19AIE201
"Introduction to Robotics"

Project Report

Project Title: Structural description & functioning of a 4-DOF SCARA Robot - A detailed case study.

Bachelor of Technology in Artificial Intelligence & Engineering

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Abstract:

This assignment aims to layout and enhance a structural description & functioning of a 4-dof scara robot. Mechanical technology has come to be a typical way in a ton of more noteworthy establishments. There are various robots accessible by keeping watch, most of them are for current purposes and moreover exorbitantly costly. Despite the fact that there is an aching to help low assessed robots for understudies in more noticeable establishments to inspect the parts of mechanical innovation like arrangement, control, kinematics, components, and sensors.

This record fosters a four certificate of opportunity (4-DOF) particular consistency meeting robot arm with 3 rotational joints and one kaleidoscopic joint (3R1P) to expand the portrayal and working of it. The state of the robot is introduced first and afterward a kinematic-model is fabricated and furthermore the kinematic examination is fundamentally founded on MATLAB. In the determination definition stage, the particulars of the SCARA mechanical are not entirely set in stone. The Inverse and Forward Kinematics elements of the robot are then demonstrated. Some specifications, simulations, and analyses have been defined in detail about the 4-dof scara robot to format and boost a structural description and functioning.

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Chapter 1

Introduction

1.1 Background Study:

1.1.1 SCARA Robots' History

The primary SCARA computerized framework was once made as a high level model in 1978-in the exploration office of Professor Hiroshi Makino, at Yamanashi University in Japan.

The 4-hub(axis) SCARA used to be planned like no other robot arm at that point(time). Its effortlessness used to be phenomenal … with a decent arrangement with substantially less movement, it should accomplish more, with high rhythm(tempo) and accuracy(precision).

1.1.2 What is a SCARA Robot, and how does one use one?

Selective Compliance Articulated Robot Arm (SCARA) is the name given to a particular sort of current(modern) robot. The SCARA robot is most ordinarily utilized for pick-and-spot or get-together tasks that need an undeniable degree of speed and accuracy(exactness). Indeed, even with non-necessary cleanroom necessities, the SCARA robot can generally work at higher paces.

"Multi-functional manipulators meant to go through a range of programmed motions" are how industrial robots are characterized. As a result, robots provide reliable, predictable performance, the ability to handle massive workloads, and the ability to function in challenging environments.

1.1.3 Configuration of SCARA Robots

SCARA robots with four axes have an internal link that pivots all over the place Z-axis(hub), which is linked to an external connection i.e turns around a Z-elbow joint, which is linked to a wrist axis(hub) that strikes all over and furthermore pivots around-Z. The linear Z movement is utilized as the second pivot in another plan. These are the most well-known calculations for vertical assembly and pick-and-place(spot) strategies with little parts.

1.1.4 SCARA Robot Characteristics:

- **Speed and movement**
  Aside from its payload, the speed with which an industrial computer accomplishes its operations is the most crucial feature.
  SCARA robots are currently moving at amazingly quick rates. The nominal operating speeds of movement, much like in the Cartesian version, are determined by the pressure strength and kinematic gear characteristics (gear ratio of the gearbox). In comparison to Cartesian mechanics and delta robots, SCARA robots have a faster rate in general.

- **Accuracy and repeatability**
  SCARA-based mechanics are recognized by non-consistency in development choices in the XY plane. It is common to speak about a decision gradient in a

specific plane when discussing SCARA mechanisms. At the foundation, the most accuracy (the smallest absolute error and spectacular resolution) is identified (in the middle of the mechanism). The resolution degrades as you move away from the centre (due to an increase in the measurement of the lever, ie, lengthening of the SCARA "arm").
The SCARA mechanism is characterized by a high degree of repeatability in movement outcomes without losing accuracy because there are no stretching portions (drive belts) in the structure. This functionality enables SCARA robots to perform operations in a consistent, sequential order.

- **Load limitation**
  The weight of the working tool and the weight of the load (or the forces acting in the working vicinity of the mechanism) make up the permitted load. At the point when SCARA mechanics are utilized, the load is applied to the functioning region situated at the crest of the mechanism's extended working shoulder (the robot's drawn-out "arm"). This results in some load constraints and a desire to increase the energy and stiffness of the mechanism's parameters.

1.1.5 SCARA Robot: Working principle

➔ **The SCARA robot arm's movement.**

Because these positions and postures are synthesized by employing the movement of several arm joints, the end effector at the front of the robot arm must be in a position and attitude appropriate to the processing workspace when operating the robot. Therefore, we should get a handle on the connection between the variable region of each joint of the robotic arm and the function and posture of the end effector in SCARA robotic action control.

➔ **Track planning for robots.**

The space bend of the movement direction from the capacity and stance of the initial component to the position and stance of the posture is the activity course of the robot controller. The purpose of trajectory planning is to create a set of "control setpoints" that may be used to manipulate robot movement by using a function to "interpolate" or "approach" a specified course. Currently, spatial joint interpolation and Cartesian spatial planning are the most often utilised music planning methods.

➔ **The control system for the SCARA robot.**

The control goal of a robotic dynamic motion equation is to keep the robot's dynamic reaction in line with preset overall performance standards. However, due to the robot's inertial force, coupling reaction force, and gravity load, manipulating it with high precision, high speed, and high dynamic quality is rather difficult. Currently, in industrial robots, the standard strategy is to treat each joint as a distinct servo mechanism, or, to put it another way, a nonlinear, inter-joint-coupled variable load system reduced to a linear non-coupled independent system.

