# IMPLEMENTATION OF SCARA ROBOT FOR PICK AND PLACE OPERATIONS

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***Abstract*— Modern world has seen a rise in popularity and importance for articulated-morphology robots with decreasing costs of computers and increasing studies on feasibility. They are used in simple as well as complex applications. In this paper, we develop a stepper motor dynamics model, inverse kinematics, and forward kinematic solutions with D-H parameters for a selective compliance articulated robot arm. By changing the main program of the robot, one can use the robotic arm for several different applications. It is most commonly used in automated assembly lines. Our integrated approach increases system performance, cost-effectiveness, efficiency, dynamism, and high performance in reality.**

**Keywords—** selective compliance articulated (SCARA) robot arm; analytical inverse kinematic problem (AIKP); automatic assembly lines; D-H parameters.

## I. INTRODUCTION

The presence of robots today is ubiquitous, from toys to office use and from the industrial to the ultra-sophisticated purposes. In the manufacturing industry, robotics encompasses the use of robots, their design, modelling, and control, which are integral part of manufacturing. A Selective Compliance Assembly Robot Arm (SCARA) is the most common kind of robotic manipulator used in industry for pick-and-place and welding tasks. In addition to their fast speed, SCARA configurations offer low maintenance, a great deal of repeatability, and sturdy architecture. SCARA has four degrees of freedom (DOF) and a Prismatic Revolute Revolute (PRR) structure. It has two revolute and one prismatic joint. SCARA robots have good mobility in the horizontal plane as well as good stability in the vertical plane. Different kinds of commercial SCARA robots are available in the market with different sizes, shapes, configurations, working linear speed, etc.Recent years have seen an increased use of robots in various applications. The robotics meets a number of diverse and challenging educational needs and this trend seems to be continuing. This prototype is equipped with a robotic arm and 3 axes capable grippers, which run on an ATMEGA 8 microcontroller. The program can be programmed using AVR Studio, simulated with PROTESUS, and dumped by PROGISP. It has two IR sensors for detecting the path and RFID for identifying the books. One kilogram of books can be picked and placed by this robot. [1]. The purpose of this paper is to examine the design of a four-axis SCARA robot. In addition, Ansys is used for analysis. The author constructs a cardboard robot for the experimental setup. We study the location of motors, the length of links, and the movement of links using the experimental model.[2] Using CAD software, we model a SCARA Robot with four degrees of freedom for deburring circular profiles. Kinematics of Robots is also easily explained. We compare the results of joint positions and joint velocities calculated using CAD Software with those obtained from MATLAB. This paper describes mathematical modelling and its results in MATLAB in the most complete way.[3] It is becoming more common for robots to be used in various industries such as food, consumer goods, wood, plastics, and electronics, but it is mostly concentrated in the automotive industry. A lightweight robot design concept has been developed using lightweight materials such as Aluminium and carbon fiber in conjunction with new stepper motor prototypes.

Additionally, the wrist is constructed in such a way that the cable is integrated within it. Changing the cables is expensive, so there is a focus on reducing friction on cable, which will increase the time between maintenance. After performing the function analysis, specifications of requirements, a concept was developed based on the established requirements. Twenty-four sustainable concepts were developed from the concept generation and divided into four groups (representing a certain part of the whole).[4] As human needs increase, technology is also developing in the same direction. Almost every day, robotic arms are developed to meet these needs. These studies are concentrated on robotic arms. Using an outside operator or by following a predetermined set of instructions, robot arms can perform tasks. As of today, the most advanced application of robotic arms is in the field of industry and medicine. Designed and implemented as part of the project, the robot arm is capable of moving in four axes with five servo motors. It is possible to carry the desired material from one place to another using this holder, as well as mixing it with the material it receives. During this process, an Arduino Nano microcontroller is connected to a Bluetooth module to control the robot.[5]

