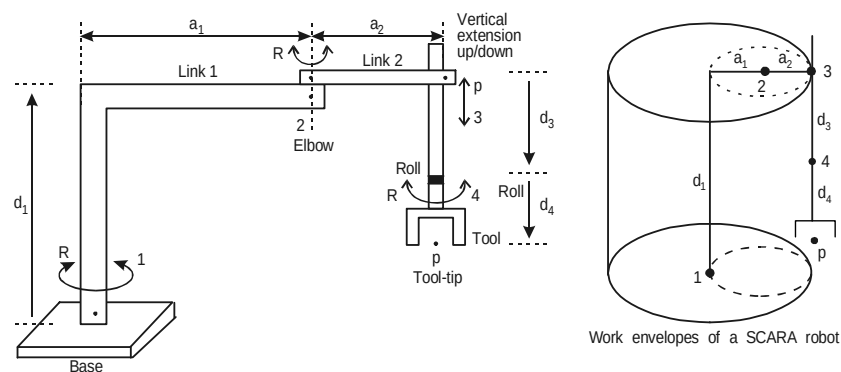


Fig 1: SCARA Configuration

- One orthogonal joint provides linear movement, enabling the arm to extend and retract.
- Due to a single rotating joint, there is rotary movement at the top of the column around the shoulder joint (along the vertical axis).
- One rotational joint cause rotary movement at the output arm about the elbow joint (along the vertical axis).

IV. FLOW-CHARTS

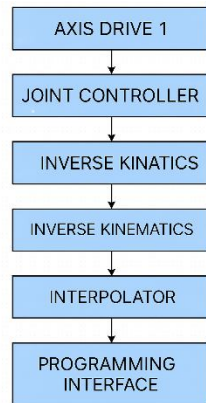


Fig. 2: Robotic Control System Block Diagram &

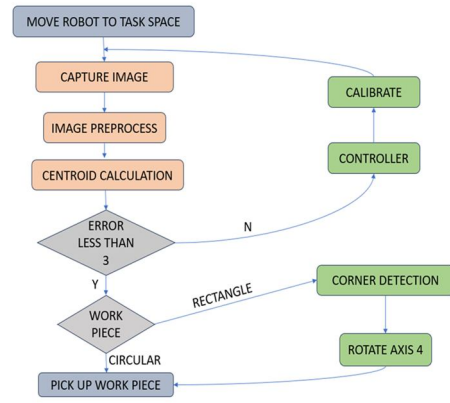


Fig. 3: Diagram for moving from one point to another point in the 3D space

The image shows a block diagram of a joint controller for a 4-axis SCARA robot along with the flow-chart in Fig. 2. The main components of the controller are Programming interface, Direct kinematics, Inverse kinematics, Interpolator, Axis drives. A more detailed explanation of the operation of each block in the controller as follows as shown in Fig. 3.

Programming interface:- The programming interface allows the user to specify the desired robot motions and other parameters. This can be done through a variety of methods, such as a graphical user interface, a text-based programming language, or a robot API.

Direct kinematics:- The direct kinematics block converts the desired robot joint angles into the corresponding Cartesian coordinates of the robot's end effector. This is done using a set of equations that describe the geometry of the robot.

V. OPERATIONS FOR THE 4-AXIS SCARA ROBOT ARMS

A. Moving to Task Space

A SCARA robot may be moved to task space by defining the target coordinates and angles in its operational environment, as well as the intended location and orientation of its end-effector in the workspace.

B. Image Capture

When capturing photos for a job, use a camera that is either in the workspace of the SCARA robot or attached to its end-effector.

C. Image Preprocessing

- Image Acquisition:- Acquire the image data from the camera.
- Image Enhancement:- Adjust image properties like brightness, contrast, and sharpness for better visibility.
- Image Filtering:- Apply filters (e.g., Gaussian, median) to reduce noise or emphasize certain features.
- Image Segmentation:- Divide the image into meaningful regions for analysis.
- Feature Extraction:- Identify and extract relevant features from the image.
- Normalization:- Normalize pixel values to a standard range.
- Resize or Crop:- Adjust the image size as needed.
- Colour Space Conversion:- Convert the image to a suitable colour space (e.g., grayscale, HSV) for processing.

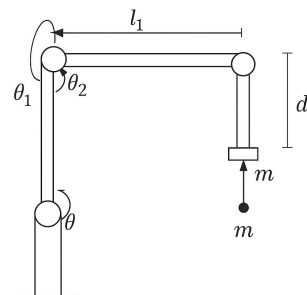
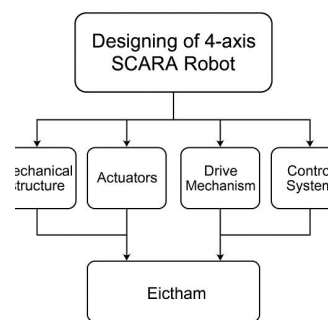
VI. WORKING PROCESS

Robots can be controlled using two different methods: forward and inverse kinematics. Forward kinematics is used to find the position and orientation of the end-effector from specified joint angles, inverse kinematics is used to find joint angles for a given end effector location. Determining the SCARA robot's kinematic model is the first step in the working process. To express the connections between joint angles and the location and orientation of the end-effector, this model consists of determining the Denavit-Hartenberg (DH) parameters and the transformation matrices for each joint. The next step is direct kinematic solution, which uses the kinematic

model to find the position and orientation of the end-effector for a given joint angle. The robot determines the exact location of the IC component that must be picked up and put on the PCB using forward kinematics. These are the forward and inverse kinematics equations that we deduced. The end effector's position and orientation may be determined using the joint angles θ_1 and θ_2 , and the joint angles for a certain end-effector location can be computed using x and y .

