Dynamic Behavior Study of 2R and 3R SCARA Robot Manipulator for Pick and Place Application

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ABSTRACT

The study and simulation of any robotic components or the whole system is very vital when comes to cut downs on the costs of fabrication, time for developing new models to suit several applications. The savings are quite large for the companies and can be utilized well for other purposes. The manipulator's trajectory forecasting is still redundant and this task entails special individualities to be made satisfactorily. So we have to develop a mathematical model for 3-link SCARA robot manipulator using Lagrangian mechanics and to find a torque calculation and trajectory planning of a robot model based on the specifications then to find out the trajectory planning for our desired path description under mat lab confirmation. And then analyze the effective movement of the end effecter using the calculated values from the mathematical model. Finally to develop the prototype for our model which contains the overall advantage of high redundancy, maneuverability, high workspace, high complexity with more degrees of freedom under the application of pick and place.

KEY WORDS: Dynamic behavior, Multi-body system, SCARA, Trajectory planning, 2R robot manipulation, 3R robot.

1. INTRODUCTION

Now a days benchmarking and meeting the several standard requirements laid by the statutory bodies help the companies to create a manufacturing environment par excellence. Implementing novel strategies helps to maintain these reliable manufacturing environment which is a key to success. Robotics is an exceptional branch in engineering dealing with design of components for a robot, modeling, assembly, infusing several controls and utilizing for the better serving of a task or problem. Recently people can be seen with robots accompanied in some of their day to day life and also they have taken over some routine activities. The utilization of a robot is very widespread, from small toys and bigger and larger industrial robots. The scientist heavily relies on the special kinds of robot for exploring space with multi functionality.

A huge classifications of robots are available around the globe which can perform tedious tasks of manufacturing processes such as automated welding of components, assembling the several entities, spray painting, movement of goods within the warehouse and several secondary process like drilling, cutting, polishing, milling etc. Industrial robots are very challenging to design and also getting more attention among the different class of robots available. Robotic manipulator of different configurations namely horizontal, cylindrical, rectangular, spherical and revolute joints exists. Non-redundant manipulators are lesser having advantage than redundant manipulators. When a manipulator arm has infinite number of points in the joint variables for a particular task, then it is said to be a redundant manipulator. Also they have optimized movements that can circumvent any obstacles. For selecting the best optimized manipulator trajectory quite a few optimization methods have been applied with consideration of avoiding obstacles, least time, and lesser kinetic energy. Robots can be pre modeled and simulated as a geometric model based on postures, positions etc., dynamic or kinematic model.

A 2R type robot is chosen for modeling with the objective of developing a better posture by comparing two distinct robot postures having uniform time period, following similar pathway line. Also a computer program code has to be developed for obtaining the dynamic and kinematic parameter. Robotic motion are simulated with the aid of MATLAB-Simulink and SolidWorks software and compared with theoretical values.

The results from both the software were discussed, compared and evaluated qualitatively to choose the right model. The validation of the selected model is done and conclusions drawn without any conflicts.

Problem Statement: The most important problem and the primary reason for this research is lack of sufficient maneuverability, poor redundancy, low work space, minimum complexity and less degrees of freedom. So we have to prove that six degrees of freedom can provide higher maneuverability compared to 3-axis robot. It has a positive impact on industrial performance. Although some previous researchers are agreed with 3RSCARA has positive impact on doing complex activities, and some believes it helps to occupy more work space. This study would like to show that 3R SCARA is a good choice for creating large work space for complex work.