1.1.6 Advantages of SCARA robots

- Compact design, wide operational range, and short set-up footprint
- Has a high level of accessibility. Joint coordinate robots can work in a closed environment like an auto body, whereas right-angle coordinate robots are unable to do so.
- There are no rails required in light of the fact that there are no moving joints. Rotating joints are easy to seal, resulting in acceptable dependability, because bearing components are a significant production of fashionable parts, resulting in friction and inertia.
- The SCARA drive torque(force) required is low, and the power utilization is low.
- Replace a lot of complex labour that is no longer manpower-intensive and harmful to one's health.

1.1.7 SCARA robots' limitations

- SCARA robots are often only successful in carrying a lighter payload due to their configuration. They regularly lift up to 2 kg ostensibly (10 kg greatest).

- A SCARA robot(automated) envelope is ordinarily circular, which doesn't fit all applications, and the robot has restricted aptitude and adaptability contrasted with elective types of robots' finished 3D limit/capacity (for example six-pivot(axis) robots).

1.2 Literature Survey

SCARA robots are distinguished from articulated robots by the presence of two concentric cylinders in their workspace. To orient the component to be assembled, the gripper can raise, descend, and rotate. SCARA is unique in that it is smooth on the x and y axes but quite powerful on the z axis.

A unique SCARA design, known as the Spine robot, was developed in Sweden and comprises many discs joined together by two pairs of hydraulic cable actuators. Each stiff part of the robot has at least four cables, for a total of eight cables with four degrees of freedom (DOF). When the cylinders in the spine robot's base pull these cables, the robot works. The SCARA arm can pick up vertically from a horizontally positioned table, move along the horizontal plane to the appropriate spot, and then pick up vertically again, and then lower the arm and insert the part in its proper placement to complete the assembly operation.

DENAVIT- HARTENBERG (D-H) Notation:

SCARA-style robotic arms with hydraulic actuators have shown that obtaining high speeds and torques using electrical actuators is actually challenging. Dwivedy and Eberhard reviewed the literature on dynamic evaluations of flexible robotic manipulators (2006). The papers in this review are divided into three categories: modelling, control, and experimental studies. They are split into two categories in modelling: the method of analysis and the amount of links involved. This study looked at 433 papers that were given between 1974 and 2005. Akda described how to construct and study robot manipulators using integrated techniques. He created three different robots that follow this procedure, as well as a new idea called "Rigidity Workspace" based on the robot's endpoint static deflections and modal behaviour. The mobility of a SCARA robot was controlled by a PLC, according to Das (2003). In 2006, Sayl designed a SCARA-type manipulator and used a CNC machine to make the pieces. He also developed kinematic equations for SCARA-type manipulators. Engelberger has been dubbed the "Father of Robotics" for his achievements. For a brief period of time, the economic viability of robots was demonstrated to be perilous, and robotics progress paused. However, in the mid-80s, the robotics sector was revived and brought back on track.The multi-jointed artificial arm, designed by George Devol

Jr. in 1954, set the foundation for today's robotics. The Programmable Universal Manipulation Arm, designed by mechanical engineer Victor Scheinman, is a totally flexible arm (PUMA).

1.3 Motivation

Pre-programmed tasks are where today's robots excel. They work well in environ ments that are well-specified and have clearly defined objects. Robotics is becoming more common in households with applications like cleaner machine robotics, in social settings with telepresence robots and nursing robots for the elderly, and for commercial or entertainment purposes. As platforms for aerial imaging Robotics, according to experts, will be widely used within the next several years. Industrial Robots protect workers from repetitive, mundane and dangerous tasks. Among those, SCARA robots are unique robots with a special place in the industrial robot family. The popularity and uses of a SCARA robot, as well as the difficulty of analyzing its kinematics and dynamics, are the motivations behind this research paper.

Chapter 2

Work & Methodology

2.1 Overview

SCARA is the name given to a certain type of industrial robot. In the early 1960s, robots were created and invented in Japan. The SCARA robot is designed for applications that demand repetitive point-to-point arm operations, such as picking and placing objects or assembly techniques that require extreme speed and precision."Multi-functional manipulators meant to move parts through multiple programmed motions" are what industrial robots are characterised as. As a result, robots deliver constant, dependable performance and repeatable accuracy. They can tolerate high workloads and operate well in adverse conditions. Furthermore, robots may be reconfigured quickly to reflect changes in production needs and different cycles. As a result, SCARA is widely used in assembly processes. SCARA's unique end-effector movement makes it suited for activities that need circular motion and accelerations.

From getting a basic idea of what exactly a SCARA robot is, we have different applications that can be used in day-to-day life, few of them are as follows:

1) Work on screw tightening using the iVY robot vision system:

The location detecting function of the iVY system can be used to address a variety of situations. When the screw hole positions are inconsistent, the conveyor workpiece position is not upright, or several types of workpieces are provided, for example, the robot may be able to work quickly. With simple processes, the iVY system can be evaluated. The teaching process will be shortened, the startup time will be reduced, and labour costs will be cut.

2) Inverse specification-based process-to-process transfer:

The opposite specifications will allow the workpiece to be held from below, preventing the matter from falling onto the workpiece.Standard floor installation, wall mounting, and inverted specification are the installation patterns available.

3) Transfer of heavy workpieces from one operation to another:

   The z-axis tolerance is high for the timing belt-less drive using the designed structure. A large hand can be used with this high tolerable inertia of the z-axis, and the transferable quantity per session increases, which in turn gains higher efficiency. And with lower inertia, there will be higher acceleration and the cycle time be minimized this way.

