MOTION ANALYSIS OF 4 AXIS ROBOTIC ARM WITH INVERSE KINEMATICS FOR INDUSTRIAL APPLICATION.

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Abstract:
This paper describes the deformation and stress induced for a particular payload of a robot. A 4 axis type industrial robotic arm has been considered for motion analysis. The modelling of articulated robotic hand has been created by 3D software SOLIDWORKS and the analysis have been performed by using ANSYS R15 software. In order to compensate the work the kinematic analysis also performed in a 2-D scale through computer simulation. This shows the 2D plot for the different combinations of joint angle within its work envelope. The forward and inverse kinematics analysis has been used to co-relate the desired location and orientation of end effector with joint variables. MATLAB simulation result has been compared with the theoretical analysis for various link positions and it has been found that both the results are in phase and have good agreement with each other.

Key words: 4 axis Robot, Forward Kinematics, Inverse kinematics, Payload, Workspace.

INTRODUCTION

Industrial robots have long been used to replace the necessity of the human operator in repetitive tasks or dangerous environments. From the early design stages, with respect to the specificity of the application each specific IR model may be efficiently integrated into a flexible manufacturing cells by primary taking into account its maximum reach ability and payload. Both of these major functional features are basically depending by the length of each IR's link, the available limits for each IR's joint orientation as well as some specific constructive features of each IR's subassemblies [1]. From this point of view the IR's work space can be defined as a relationship between the length of the arms, the number of degrees of freedom and the type of the joint (rotational, translational or combinations between the two) [2, 9]. The kinematics of the robot is usually represented using a symbolic structure describing each joint and link and the relationship between the two in the path of the motion. Modeling the chains of bodies connected by joints is done using the Denavit-Hartenberg (D-H) conventions [2, 3, 7, 8, and 9]. The representation of D-H convention results in a 4 ´ 4 matrix called the homogenous transformation matrix. For an n degrees of freedom robot, the resulting number of homogenous transformation matrix is $n + 1$. The products of the coordinates frames transformations matrices for each link are used to determine the forward kinematics. By this mean the position and orientation of the tool attached to the robot can be computed using a given set of joint angles. Also, the form and limit of the robot's working envelope can be analyzed using the position vector from the transformation matrix describing the forward kinematics [3]. The inverse kinematics problem is solved to achieve a desired position and orientation of the tool relative to the workstation. The inverse kinematics problem r equires solving at first the inverse kinematics equations for the position fallowed by the equations for the orientation of the tool relatively to the robot's base frame. The number of solutions for the joint angles is affected by the number of IR specific configurations and number of degrees of freedom. While the problem of inverse kinematics may

have 8 solutions for the most 6 DOF robots, the problem for 7 DOF robots is more complex because an infinity of solutions may be identified. Therefore, sometimes one DOF in suppressed when solving the kinematics equations. To analytically validate the inverse kinematics results, the value of joint angles determined for a specified pose of the IR's end effector should correspond with the value of joint angles from the inverse kinematics [15]. In order for this purpose a geometric validation may be used too by mean of constrained 3D models of the studied real scale IR achieved by taking into account their complete set of constructive parameters and design features [4, 5, and 6]. After defining each value corresponding to each joint angle, the final tool frame should correspond with the desired pose frame.Forward and inverse kinematics was analytically computed in [7] for a seriallink opened kinematics KUKA KR60 6 DOF IR, the accuracy of the results being verified using a simulation program which uses the Unified System for Automation and Robot Simulation (USARSim). The forward kinematics, inverse kinematics, workspace and joint accelerations and velocities were determined and results were also verified using Robo-analyzer software [8].
In this paper we proposed the modelling and analysis of 4 axis robotic arm using inverse kinematics and forward kinematics are discussed .Section 1 contains modelling of robotic arm and section 2 contain analysis in both ANYSYS and MATLAB software's. Section 3 conclusion of this research work.

Modelling of Robot

The model of the articulated robotic joint has been created by using software SOLID WORKS. The complete model has been assembled by using the various parts of the robot. The assembly includes parts such as base, body, upper arm, fore arm, end gripper etc. To provide relative motion between these parts a cylindrical type pin has been used. Each and every part of the model having different dimensions. The model specification has been shown in the table
For complete modelling used software SOLID WORKS contains four important sections which is manual drawing, part module, assembly module and drawing module shown [1]. First two sections provide the model and design parts of the robot to user. The assembly module enables the parts to be modelled in the assembly which provides the relative motion between the parts by using the revolute joints through cylindrical pin..