## II. METHODOLOGY

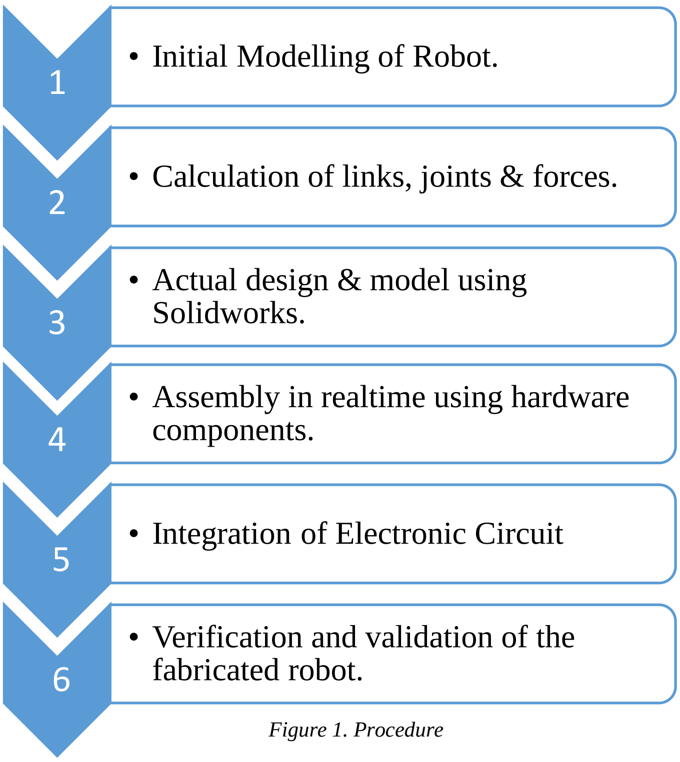


*Figure 1. Procedure*

## III. DESIGN OF SCARA ROBOT

a) **3D Model of SCARA Robot**

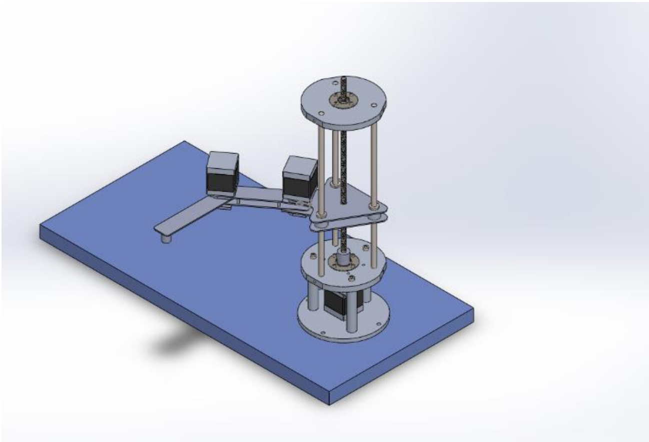

*Figure 2. Isometric View*

b) **2D Sketch of SCARA Robot**

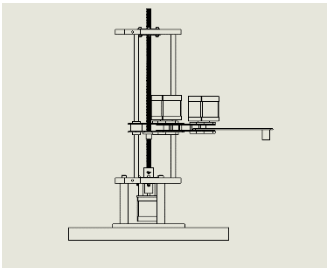

*Figure 3. Front view*

## IV. KINEMATICS CALCULATION

### FORWARD KINEMATICS

DH Parameters

| i | $\alpha_i$ | $a_i$ | $\theta_i$ | $d_i$ |
|---|---|---|---|---|
| 1 | 0 | 0 | 0 | $d_1$ |
| 2 | 0 | 0 | $\theta_1$ | 0 |
| 3 | 0 | $l_1$ | $\theta_2$ | 0 |
| 4 | 0 | $l_2$ | 0 | 0 |

*Table 1. DH Parameters*

$d_1$ is calculated considering height of end effector, α is the angular movement along Z axis whereas θ is the angular movement about X axis, a is the linear movement about Z axis and d is the linear movement about X axis

$$^{0}T_1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^{1}T_2 = \begin{bmatrix} c_1 & -s_1 & 0 & l_1 \\ s_1 & c_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^{2}T_3 = \begin{bmatrix} c_2 & -s_2 & 0 & l_2 \\ s_2 & c_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^{0}T_3 = \begin{bmatrix} c_{12} & -s_{12} & 0 & c_1l_1 + c_{12}l_2 \\ s_{12} & c_{12} & 0 & s_1l_1 + s_{12}l_2 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$P_x = c_1l_1 + c_{12}l_2,\quad P_y = s_1l_1 + s_{12}l_2,\quad P_z = d_1$

Here,
$c_1$, $s_1$, $c_2$, $s_2$, $c_{12}$, $s_{12}$ represents $\cos\theta_1$, $\sin\theta_1$, $\cos\theta_2$, $\sin\theta_2$, $\cos(\theta_1+\theta_2)$, $\sin(\theta_1+\theta_2)$ respectively
$P_x$, $P_y$, $P_z$ represents the position along the x, y and z axis respectively.