2.2 In-depth study

The arm is somewhat compliant in the X-Y direction but solidly in the Z-direction because to the incorporated SCARA aligned axis construction., hence the name: Selected Compliance. This comes in handy for a variety of assembly tasks, such as fitting a round pin into a circular hole without tying it.

Its second characteristic is a two-legged arm that looks like human arms, thus the term "Specified." This feature enables the arm to reach into tight spaces and pull or "roll" the vehicle off the road. This has the benefit of allowing parts to be moved from cell to cell or closed process channels to be loaded or unloaded..

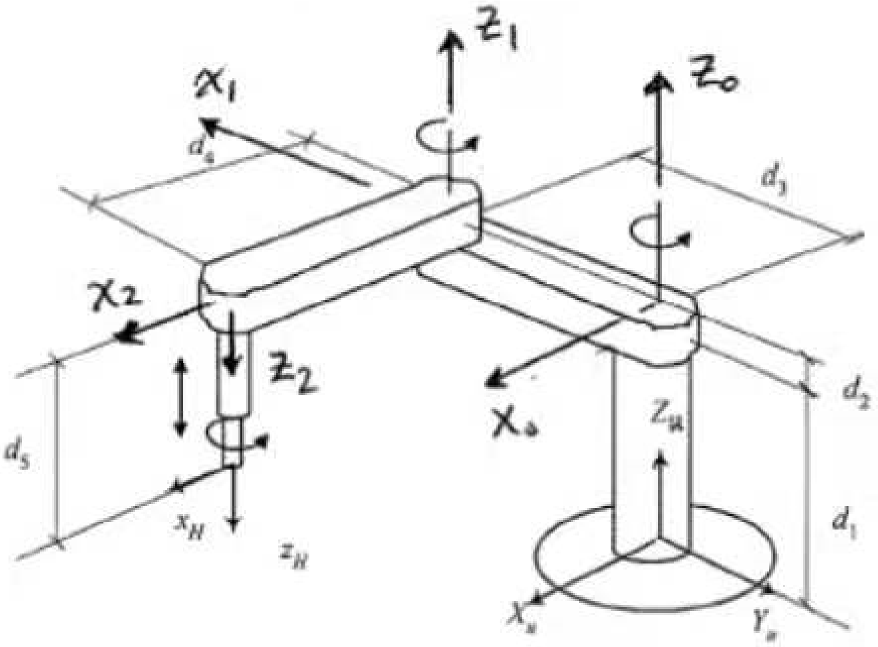
SCARAs outperform equivalent Cartesian robotic systems in terms of speed.

Their single base takes less room to install and is a simple, inconspicuous method to mount. This software, on the other hand, normally comes with SCARA and is transparent to the end user.

2.2.2 Design Simulation

The robotic toolbox offered by Matlab can be used to simulate the SCARA robot. SCARA robot kinematics simulation consists of two parts: forward kinematics and inverse kinematics simulation. The mapping from joint coordinates, or robot configuration, to end-effector pose is known as forward kinematics. In inverse kinematics, the input is the object's Cartesian pose, and the output is the joint coordinates the robot needs to attain it.

Structure diagram and D-H parameter table



#	θ	d	a	α
0-1	θ_1	0	d_3	0
1-2	θ_2	0	d_4	180
2-*H*	θ_3	d_5	0	0

Fig 1: Structure Diagram and DH Parameter Table

Modelling

By default, the D-H parameter approach has been learnt. The following are the required Matlab commands:

```
L1 = Link([ 0   0    1    0    ]);
L2 = Link([ 0   0    0.75  pi  ]);
L3 = Link([ 0   1.5  0    0    ]);
L3.jointtype='P';
L3.qlim=[0 2];
SCARA = SerialLink([L1 L2 L3], 'name', 'Scara'');
```

The model can be displayed using any joint variables. The required Matlab commands are as follows:

```
figure(1);
view(3);
SCARA.plot([pi/3 pi/2 1.4]);
```

The three joint variables, L1, L2, and L3, are the input parameters. The command 'view(3)' must be added; otherwise, the robot toolbox will give an error because it is unable to print the 3D robot model directly. This is only applicable for versions after 10.3.1.

