Design and Fabrication of an Affordable SCARA 4-DOF Robotic Manipulator for Pick and Place Objects

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***Abstract* – Automation of industrial sector is growing rapidly due to deployment of precision robots. In this article, we present a low cost local manufactured 4 degree of freedom (DOF) pick and place robotic manipulator can be used for industrial assembly line applications such as textile, automobile and agriculture sectors. The main concerns persist in most of these robotic manipulators are precision and control. To emphasis on this we used Selective Compliance Assembly Robot Arm (SCARA) to automate pick and place tasks. Our designed robotic arm can carry maximum payload of 2 kg with an arm length of 300mm. We also discuss in detail the fabrication process and testing results of our developed SCARA robotic manipulator.**

Index Terms: SCARA, 4-DOF Grasping Manipulator, Pick and Place.

I. INTRODUCTION

The concept of robot machine is developing very quickly in today's scenario and it works better than human man power. The robots are deployed in many of the industrial sectors to improve the accuracy as well as the automation of the work in order to increase the production and efficiency of the systems. Since manual pick and place tasks are extremely tedious, troublesome and costly [1]. Additionally, human supervisory control causes errors and mistakes. Therefore, robotic control is of great importance. In the modem situation, Robots have progressed toward becoming an integral part industrial revolution. Automation of robotic has made significant progress in a various field such as products identification, wood placement, plastics and hardware sorting [2-3]. The main reason for utilizing robotic manipulator is to reduce human efforts. These robotic manipulators are popular for speed processing, control, precision and accuracy for pick and place activity which is required in assembly line operations. The Selective Compliance Assembly Robot Arm (SCARA) normally has 4-DOF in which one is linear motion and three rotational movements.

To control the manipulator robotic, wireless RF 2.4 GHz radio systems can be used [4-5]. Portable android application with Bluetooth module HC05 has been used as well [6]. However, these need to be ensured for proper reliability. In industries, the SCARA robot is used for different tasks like palletizing, and de-palletizing operations and robotic manipulator is most often made to do the task that it is required to perform [7]. Today, technology is advancing with same pace with increasing human needs. The work done to meet these demands can make life easier, which are determined by robotic manipulator studies. Robot manipulators can work with an outside human user or perform predetermined tasks.

Presently, robotic manipulators are used in various industry such as automobile and food sectors. We designed and developed robot manipulator with 4-DOF using 5 DC servo motors. The robotic manipulator can be connected to the android application via Bluetooth module as reported in [8]. Currently, there are many manipulator robotic manipulators available in the market. However, most of them are very costly [9]. Our aim is to develop a low-cost robotic manipulator for researchers and academicians in educational and research institutions to learn the fundamentals of robotics such as design, control, dynamics, kinematics and sensing [10]. Also, robotic manipulators can be deployed on other mobile platforms for performing tasks in unstructured environments [11].

This paper discusses the steps used in design and fabrication of a 4 degree of freedom (DOF) SCARA robot without deploying complex PLC system to reduce cost. We started with initial specification, design concept, product manufacturing, and testing. In initial specification phase, suitable parameters of the SCARA robotic manipulator are first found. After that, the best design concept for our SCARA robot was chosen among all set parameters. In third phase, product manufacturing is done; the chosen design of the SCARA robot is developed. The direct and inverse kinematics, dynamics of the robot are then modeled. Off shelf parts were selected based on the derived parameters from initial calculations. Electronic parts such as switches and a controller were selected. Finally, the developed SCARA robotic manipulator was tested in lab environment lifting different payloads up to 2 kg weight to verify our initial targeted specifications.

The paper is further organized as; section II explains the design methodology and modeling. Section III shows the CAED design and fabrication. Robotic arm main features and capabilities presented in section IV, selected parameters, testing and electronic design in sections V and VI. Modeling and Calculations are shown in VII while simulation and system overview in section VIII followed by conclusion and future direction in sections IX and X.