**INVERSE KINEMATICS**

**Calculation of $\theta_2$:**
$X = l_1\cos\theta_1+l_2\cos(\theta_1+\theta_2)$
$= l_1\cos\theta_1+l_2\cos\theta_1\cos\theta_2+l_2\sin\theta_1\sin\theta_2$
$y = l_1\sin\theta_1 + l_2\sin(\theta_1+\theta_2)$
$= l_1\sin\theta_1+l_2\cos\theta_1\sin\theta_2+l_2\sin\theta_1 \cos\theta_2$
$\cos\theta_2 = (x^2+y^2-l_1^2-l_2^2) / (2\, l_1\, l_2)$
$\theta_2 = \cos$^-1{$(x^2+y^2-l_1^2-l_2^2) / (2\, l_1\, l_2)$}

**Calculation of $\theta_1$:**
Here $\theta_1=\beta-\alpha$
$\tan\alpha=(c_2\sin\theta_2) / (c_2\cos\theta_2+4)$
$\tan\beta=y/x$
WKT,
$\tan(A-B) = (\tan A - \tan B) / (1+ \tan A\tan B)$
=>$\tan\theta_1 = \tan(\beta-\alpha)$
$\theta_1 = \tan$^-1{{$y(l_1+l_2\cos\theta_2) - (xl_2\sin\theta_2)$} / {$x(l_1+l_2\cos\theta_2)+(yl_2\sin\theta_2)$}}

## V. CALCULATIONS

**Bending moment Calculation:**
**Link 1:**
Length = 0.15 m
Load = 9.81 N
Bending moment = 9.81*0.15 = 1.,417 N-m
Shear Force = 9.81 N
Shear stress = Force/Area = $2.18*10^{-3}$N/mm$^2$
Moment of Inertia I = $bh^3/12 = 3.375*10^{-7}$ m$^4$
Maximum deflection = $PL^3/3EI$
Maximum deflection = $(9.81*(0.15)^3)/(3*210*10^2*3.375)$
= $1.58*10^{-7}$m
Tensile stress due to bending = Md/I = $6.29*10^5$ N/m$^2$
Compressive stress due to bending = $-6.29*10^5$ N/m$^2$

**Link 2:**
Payload weight = 0.5 kg
Total load = 5.39 N
Bending moment = 5.39*0.15 = 0.808 N-m
Shear force = 5.39 N
Shear stress = Force / area = 5.39/ (150*30)
= $1.198*10^{-3}$ N/mm$^2$
Moment of Inertia I = $bh^3/12 = 3.375*10^{-7}$ m$^4$
Max deflection = $(PL^3)/(3EI)$
P = 5.39N, E = $210*10^9$ N/m$^2$, I = $3.375*10^{-7}$ m$^4$
Maximum deflection = $8.56*10^{-8}$ m
Tensile stress due to bending = Md/I
M = 0.8085 Nm, d = 0.15 m, I = $3.375*10^5$ m$^4$
Tensile stress due to bending = $3.593*10^5$ N/m$^2$
Compressive stress due to bending = $-3.593*10^5$ N/m$^2$
Allowable stress of Mild steel = $2.5*10^8$ N/m$^2$
Working stress < Allowable stress
Hence, we use MS as our material for fabrication.

**Motor calculations:**
**For Motor 1:**
Load = 9.81 N
Total Required Torque = Torque required for static load + Torque required for dynamic load
Torque required for static load:
Torque = Force * Perpendicular distance = 9.81*0.15
= 1.471N-m
Torque required for dynamic load:
From Lagrange's equation,
For motor 1,
$\theta_1'' = 0.1012$
$\theta_2'' = 0.0337$
$\theta_1'\theta_2' = 0.03897$
$\theta_2'^2 = 0.0914$
g = 3.3105
Combined Dynamic load = 3.5037 N-m
Total required torque = 1.471 + 3.5 N-m
= 4.971N-m = 50.06 kg-cm
Torque of Nema 34 stepper motor = 87 kg-cm
Hence, we use Nema 34 stepper motor as Joint 1 motor

**For Motor 2**:
Load = 0.75*9.81 = 7.357 N
Total Required Torque = Torque required for static load + Torque required for dynamic load
Torque required for static load:
Torque =Force * Perpendicular distance = 7.375*0.15
= 1.1035 N-m
Torque due to dynamic load:
From Lagrange's equation,
For motor 2,
$\theta_1'' = 0.0337$
$\theta_2'' = 0.0225$
$\theta_1'\theta_2' = 0.0194$
g = 1.47
Combined dynamic load = 1.54 N-m
Total required torque = 1.1035 + 1.5399 N-m
= 2.6434 N-m = 26.955 kg-cm
Torque of Nema 23 stepper motor = 30.61 kg-cm
Hence, we use Nema 23 stepper motor for joint 2 motor.