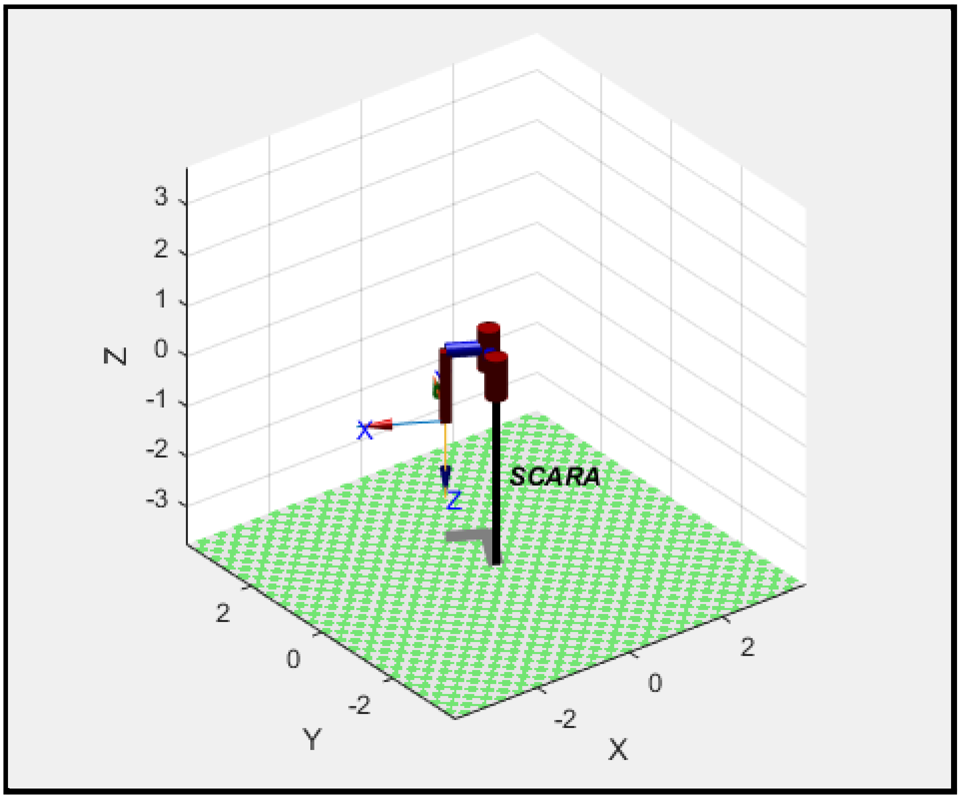


Fig 2: Matlab Simulation of SCARA robot

Motion Simulation

In order to simulate motion of the Scara robot, Matlab function 'jtraj()' is utilised which accepts starting point, end point and the number of iterations as input parameters. Matlab commands are as follows:

```
q1 = [0 0 1.4];
q2 = [pi/3 pi/2 0];
q = jtraj(q1, q2, 50);
figure(1);
view(3);
SCARA.plot(q);
```