II. DESIGN METHODOLOGY AND MODELING

The basic aim of our prototype is to build an automated robotic manipulator for pick and place in assembly line manufacturing. The methodology for the whole process is shown in Fig. 1.

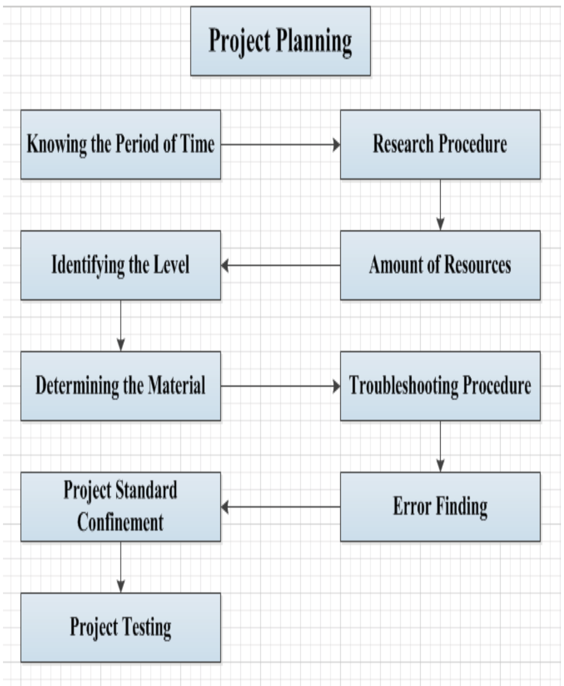

Fig. 1: Project Overview

Robotic manipulator general configuration includes kinematics demonstration, outline structure, electronic and programming working plan [12]. Our proposed robotic manipulator Link diagram is shown in Fig. 2

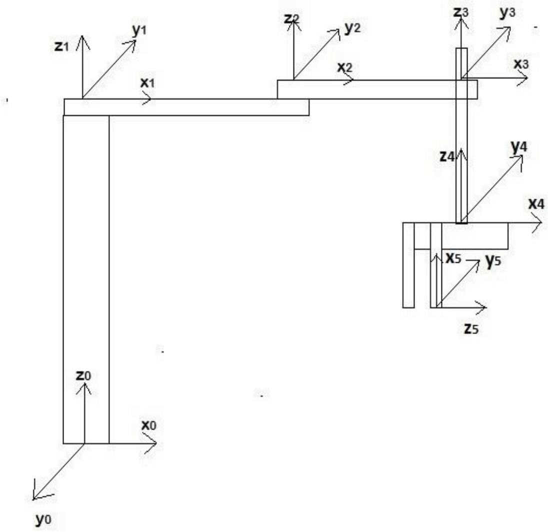

Fig. 2: Link Diagram

Where,
α_{i-1} = angle from Z_i to Z_{i+1} along X_i
a_{i-1} = distance from Z_i to Z_{i+1} along X_i
d_i = distance from X_{i-1} to X_i along Z_i
Θ_i = angle from X_{i-1} to X_i along Z_i

$L_1 = 1^{st}$ Link Length
$L_2 = 2^{nd}$ Link Length
$L_5 = 5^{th}$ Link Length

The DH calculated parameter values are shown in Table I.

TABLE I: DH PARAMETERS

I	α i-1	a i-1	di	Θi
1	90	0	0	Θ_1
2	0	L_1	0	Θ_2
3	0	L_2	0	Θ_3
4	0	0	0	Θ_4
5	90	L_5	0	Θ_5

III. CAED DESIGN AND FABRICATION

We designed 3-D robotic manipulator in Solid Edge Design as shown in Fig. 3.