Literature Review: The Lagrangian mathematical model on robotic system's platform was modelled and validated by (Babak Rohani, 2014). Both the complex dynamic and kinematic model was developed and analyzed. The mathematical equations were developed while accounting the mass and friction of actuators and also in absentia. A comparative validation of the models derived from physical and mathematical is made to extend best fit. Huang (2007), experimented a trajectory path covered in lesser time for a translational robot having 2 degree of freedom. Parametric functions were used to frame dynamics and kinematics motions. An algorithm for attaining very minimal traverse period while overwhelming path jerk limitations was developed. Zheng (1989), mathematically modelled the dynamic and kinetic behavior of a robot with 2 coordinates. The picking or fetching of an object, effects of collision on the surroundings and constraints arisen were concentrated on three phases. SCARA (Selective Compliance Assembly Robot Arm) robots are pretty good for industrial applications. So Sisir (1992), studied the effects of the SCARA and derived a closed solution. A code is developed for the links of the arm with respect to different torques and he found that the angular position has nothing to do with the torque.

A 2-link flexi robotic arm was modelled and studied by Fukuda and Arakawa (1987), for controlling the vibrations. The equations governing the bending vibration of the arms were derived with the help of transformation matrix. Lee (2005), exposed the Lagrangian modelling of flexi-robotic link robots never include the bending of the flexi link mechanism which causes the inaccuracy while modeling the links. So a fresh dynamic model was put forth. Baruh and Tadikonda (1989), addressed the several drawbacks in the dynamic controls. Those points should be focused for better solutions. Sharan (1992), discussed several methods which would solve the dynamic problems effectively. The methods discussed were extensively helping the flexible manipulators analysis. Gasparetto (2004), utilized rigid link models and established a dynamic model for planar flexible link mechanisms and validated the established models experimentally for a five-bar mechanism.

2. METHODS FOR THE MANIPULATION OF 2R SCARA ROBOT

Dynamic Study of 2R SCARA Robot Manipulator:

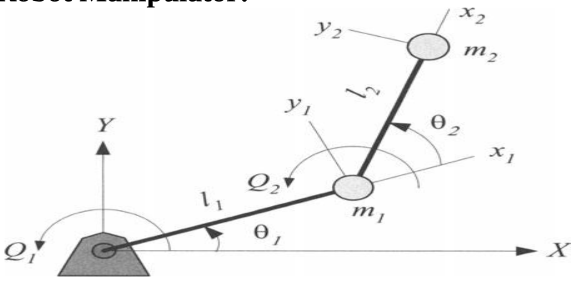

Fig.1. Links of 2R SCARA robot

Where, Q_1, Q_2, Q_3 - Torque for each individual link, L_1, L_2, L_3 - Length of each link, M_1, M_2, M_3 - Mass of each link, Θ_1,Θ_2, Θ_3 - Angle between each succession links.

In this research modelling, a 2R robotic system for a pick and place task is carefully designed by Solid Works and also by MATLAB-Simulink concurrently. The designed 2R robotic arm is shown below in figure.2.

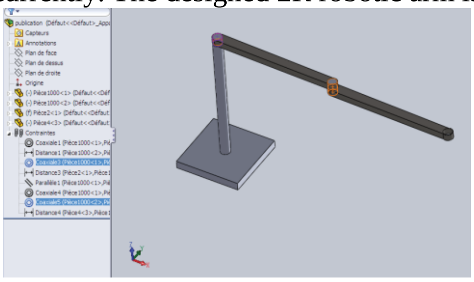

Fig.2. 2R robotic arm in Solid works

The torque equation for 2R SCARA robot manipulator is already derived under Lagrangian mechanics is given below,

$$Q_1 = \left((m_1+m_2)l_1^2 + m_2 l_2(l_2 + 2l_1 cos\,\theta_2)\right)\theta 1 + m_2 l_2(l2 + l1\,cos\theta_2)\theta_2 - 2m_2 l_1 l_2\,sin\theta_2\theta_1\theta_2$$
$$- m_2 l_1 l_2\,sin\theta_2\theta_2^2 + (m_1+m_2)g l_1 cos\theta_1 + m_2 g l_2 \cos(\theta_1+\theta_2)\,l_1$$
$$Q_2 = m_2 l_2(l_2 + 2l_1 cos\,\theta_2)\,\theta 1 + m_2 l_2^2\theta 2 + m_2 l_1 l_2\,sin\theta_2\theta_1^2 + m_2 g l_2 \cos(\theta_1+\theta_2)$$

Torque Calculation for 2R SCARA: For angle θ_1=10º and θ_2=15º.