Start Position

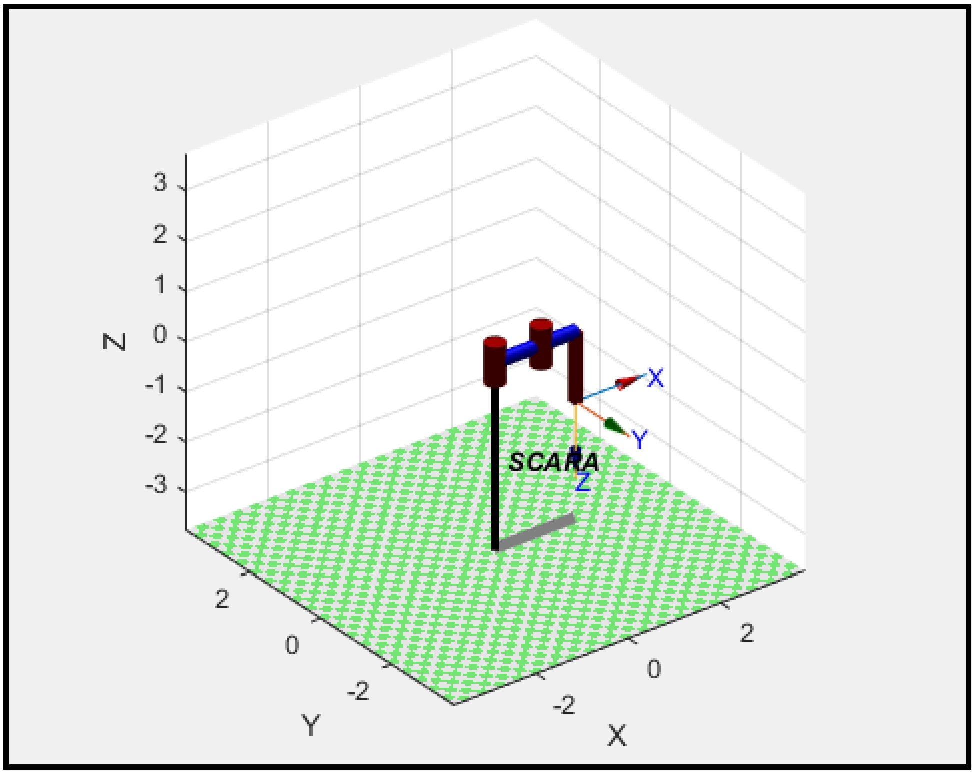


Fig 3: Motion simulation of SCARA robot - start position

End position

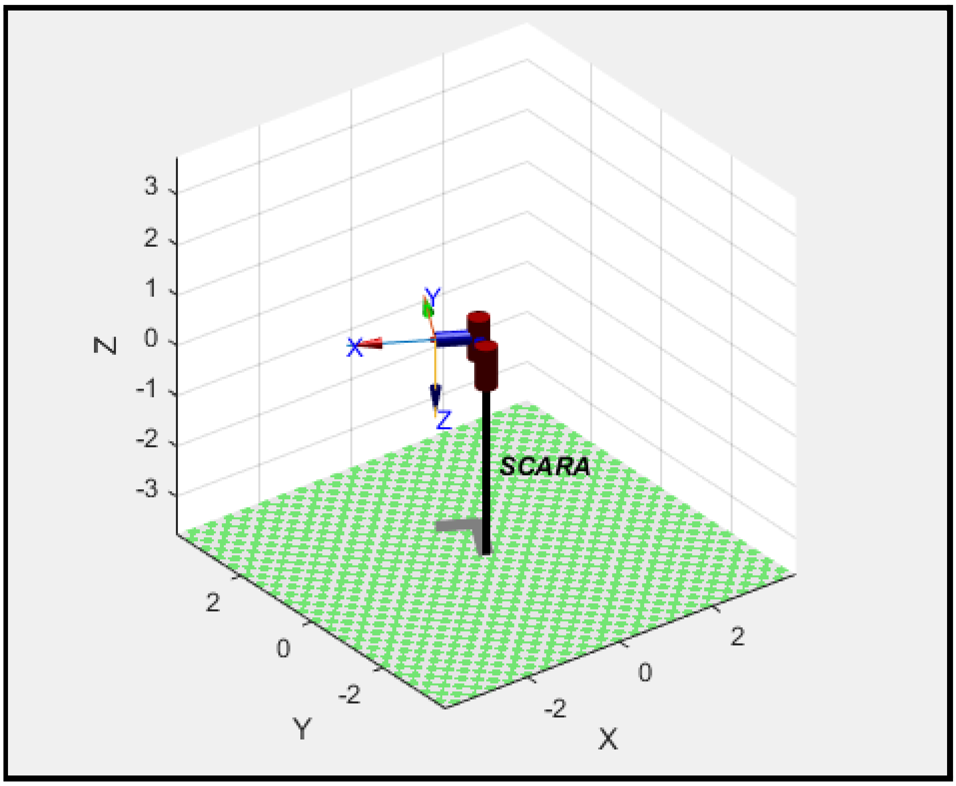


Fig 4: Motion simulation of SCARA robot - end position

Multistage Movement

The ‘jtraj()’ function provided by the Matlab robot toolbox can only be utilised to make each joint of the robot move in a single direction. However, if the ‘jtraj()’ function is used in succession, it can simulate the multistage movement of the robot. Matlab commands are as follows:

```
q11 = [0 0 1.4];
q12 = [pi/3/2 pi/2/2 0.5];
[q_1, v_1, a_1] = jtraj(q11, q12, 25);
q21 = [pi/3/2 pi/2/2 0.5];
```

```
q22 = [pi/3 pi/2 1.4];
[q_2, v_2, a_2] = jtraj(q21, q22, 25);

Q = [q_1; q_2];
figure(1);
view(3);
SCARA.plot(Q);
```

2.2.3 Kinematic Analysis

The kinematic analysis is the study of the relationships between the positions, velocities, and accelerations of the links of a manipulator. The Denavit-Hartenberg (D-H) model of representation, also known as the Denavit Hartenberg convention, was used to model robot links and joints using the forward kinematics approach.

i	a_{i-1}	α_{i-1}	d_i	Θ_i
1	0	$\Pi/2$	d_1	0
2	0	$-\Pi/2$	l_i	Θ_2
3	l_2	0	0	Θ_3
4	l_3	Π	d_4	0
5	0	0	d_5	0

Forward Kinematics

Forward kinematics is the mapping from joint coordinates, or robot configuration, to end-effector pose. The general form of the transformation matrix that transforms vectors is given as:

$$
{}^{i-1}_{i}T = \begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & a_{i-1} \\ \sin\theta_i \cos\alpha_{i-1} & \cos\theta_i \cos\alpha_{i-1} & -\sin\alpha_{i-1} & -\sin\alpha_{i-1} d_i \\ \sin\theta_i \sin\alpha_{i-1} & \cos\theta_i \sin\alpha_{i-1} & \cos\alpha_{i-1} & \cos\alpha_{i-1} d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

Below is the transformation matrix for each frame to determine forward kinematics.

$$
{}^{0}_{1}T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & -d_1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

$$
{}^{1}_{2}T = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & 0 \\ 0 & 0 & 1 & l_1 \\ -\sin\theta_2 & -\cos\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

$$
{}^{2}_{3}T = \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & l_2 \\ \sin\theta_3 & \cos\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

$$
{}^{3}_{4}T = \begin{bmatrix} 1 & 0 & 0 & l_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & -d_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

$$
{}^{4}_{T}T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_5 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

Multiplying the above frames yields the link transformation that connects frame {T} to frame {0}.

$$ {}^{0}_{T}T = {}^{0}_{1}T\,{}^{1}_{2}T\,{}^{2}_{3}T\,{}^{3}_{4}T\,{}^{4}_{T}T $$

$$ {}^{0}_{T}T = \begin{bmatrix} c_{23} & -s_{23} & 0 & l_2c_2 + l_3c_{23} \\ s_{23} & c_{23} & 0 & l_2s_2 + l_3s_{23} - d_1 \\ 0 & 0 & -1 & l_1 - d_4 - d_5 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

This can be reformatted as:

$$ {}^{0}_{T}T = \begin{bmatrix} c_{\phi} & -s_{\phi} & 0 & x \\ s_{\phi} & c_{\phi} & 0 & y \\ r_{31} & r_{32} & -1 & z \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

The end-effector position is given by:

$$ \begin{bmatrix} x \\ y \\ z \\ \phi \end{bmatrix} = \begin{bmatrix} l_2c_2 + l_3c_{23} \\ l_2s_2 + l_3s_{23} - d_1 \\ l_1 - d_4 - d_5 \\ \theta_2 + \theta_3 \end{bmatrix} $$

Inverse Kinematics

The input of inverse kinematics is the object's Cartesian pose, and the output is the joint coordinates the robot needs to attain it. The inverse kinematic equations can be deduced from the provided figure. Inverse kinematics of a robot are calculated by solving for the values of two joint parameters (θ2, θ3) and two link parameters (d1, d4).