**Lifting and lowering torque for lead screw:**
The standard lead screw specifications:
Diameter, d = 8mm
Core diameter, $d_c$ = 6mm
Mean diameter, $d_m$ = 7mm
Helix angle, $\tan\alpha = 1/(\pi d_m)$
$\alpha = 2.57°$
Thread angle for standard trapezoidal lead screw $2\theta = 30°$
$\theta = 15°$
Coefficient of friction for lead screw
with brass nut and stainless-steel lead screw = $\mu_c = 0.15$
Load = 3*9.81 = 29.43 N

**Lifting Torque:**
$M_t = W d_m/2 *((\mu \sec\theta + \tan\alpha)/(1-\mu \sec\theta \tan\alpha))$
= 51.5*(0.2/0.993) = 10.3 N-mm

**Lowering torque:**
$M_t = W d_m/2 *((\mu \sec\theta - \tan\alpha)/(1 + \sec\theta \tan\alpha))$
= 51.5 (0.11/1.0069) = 5.66 N-mm
Torque of Nema 17 stepper motor = 50 N-mm
Hence, we use Nema 17 to lift and lower the load in lead screw

**Buckling calculations:**
**Column 1**:
Stress, $\sigma = P/A$
P = 5*9.81 = 49.05 N
$\sigma$ = Yield strength / FOS = 250/2 = 125 N/mm$^2$
$A = P/\sigma$
A = 49.05/125 = 0.392 mm$^2$
Area of circle = $\pi r^2$ = 0.392 mm$^2$
r = 0.352 mm
As per the market standards we took d = 3mm
Area of cross section of circle = $\pi r^2$ = 7 mm$^2$
$I_{xx} = I_{yy} = \pi d^4/64$ = 3.94 mm$^4$ ≈ 4 mm$^4$
K = √ (4/7) = 0.75
l/k = 100/0.75 = 133.32
$\sigma = n\pi^2E / (l/k)^2$
Since both the ends are fixed, n = 4
$(l/k)^2$ = 63101.44
l/k = 251
251 >133.32
Hence, it is a short column
<u>Johnson's formula:</u>
$P_{cr} = S_y A (1 - (S_y/(4n\pi^2 E)) *(l/k)^2)$
$P_{cr}$ = 876 N
$P_{cr} > P_{act}$
Hence, Design is safe

**Column 2:**
Moment, $M_y$ = 3.78 N-m
$\sigma_Y$ / FOS = P/A + $M_y$ / I
Where I = $\pi d^4/64$
FOS = 2
Area = $\pi d^4/4$
P = 9.81 N
By solving we get, d = 6.63 mm
Hence, we are considering 8 mm diameter
Area = $\pi r^2$ = 34.42 mm$^2$
$I_{xx} = I_{yy} = \pi d^4/64$ = 94.84 mm$^4$
K = √(I/A) = 1.659
l/k = 350/1.659 = 210.97
$\sigma = n\pi^2E / (l/k)^2$
Since both the ends are fixed, n = 4
$(l/k)^2$ = 63101.44
l/k = 251
251>210.97
Hence it is a short column
<u>Johnson's formula:</u>
$P_{cr} = S_yA (1 - (S_y/(4n^2 E)) *(l/k)^2)$
$P_{cr}$ = 4313.68 N
$P_{cr} > P_{act}$
Hence, Design is safe.

## VI. WORKING

The Robot having four degrees of freedom is driven by stepper motors. A small servo motor operates the end effector. This SCARA robot's brain is a Printed Circuit Board (PCB) coupled with a CNC shield and stepper drivers. When it comes to controlling robots, there are two different approaches: forward kinematics and inverse kinematics. Forward kinematics is used to determine a joint's location and orientation based on a joint angle. A joint angle is determined using inverse kinematics, in contrast, when end-effector locations are known. Using joint angles $\theta_1$ and $\theta_2$, it can be calculated where and how the end effector is positioned. Also based on $P_x$ and $P_y$, one can calculate the joint angles for a given position of the end-effector.