Table.1. Torque Calculation for 2R SCARA

Length (m)	**Mass** (KN)	$\mathbf{Q_1}$ (N-m)	$\mathbf{Q_2}$ (N-m)
L_1 =300 L_2 =300	m_1=0.01706 m_2 =0.01706	144.38	45.50
L_1 =200 L_2 =400	m_1 =0.01014 m_2 =0.02274	144.41	80.88
L_1 =400 L_2 =200	m_1 =0.02274 m_2 =0.01014	145.09	18.03
L_1 =350 L_2 =250	m_1 =0.01990 m_2 =0.01268	138.35	28.184
L_1 =450 L_2 =150	m_1 =0.02559 m_2 =0.00760	154.43	10.15

Trajectory Equation for 2R Planar Manipulator: The following polynomial equation gives the movement for the designated path for "elbow down" to reach the desired position.

$$\theta_1 = (10t^4 + 10t^3 + 10t^2)^{\circ}$$
$$\theta_2 = 50t^4 + 10t^3)^{\circ}$$

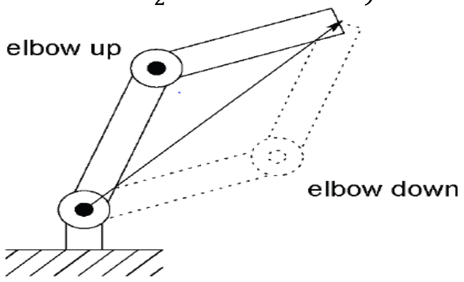

Fig.3. Two posture of SCARA

By comparing overall manipulator transformation matrix and the desired location of 2R robot matrix. The equations were given below,

$$p_{x}=a_1c_1+a_2c_{12}$$
$$p_{y}=a_1s_1+a_2s_{12}$$

Table.2. Elbow Down movements

Time (sec)	**Elbow Down**			
	θ_1 (Deg)	θ_2 (Deg)	p_x (mm)	p_y (mm)
0	0	0	600	0
0.1	0.11	0.015	599.99	1.23
0.2	0.49	0.16	599.96	5.96
0.3	1.25	0.67	599.76	16.59
0.4	2.49	1.92	598.82	36.10
0.5	4.37	4.37	595.64	68.44
0.6	7.05	8.64	586.55	117.95
0.7	10.73	15.43	564.02	188.11
0.8	15.61	25.6	514.62	278.37
0.9	20	40.09	431.49	362.64
1	30	60	259.80	450

The above table.2, portrays the elbow down movements of the SCARA's manipulator. The elbow graph which is drawn on the basis of the tabular data is shown in the below figure.4.

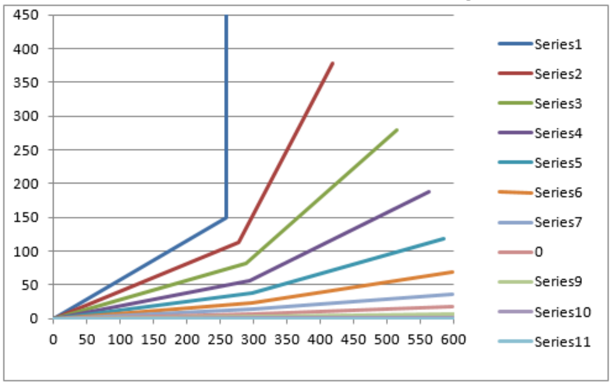

Fig.4. Elbow down graph

Dynamic Study of 3R SCARA Robot Manipulator:

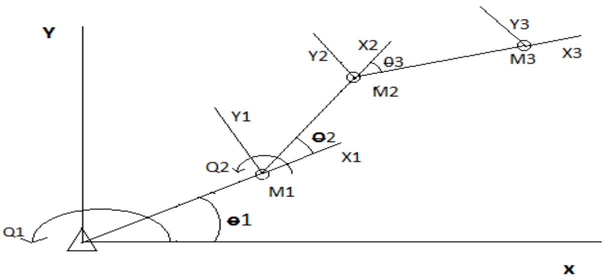

Fig.5. Links of 3R SCARA robot

Torque Equation: The same procedure what they done to find out the torque equation in 2R manipulator is followed by adding extra one link for 3R manipulator.

$$Q1 = [(m1 + m2 + m3)l12\theta1 + l22(\theta1 + \theta2) - 2l1l2\theta2sin\theta2(2\theta1 + \theta2) + 2l1l2cos\theta2(\theta1 + \theta2) + l22(\theta1 + \theta2) + l32(\theta1 + \theta2 + \theta3) + l1l2cos\theta2(2\theta1 + \theta2) - l1l2\theta2sin\theta2(2\theta1 + \theta2) + l2l3cos\theta3(2\theta1 + 2\theta2 + \theta3) - l2l3\theta3sin\theta3(2\theta1 + 2\theta2 + \theta3) + l1l3cos(\theta2 + \theta3)(2\theta1 + 2\theta2 + \theta3) - l1l3(\theta2 + \theta3)sin(\theta2 + \theta3)(2\theta1 + 2\theta2 + \theta3)] - [m1l12\theta1 + 1/2m2(2l12\theta12l22(\theta1 + \theta2) + 2l1l2\theta1cos\theta2 + 2l1l2(\theta1 + \theta2)\,cos\theta2 + 1/2m3[2l12\,\theta12l22(\theta1 + \theta2)2l32(\theta1 + 2\theta2 + \theta3) + 2l1l2cos\theta2(\theta1 + \theta2) + \theta1] + 2l2l3cos\,\theta3(\theta1 + \theta2) + (\theta1 + \theta2 + \theta3)] + 2l1l3cos(\theta2 + \theta3)[(\theta1 + \theta1 + \theta2 + \theta3)]$$

$$Q2 = m2[l22(\theta1 + \theta2) + l1l2\theta1cos\theta2 - l1l2\theta1sin\theta2] + m3[l22(\theta1 + \theta2) + l32(\theta1 + \theta2 + \theta3) + l1l2\theta1cos\theta2 - l1l2\theta1sin\theta2 + l2l3(\theta1 + \theta2 + \theta3)cos\theta3 - l2l3(\theta1 + \theta2 + \theta3)sin\theta3 + l2l3(\theta1 + \theta2)cos\theta3 - l2l3(\theta1 + \theta2)sin\theta3 - l1l3\theta1\,cos(\theta2 + \theta3)l1l3\theta1(\theta2 + \theta3)sin(\theta2 + \theta3)][m2l22(\theta1 + \theta2) + l1l2\theta1cos\theta2] + 1/2m3[2l22(\theta1 + \theta2) + 2l32(\theta1 + \theta2 + \theta3) + 2l1l2\theta1cos\theta2 + 2l2l3cos\theta32l2l3cos\theta3(\theta1 + \theta2 + \theta3) + 2l2l3cos\theta3[((\theta1 + \theta2) + 2l1l3cos\,(\theta2 + \theta3)]$$

$$Q3 = (m_3\,[l_3^2\,(\theta_1 + \theta_2 + \theta_3) + l_2l_3\,(\theta_1 + \theta_2)\cos\theta_3 - l_2l_3\,(\theta_1 + \theta_2)\sin\theta_3 + l_1l_3\theta_1\cos(\theta_1 + \theta_3) - l_1l_3\theta_1\sin(\theta_1 + \theta_3)(\theta_2 + \theta_3)] - \frac{1}{2}m3\,[2l_3^2\,(\theta_1 + \theta_2 + \theta_3) + 2l_2l_3\cos\theta_3\,[(\theta_1 + \theta_2) + 2l_1l_3\theta_1\cos(\theta_2 + \theta_3)]$$

3. RESULTS AND DISCUSSION

Torque Calculation: The torque is calculated from the designated equations for the 3R SCARA manipulator and shown in below table.3.