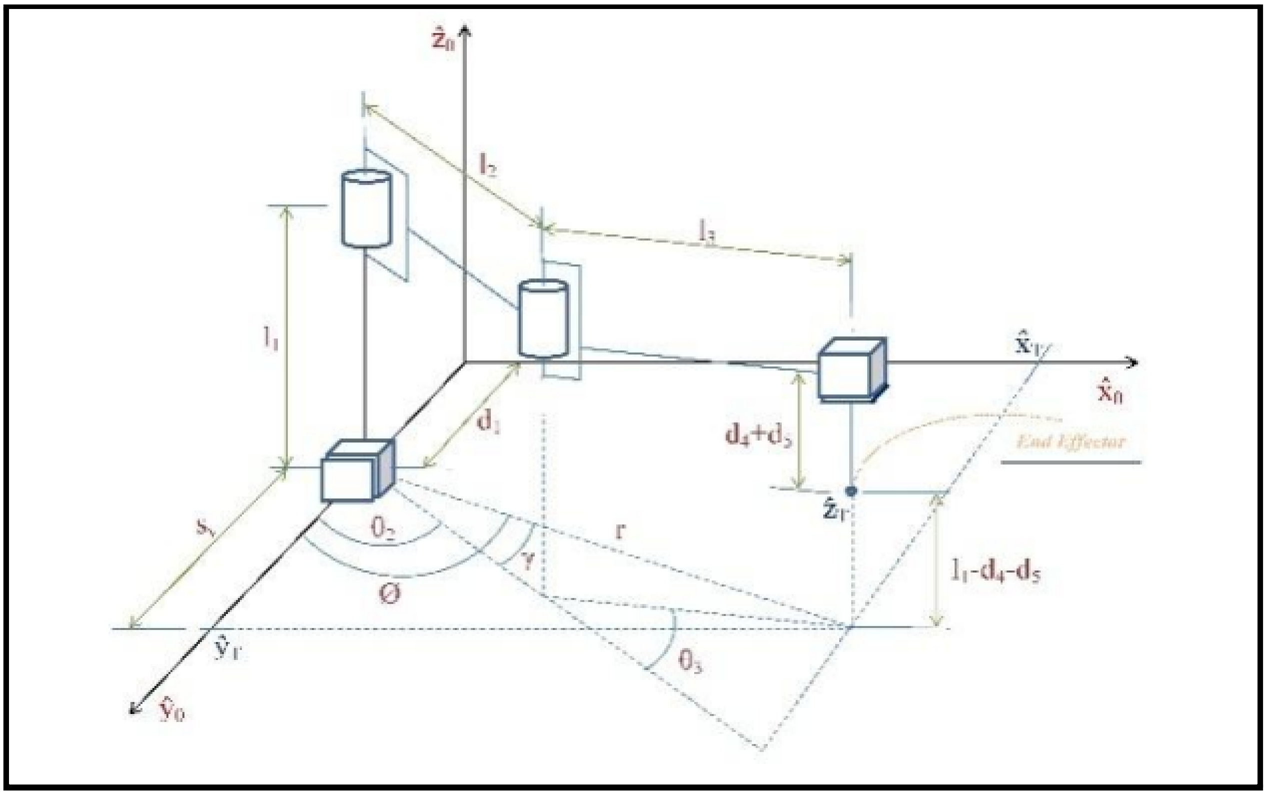


Fig 5: Structural Diagram of SCARA robot

Let coordinates of end effector frame origin be given by oT[xT,yT,zT].
Relationship between variables:

$$
\begin{cases}
d_4 = l_1 - z_T - d_5 \\
d_1 = y_T - s_y = where\ s_y = l_2 s_2 + l_3 s_{23} \\
\theta_3 = a\tan 2(\pm\sqrt{1-c_3^2}, c_3)\ where\ c_3 = \dfrac{s_y^2 + x_T^2 - l_2^2 - l_3^2}{2 l_2 l_3} \\
\theta_2 = a\tan 2(s_y, x_T) - a\tan 2(l_3 s_3, l_2 + l_3 c_3)
\end{cases}
$$

With these relationships, only one parameter, d4, can be solved, while the other three are interdependent and related to two coordinate values of the robot's end-effector (xT, yT). Only two supplied xT and yT would suffice to solve these three equations with three unknown values. In this scenario, one option suggested is to set d1 to an arbitrary value.

Note that 2 and 3 may be found by calculating the cosine equation, but the atan2 function was employed to ensure the exact quadrant where the robot end-effector was situated.
The left-handed coordinate in Figure 2 is characterised by a motion from the first or X-axis to the second or Y axis, with the left thumb pointing in a positive Z-direction along the Z-axis and the curled fingers of the left hand representing a motion from the first or X-axis to the second or Y-axis. This coordinate system makes it easier to view the system's details and analyse them.

Symbol	Description	Unit
a_{i-1}	The distance from $\hat{Z}_i$ to $\hat{Z}_{i+1}$ measured along $\hat{X}_i$	m
α_{i-1}	The angle from $\hat{Z}_i$ to $\hat{Z}_{i+1}$ measured about $\hat{X}_i$	rad
d_i	The distance from $\hat{X}_{i-1}$ to $\hat{X}_i$ measured along $\hat{Z}_i$	m
θ_i	The angle from $\hat{X}_{i-1}$ to $\hat{X}_i$ measured about $\hat{Z}_i$	rad
${}^{i-1}_{i}T$	Transformations matrix that transforms vectors defined in{i} to their description in{i-1}	-
t_2	$\tan\theta_2$	-
c_2	$\cos\theta_2$	-
s_2	$\sin\theta_2$	-
c_{23}	$\cos(\theta_2+\theta_3)$	-
s_{23}	$\sin(\theta_2+\theta_3)$	-
x	$\hat{x}$ vector of end effector attached frame related to zero frame	m
y	$\hat{y}$ vector of end effector attached frame related to zero frame	m
z	$\hat{z}$ vector of end effector attached frame related to zero frame	m
θ	Rotation angle of end effector attached frame related to zero frame	rad

Fig 6: Parameter Nomenclature

2.3 Qualitative/Quantitative Discussion

The Robotics Toolbox of MATLAB is widely used in robot development and gives a range of kinematic and path planning functions to robot research. In the meanwhile, the toolkit can do picture simulations using robots. Building the joint model in the Robotics Toolbox is crucial. In modeling, both Function Link and SerialLink can be employed. The simulation model is depicted in 3-D space in the diagram below.