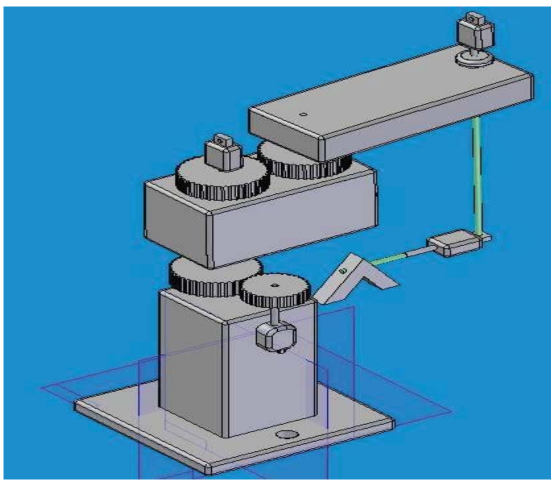

Fig. 3: 3-D Designed Robotic Manipulator

The final SCARA prototype mechanism is shown in Fig. 4 which is powered by 12V DC using Switching Mode Power Supply (SMPS).

Fig. 4: SCARA Robotic Manipulator

The cost of our developed robotic manipulator is under $250 (35000 PKR approx.). It is very less as compared to most of the available SCARA robotic manipulators in market.

IV. MAIN FEATURES AND CAPABILITIES

The main features of our designed SCARA robotic manipulator are given in Table II below:

TABLE II: FEATURES AND CAPABILITIES

Features	Capabilities
Control Unit	Robotic manipulator is controlled using PIC18F452 microcontroller and H-bridge circuits
Communication	Manual communication is used for pick and place objects using limit switches.
Robotic Manipulator	It has 4-DOF, 1st Link can rotate complete 360 degrees, 2nd Link by 180 degree, gripper can move only vertically.
Benefits	Minimum human effort, low cost, continuous usage, good accuracy.
Purpose	Our SCARA robot is specifically designed for pick and place operation for industrial applications.

We designed an affordable customized robotic platform for industrial sector.

V. SELECTED VALUES, TESTING AND JUSTIFICATION

We selected best suitable measurements for our mechanism with calculated values in Table III.

TABLE III: DESIGN CALCULATION OF MECHANISM

Component	Type	Dimensions (inch)
1st Link	Iron	Thickness: 1 Width: 2 Length: 12
2nd Link	Iron	Thickness: 1 Width: 2 Length: 10
3rd Link	Aluminum	Thickness: 1 Width: 2 Length: 10
4th Link	Iron	Diameter: 0.3 Length: 9
Gripper Screw	Iron	Diameter: 0.3 Length: 3.6
Gripper	Aluminum	Length: 6.4 Height: 4

Our aim is for industrial assembly line application; therefore, we didn't use 5-DOF with more complex design and higher cost. The designed SCARA robot is used for pick and place for a maximum of 2 kg payload with a simpler approach while making it cost effective. The trial experiments were made on different material and weights of varying sizes including randomly lifting packing box and a plastic bottle randomly.

We had used two iron links in SCARA robotic manipulator because iron is rigid. Aluminum is used for 3rd Link showing good weight ratio. We didn't use iron here because aluminum is light and exert minimum load on motors. We used plastic gears due to weight reduction. Screw mechanisms were used because of strong mechanism and currently many industries are using it. Gripper is also made of aluminum due to lower weight. Bearing are used for motion of links and gears.

VI. ELECTRONIC DESIGN

We first simulated our designed electronic board on Proteus software and fabrcated its PCB. The complete circuit is shown in Figure 5.

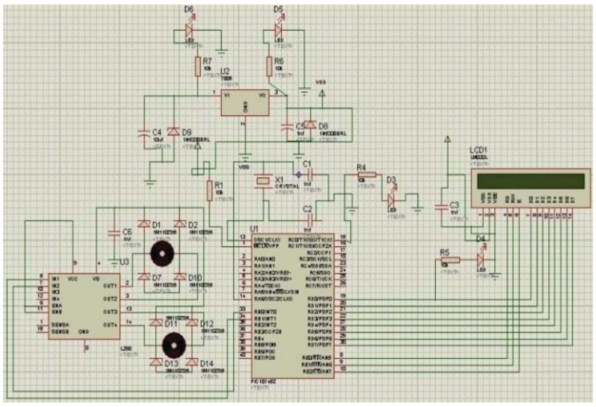

Fig 5: Designed Circuit Simulation

A simple electronics module is designed with push buttons for object grasping. The input signals are processing via controller board to drive the DC motors.