Table.3. Torque Calculation for 3R SCARA

Length (m)	**Mass** (KN)	$\mathbf{Q_1}$ (N-m)	$\mathbf{Q_2}$ (N-m)	$\mathbf{Q_3}$ (N-m)
L_1 =150 L_2 =200 L_3 =250	m_1=0.00760 m_2=0.01014 m_3=0.01268	106.63	62.55	21.98
L_1 =200 L_2 =200 L_3 =200	m_1=0.01014 m_2=0.01014 m_3 =0.01014	108.89	50.12	14.06
L_1 =300 L_2 =150 L_3 =150	m_1=0.01706 m_2=0.00760 m_3 =0.00760	121.66	28.17	7.90
L_1 =200 L_2 =150 L_3 =250	m_1=0.01014 m_2=0.00760 m_3 =0.01268	107.79	49.02	21.98
L_1 =150 L_2 =150 L_3 =300	m_1=0.00760 m_2=0.00760 m_3 =0.01706	115.12	68.38	35.50

From the above calculations it is analyzed that the elbow movement of robot varies accordingly with various degrees of freedom.

From table.1, it is found that the length of the robot arm indirectly stimulates the degree of freedom.

From table.2, it is found that the p_x value stimulates θ_1 and p_y stimulates θ_2.

From table 3 it is found that Q_1, Q_2, Q_3 increases with the increase in L and M simultaneously.

4. CONCLUSION

Designing and comparing of 2R and 3R SCARA arm manipulator by dynamic study for pick and place application is accomplished and analyzed by MATLAB simulation for determining which robot occupying more work space and high maneuverability.

In this work the dynamic study is performed to position the tool profile by effectively using the compliance device.

It is planned to develop the trajectory planning using motion equation under MATLAB simulation as further progress towards this research. The position of the tool must be identified using the MATLAB simulation and equations. To develop a working SCARA model based on the dynamic results for positioning the tool or to do the pick and place process for various purpose and validating the positions with the aid of prototype and also by similar and advanced simulation tools.

REFERENCES

Athijayamani A, Manickam C, Kumar J, Natesan Diwahar, Mechanical and wear behaviors of untreated and alkali treated roselle fiber-reinforced vinyl ester composite, Journal of Engineering Research, 3 (3), 2015.

Babak Rohani, Yazicioglu Y, Mutlu M, Ogucu O, Akgul E, & Saranli A, Lagrangian based mathematical modeling and experimental validation of a planar stabilized platform for mobile systems, Journal of Computational and Applied Mathematics, 259, 2014, 955–964.

Baruh H, Tadikonda S.S.K, Issues in the dynamics and control of flexible robot manipulators, AIAA Journal of Guidance, Control and Dynamics, 12 (5), 1989, 659–671.

Chandrasekar M, Rajkumar S, Valavan D, A review on the thermal regulation techniques for nonintegrated flat PV modules mounted on building top, Energy and Buildings 2015, 86, 2015, 692–697.

Fukuda T, Arakawa A, Modeling and control characteristics for a two-degrees-of-freedom coupling system of flexible robotic arms, JSME, Series C, 30, 1987, 1458–1464.

Gasparetto A, On the modelling of flexible-link planner mechanisms: experimental validation of an accurate dynamic model, ASME Journal of Dynamic Systems, Measurement, and Control, 126, 2004, 365–375.

Huang T, Wang P.F, Mei J.P, Zhao X.M, & Chetwynd D.G, Time Minimum Trajectory Planning of a 2-DOF Translational Parallel Robot for Pick-and-place Operations, CIRP Annals - Manufacturing Technology, 56 (1), 2007, 365–368.

Karthe M, Tamilarasan M, Prasanna S.C, Manikandan A, Experimental Investigation on Reduction of NOx Emission Using Zeolite Coated Converter in CI Engine, Applied Mechanics and Materials, 854, 2017, 72-77.