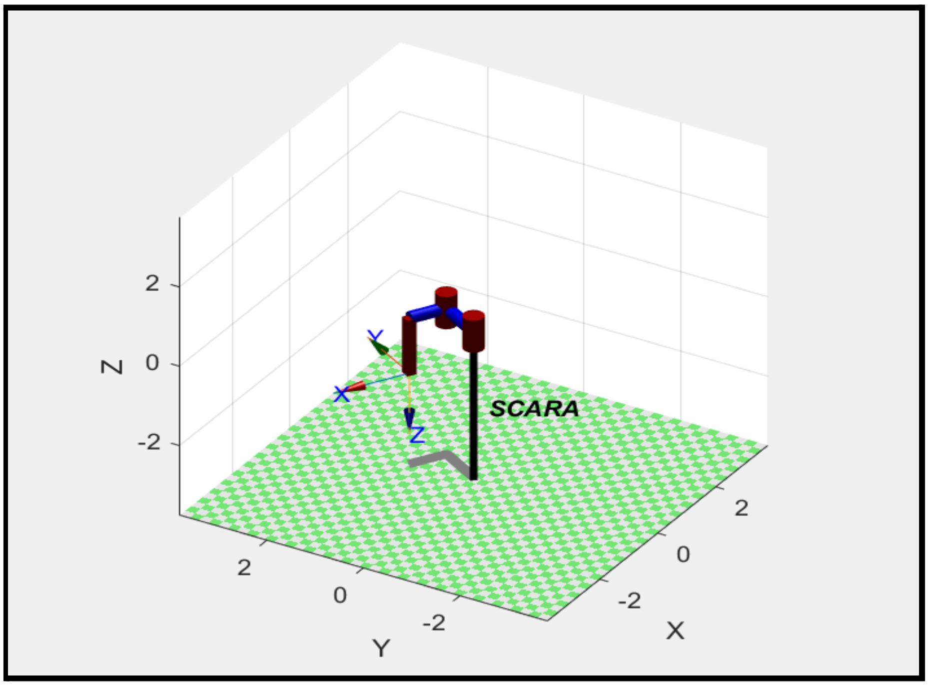


Fig 7: SCARA 3-D Simulation model

The SCARA simulation model is used to make a link to the robot robotic toolbox in the Matlab toolbox. For Matlab 9.0, we choose Windows as the operating system platform. SCARA robot kinematics simulation consists of two parts:i) forward kinematics ii) inverse kinematics simulation.

The former is input to influence the anticipated endpoint of the space coordinate system point in the output end of the robot joint angle variation point, and the method output end of the robot is to achieve the space coordinates and explains this tells the robot pose state; the latter is input to reach the desired endpoint of the space coordinate system point in the output end of the robot joint angle variation point and validates this state robot pose state.

Forward and inverse kinematics are two methods for commanding robots in terms of placement and orientation. Forward kinematics is used when we are required to determine the position and orientation of an end-effector based on joint angles. Inverse kinematics, on the other hand, is utilized to calculate joint angles for a particular end-effector position.

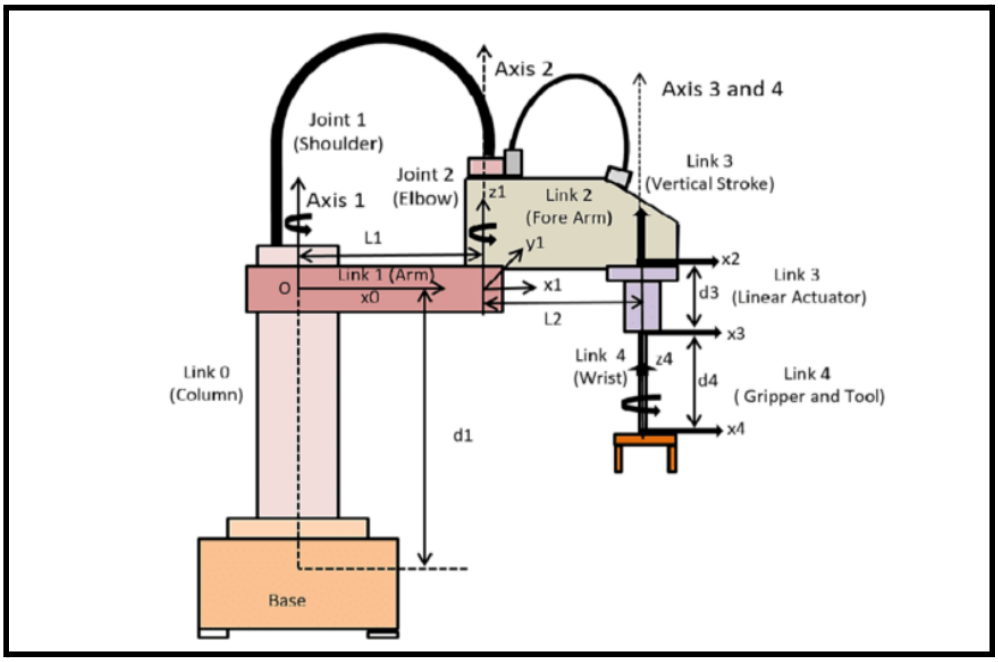


Fig 8: (R-R-P-R) SCARA 4-DOF Manipulator Arm

2.4 Future developments

SCARA robot, as any technology, is under constant development by many global companies like Epson, Yamaha, Stäubli etc.. SCARA robot design is improving in a variety of subtle ways, from the rotary tip to the controller interface, to improve performance, speed, and reliability, allowing for more productivity and a faster return on investment. SCARA robots are also improving in terms of performance and functionality. Smaller robots can now undertake increasingly heavier jobs while retaining high speeds and short cycle times thanks to new designs. Vision systems are now plug-and-play, making installation and programming even easier. In addition, innovative methods to reduce mechanical wear and tear and improve maintenance are being launched. By peering under the hood of current SCARA robots, we may examine these modifications.