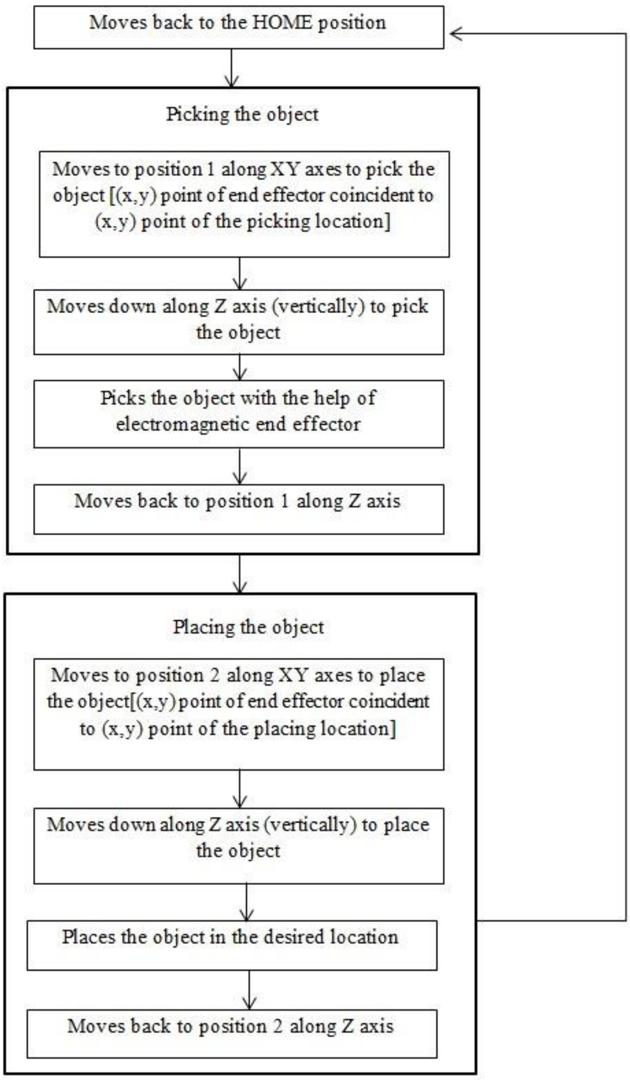


*Figure 4. Process Flow Chart*

## VII. CIRCUIT DIAGRAM

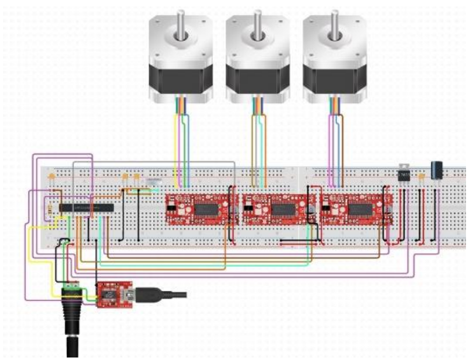

*Figure 5. Circuit Diagram*

## VIII. FABRICATION

In order to comprehend the actual working of the robotic arm, mild steel is selected based on properties such as high density, heavy-duty, and efficiency. From the production drawing, various linkages, parts, end effector and spacers are cut using a LASER cutting machine. Following the cutting stage, assembly is carried out with adhesive, screws, nuts and spacers. Stepper motors provide motion to the various links with 12V power supply from SMPS module.

## IX. CONCLUSION

The Robot is designed in such a way to meet all the industrial needs for the production. The technology used is also revised to current standards. The following design aspects are peculiarly made to match the following aspects.

- The Inverse kinematics of the links are calculated.
- Motor torque and power output are optimized.
- Link kinematics is designed to access maximum work area.
- The sturdy design of the frame ensures extreme durability.
- Thus, the SCARA robot with electromagnetic arm is more efficient and admirably suitable for pick and place operations in various industries.

## X. SPECIFICATION

| S. No | Specifications | |
|---|---|---|
| 1 | Degrees of freedom | 4 |
| 2 | Maximum payload capacity | 500 g |
| 3 | Maximum reachability | 300 mm |
| 4 | Rated speed (Adjustable) | 0-80 rpm |
| 5 | Arm-1 spin | $180^0$ |
| 6 | Arm-2 spin | $180^0$ |
| 7 | End effector type | Electromagnet |

*Table 2. Specification*

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