VII. MODELING AND CALCULATION

We have calculated all the inertia of the mechanical design. The general formulas used to calculate values are given below.

1st gear:

$$JB = \frac{1}{8}W[D^2 + d^2] \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

1st Link:

$$JA = \frac{1}{3}WL^2 \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

2nd Link:

$$JD = \frac{1}{3}WL^2 \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

3rd Link (aluminum):

$$JG = \frac{1}{3}WL^2 \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

2nd Gear:

$$JC = \frac{1}{8}W[D^2 + d^2] \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

3rd Gear:

$$JE = \frac{1}{8}W[D^2 + d^2] \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

4th Link (iron screw mechanism):

$$JI = \frac{W(3D^2+4L^2)}{48} \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

4th Link Nut (iron Screw Mechanism):

$$JH = \frac{1}{8}W[D^2 + d^2] \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Nut of Gripper Mechanism:

$$JK = \frac{1}{8}W[D^2 + d^2] \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Bolt of Gripper Mechanism:

$$JL = \frac{W(3D^2+4L^2)}{48} \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

We final calculated values are tabulated below in Table IV:

TABLE IV: DERIVED VALUES

Moment of Inertia (kgm^2)	**Part**
JA = 0.0758	1st Link(iron)
JB = 0.000027	1st Gear
JC = 0.0000441	2nd Gear
JD = 0.4215	2nd Link (iron)
JE = 0.000380	3rd Gear
JF = 0.000380	4th Gear
JG = 0.02107	3rd Link (aluminum)
JH = 0.000000034	Nut of 4th Link (Iron screw mechanism)
JI = 0.0064	4th Link (iron screw mechanism)
JK = 0.000000034	Nut of Gripper Mechanism
JL = 0.0003432	Bolt of Gripper Mechanism

VIII. SYSTEM SIMULATION AND OVERALL DESIGN

We system was verified in MATLAB using Transfer Function equations with pre-defined values. The overall block diagram of our designed system is shown in Fig. 6.

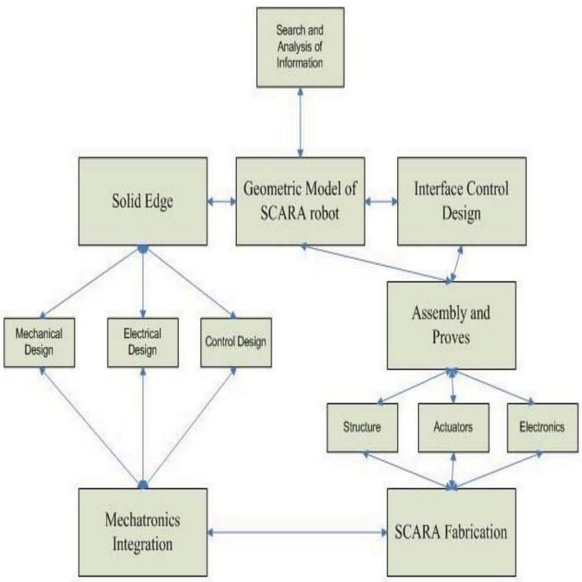

Fig. 6: System Block Diagram

IX. CONCLUSION

Robotic Manipulators with fewer DOF's are more flexible to handle. Our designed 4-DOF robotic manipulator was tested in lab for carrying payloads up to 2Kg. Modeling and simulations were done to verify our design. We designed an affordable customized robotic prototype manipulator using local materials available in Pakistan. The trail test performance and reliability parameters evaluated for precision and control showed good agreement.

X. FUTURE DIRECTION

DC gear motors can be replaced with servo motors for more accurate precision. Vision based object detection can be added using CCTV imaging to replace manual control as proposed in [13]. Increase in DOF can provide less error probability in compensation of higher cost.

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