Chapter 3

Summary

The SCARA robot is a parallelly linked articulating robot that can pivot in the x axis and y axis and move about perpendicularly in the z-axis. The SCARA robot outdoes pick and place functions owing to its structure. It's great for planar activities because it has a circular work envelope. This broad scope of movement gives us additional alternatives. In the x-y plane, a SCARA robot has great conformity, meaning the arm moves generously to complete the assembly process. The design and development of a SCARA robot that can do specific activities for academical, scientific, and implementation reasons are discussed in this project.

The robot's improvement also involves the creation of a graphical user interface that can operate simulations and monitor the SCARA robot. The design and development procedure for the proposed SCARA robot. After studying prior work on the SCARA robot and its application, the initial stage of the project is to build a manipulator for this project. The manipulator's mechanical structure will then be modeled. Each object's attitude in relation to the manipulator base frame will be determined by the machine vision system. The path organizer will generate the trajectory that the manipulator must understand based on these areas. With precise, consistent selecting and placing missions, the Robot is anticipated to sort things based on their hue.

We utilized the Robotics Toolbox forward kinematics of the robot opposite kinematics reproduction in this venture for four levels of opportunity SCARA robot kinematics displaying, and later used the Robotics Toolbox forward kinematics of the robot inverse kinematics model in the MATLAB setting. In the recreation, the noticed movement of each joint SCARA robot state affirms that the proposed model is right in acquiring the ideal outcome.

A 4-level-of-opportunity (4-DOF) particular congruence get together SCARA robot with three rotating joints and one kaleidoscopic joint (3R-1P) was made to execute pick-and-put activities on circular and rectangular workpieces. The design of the robot is first shown. The kinematic model is additionally created, and the kinematic study is performed with MATLAB. The direction arranging is completed further. Preliminary information is applied to approve the legitimacy of the gathered robot.

The SCARA robot's kinematic model is created using the denavit-hartenberg (D-H) approach, and the forward and inverse kinematics are studied using MATLAB. The Robotics Toolbox of MATLAB is used to plan a straight path and an arc line for trajectory motion in joint coordinates. The 4-DOF SCARA robot prototype with 3R1P. The rotating joints are Axis 1, 2, and 4, while the prismatic joint is Axis 3. Concept 1 employs a belt system to revolve the second link, which is located towards the base. To revolve both connections, Concept 2 employs a belt system. Gears are used in Concept 3 to revolute linkages 1 and 2. Idea 4 is similar to concept 2, with the exception that the motors are located in the center of link 1.

In the forward kinematics of robot position and orientations, link size and joint angles have been utilized; on the other hand, link size and position formats were applied to determine the inverse kinematics of robot joint angle.

From gaining a fundamental understanding of what a SCARA robot is, we have a variety of applications that may be employed in everyday life, including the following:

- Work with a robot visualization Ivy approach to tighten screws.
- Inverse requirements are used to transmit data from one process to another.
- Strong work sections are shifted from one process to another.
- Touch-panel type assessment machine for finished product inspection.

Kinematic Analysis

Forward Kinematics:

The SCARA robot's forward kinematics study was applied to determine the function among joint displacements and the position of the end effector comparative to the base structure. The Denavit-Hartenberg kinematic parameters were calculated.

The end effector's position is defined with the following:

$$\begin{bmatrix} x \\ y \\ z \\ \phi \end{bmatrix} = \begin{bmatrix} l_2 c_2 + l_3 c_{23} \\ l_2 s_2 + l_3 s_{23} - d_1 \\ l_1 - d_4 - d_5 \\ \theta_2 + \theta_3 \end{bmatrix}$$

Inverse Kinematics:

Inverse kinematics separates each possible pattern of joint variables that would ultimately bring the end effector to the ideal position and orientation, whereas direct kinematics connects joint space and Cartesian space. Calculating the joint variables required to execute desired missions based on end-effector locations is critical in tackling such an issue. A geometrical technique can be used to tackle the inverse kinematics problem. This is appropriate for a simple structured robot, but an analytical approach is preferable for more complex structured robots.

SCARA robots' advantages

- Small installation footprint, compact structure, and extended operational range.
- It's easy to get to. Right-angle coordinate robots are unable to maneuver their hands into a tight place such as a car body for work.
- Because there isn't a moving joint, rails aren't needed. Because bearing parts are mass-produced in huge quantities, friction and inertia are low, making rotating joints simple to seal.
- SCARA drive force is at a low level, and power utilization is minimal.

In MATLAB, we created a design simulation.

By default, the D-H parameter technique for modeling has been learned.

Simulation of Motion

The Matlab function 'jtraj()' is used to simulate the Scara robot's mobility. It receives three input parameters: a start point, an end point, and the number of repetitions.

Movement in Multiple Stages

The Matlab robot toolbox's 'jtraj()' function can only be used to do every joint of the robot in a single path. When the 'jtraj()' method is applied repeatedly, it can replicate the robot's multistage movement.

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