Krishnan M, Karthikeyan T, Chinnusamy TR, Venkatesh Raja K, A novel hybrid metaheuristic scatter search-simulated annealing algorithm for solving flexible manufacturing system layout, Eur J Sci Res, 2012, 52-61.

Lee H.H, New dynamic modeling of flexible-link robots, ASME Journal of Dynamic Systems, Measurement, and Control, 127, 2005, 307–309.

Manickam C, Kumar J, Athijayamani A, Karthik K, Modeling and multi response optimization of the mechanical properties of Roselle fiber-reinforced vinyl ester composite, Polymer-Plastics Technology and Engineering, 54 (16), 2015, 1694-1703.

Prabhu T, Ramesh C, Kumar J, Sivakuma S, Hybrid Solar PVT System based on Neural Network Models to track optimal Thermal and electrical power, International Journal of Applied Engineering Research, 10 (28), 2015, 22075 – 22081.

Prasanna S.C, Ramesh C, Manivel R, Manikandan A, Preparation of Al6061-SiC with Neem Leaf Ash in AMMC's by Using Stir Casting Method and Evaluation of Mechanical, Wear Properties and Investigation on Microstructures, Applied Mechanics and Materials, 854, 2017, 115-120.

Prasanna S.C, Ramesh C, Property Evaluation of Aluminium Metal Matrix Composites Fabricated Using Stir Casting Method for Hand Lever In Automobile Applications, International Journal of Applied Engineering Research (IJAER), 10 (85), 2015.

Rajakumar S, Balasubramanian V, Balakrishnan M, Friction surfacing for enhanced surface protection of marine engineering components: erosion-corrosion study, Journal of the Mechanical Behavior of Materials, 25 (3-4), 2016, 111–119.

Ramesh C, Manickam C, Prasanna S.C, Lean Six Sigma Approach to Improve Overall Equipment Effectiveness Performance: A Case Study in the Indian Small Manufacturing Firm, Asian Journal of Research in Social Sciences and Humanities, 6 (12), 2016.

Ramesh C, Valliappan M, Prasanna S.C, Fabrication of Ammcs by using Stir Casting Method For Hand Lever, International Journal of New Technologies in Science and Engineering, 2 (1), 2015.

Ramesh M, Karthic K.S, Karthikeyan T, Kumaravel A, Construction materials from industrial wastes—a review of current practices, International journal of environmental research and development, 2014, 317-324.

Ramesh M, Karthikeyan T, Effect of Reinforcement of Natural Residue (Quarry Dust) to Enhance the Properties of Aluminium Metal, Journal of Industrial Pollution Control, 2013.

Ramesh R, Ramesh C, Design, analysis and fabrication of canard wing configuration, International Journal of Research and Innovation in Engineering Technology, 2 (09), 2016.

Sethusundaram P.P, Arulshri K.P, Mylsamy K, Biodiesel blend, fuel properties and its emission characteristics Sterculia oil in diesel engine, International Review of Mechanical Engineering, 7 (5), 2013.

Sharan A.M, Jain J, Kalra P, Efficient methods for solving dynamic problems of flexible manipulators, ASME Journal of Dynamic Systems, Measurement, and Control, 114, 1992, 78–88.

Sisir Padhy K, On the dynamics of SCARA robot, Robotics and Autonomous Systems, 10 (1), 1992, 71–78.

Sivaraman B, Padmavathy S, Jothiprakash P, Keerthivasan T, Multi-Response Optimisation of Cutting Parameters of Wire EDM in Titanium Using Response Surface Methodology, Applied Mechanics and Materials, 854, 2017, 93-100.

Vijayan V, Karthikeyan T, Design and Analysis of Compliant Mechanism for Active Vibration Isolation Using FEA Technique, International Journal of Recent Trends in Engineering, 1 (5), 2009.

Zheng Y.F, Dynamic and kinetic behavior of two coordinating robots in assembly, Mathematical and Computer Modelling, 12 (1), 1989, 77–88.