VII. DESIGN PROCESS

For selecting and positioning an Integrated Circuit (IC) component onto a Printed Circuit Board (PCB), a 4-axis Selective Compliance Assembly Robot Arm (SCARA) is designed using a multidisciplinary approach that includes mechanical design, kinematic modelling, control system development, and vision system integration. The goal of this procedure is to develop a precise and effective robotic system that can precisely manipulate and position integrated circuit (IC) components onto printed circuit boards (PCBs), maximizing production efficiency and guaranteeing premium assembly in the electronics sector. The design process is shown in the Fig. 4 & 5 respectively.



Free Body Diagram of SCARA Robot

Fig. 4 : Designing of 4-axis SCARA Robot Fig.5 : Free Body Diagram of Scara Robot

VIII. MATHEMATICAL MODEL DEVELOPED

Denavit-Hartenberg (DH) parameters and forward kinematics equations are used in the mathematical model for a 4-axis Selective Compliance Assembly Robot Arm (SCARA) as shown in the Fig. 4 in order to pick and place an Integrated Circuit (IC) component onto a Printed Circuit Board (PCB) to describe the relationship between joint angles and the position and orientation of the end-effector. The SCARA robot kinematics can be represented using the DH parameters and transformation matrices. In the context of a SCARA robot, the Free Body Diagram might focus on various components as shown in the Fig. 5.

- Base Structure:** This refers to the SCARA robot's frame or base platform. Gravitational forces, frictional forces between the base and the ground, and reaction forces from the robot's motions are some examples of forces that might be operating on the base.
- Robot Arm Links:** Every joint and link in the SCARA robot arm would have a unique set of forces shown in the FBD. These forces may consist of response forces from neighbouring links, internal torques or moments resulting from motor operations, and gravity forces acting on each link.
- End-Effector:** During picking, putting, or manipulating things, the end-effector or tooling attached to the robot arm may be subject to forces resulting from the gripper's engagement with the IC component or from any external forces.

IX. KINEMATIC ANALYSIS OF DIFFERENT JOINTS

The study of motion without considering the forces causing it is known as kinematics. Here, two different kinematics were suggested to play a crucial part in the analysis of the robot's movements. The technique of determining the location and orientation of the end effector given values for the robot's joint variables is known as forward kinematics. The frame is assigned as shown in the Fig. 6.

The inverse procedure known as "inverse kinematics" establishes the values of the joint variables for a given end effector location and orientation. To model robot linkages and joints, the forward kinematics approach employed the Denavit-Hartenberg (D-H) model of representation, also known as the Denavit-Hartenberg convention, the DK & IK model is shown in the Fig. 7 [14].

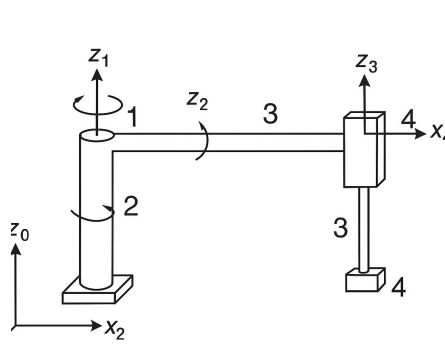


Fig. 6: Frame assignment of a 4-axis SCARA robot arm

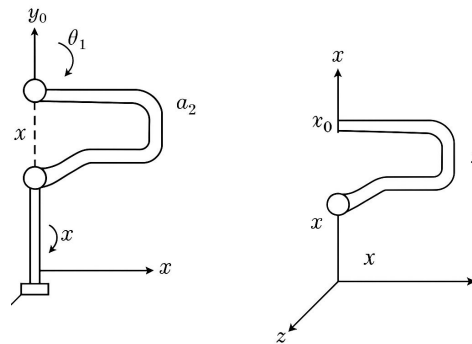


Fig. 7: The direct and inverse kinematical model of a SCARA robot

X. SIMULATIONS

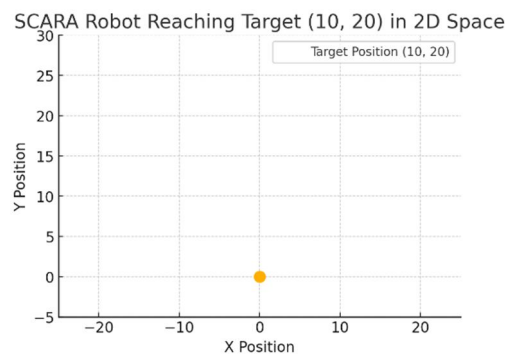


Fig. 8 : Output of SCARA shown in the 2D environment for positioning the end-effector at the origin home position

Applying these simulations to a real robot in the real world, engineers and researchers may use them to test ideas, refine algorithms, and access how the robot behaves. The output of SCARA shown in the 2D environment for positioning the end-effector at the origin home position is shown in the Fig. 8 [15].

XI. CONCLUSIVE REMARKS

The effective application of a 4-axis SCARA robot arm and direct kinematic solution to a pick-and-place operation is evidence of the progress made in robotics and its revolutionary influence on industrial automation. This achievement demonstrates the SCARA robot's ability to carry out the complex and precise motions needed to precisely place Integrated Circuit (IC) components onto Printed Circuit Boards (PCBs). In addition to demonstrating technological skill, the robot's ability to compute and execute these motions using advanced direct kinematic algorithms highlights how robotics can seamlessly integrate mathematical modeling with real-world manufacturing tasks, ensuring both speed and accuracy in automated assembly processes.

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