Specification of Model

Specification	value
Number of axis	4
Horizontal reach	300mm
Vertical reach	450mm
Drives	4 servo motors
Configuration	a)All axes completely Independent b)All axes can be controlled simultaneously
Work envelope	a)Shoulder rotation b)Elbow rotation c)Gripper rotation
Material	Structural steel Density- 7800 kg/m.3 Poisson's Ratio – 0.3

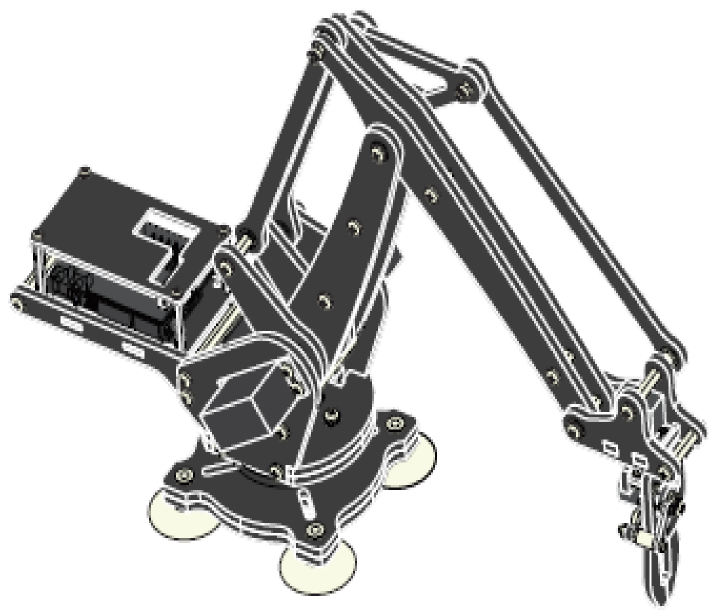

Fig. 1: Assembled model

Mathematical Calculation

The load which is to be lifted by the robot provide its effect on every part of the model, its effect should be analyzed on each joint in terms of moment provided by load lifted and weight of the motor which gives the direct loading on the joints[2]. Direct force and moment calculation gives the result in terms of stress and the deformation of the part. To calculate the parameters under consideration are as follows:

I. weight of each linkage
II. weight of each joint
III. weight of object to lift
IV. length of each linkage

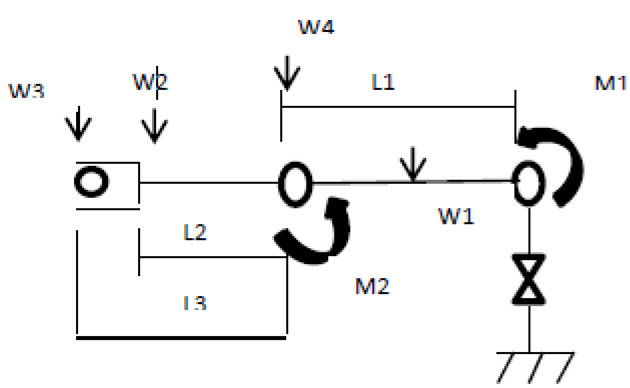

Fig 2: Force and moment calculation

Torque About Joint 1:
M1 = L1/2 * W1 + L1 * W4 + (L1 + L2/2) * W2 + (L1 + L3) * W3
Torque About Joint 2:
M2 = L2/2 * W2 + L3 * W3

Stress and deformation calculation

To find out the analytical solution the main assumption is that the loading condition makes the arm like a beam is in bending. Hence, by using bending equation

Stress value can be found by $\sigma = \frac{MY}{I}$

Maximum deformation is given by $\delta_{\max} = \frac{PL^3}{3EI}$ and $\delta_{\max} = \frac{MI^2}{2EI}$

Kinematic analysis of Robot

Forward Kinematics

It involves the computation of position and orientation of the end effector, while knowing the joint angle and link length. The forward kinematics of the end-effector with respect to the base frame is determined by multiplying all of the ${}^{i-1}_{i}T$ matrices.

$$ {}^{base}_{end\_effector}T = {}^{0}_{1}T\, {}^{1}_{2}T \ldots\ldots\ldots\ldots {}^{n-1}_{n}T $$

An alternative representation of ${}^{base}_{end\_effector}T$ can be written as

$$ {}^{base}_{end\_effector}T = \begin{bmatrix} r_{11} & r_{12} & r_{13} & p_x \\ r_{21} & r_{22} & r_{23} & p_y \\ r_{31} & r_{32} & r_{33} & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Inverse Kinematics

It involves the calculation of joint angle and link parameters for the desired position and orientation of the end effector. To find the inverse kinematics solution for the first joint (q1) as a function of the known elements of ${}^{base}_{end\_effector}T$, the link transformation inverses are pre multiplied as follows

$$ \left[{}^{0}_{1}T(q_1)\right]^{-1} {}^{0}_{6}T = {}^{1}_{2}T(q_2)\,{}^{2}_{3}T(q_3)\,{}^{3}_{4}T(q_4)\,{}^{4}_{5}T(q_5)\,{}^{5}_{6}T(q_6) $$

To find the other variables, the following equations are obtained as a similar manner

$$ \left[{}^{0}_{1}T(q_1)\,{}^{1}_{2}T(q_2)\,{}^{2}_{3}T(q_3)\,{}^{3}_{4}T(q_4)\,{}^{4}_{5}T(q_5)\right]^{-1} {}^{0}_{6}T = {}^{5}_{6}T(q_6) $$

Result and discussion

To analyse the design the structural analysis has been performed by using software ANSYS R15.0. The result shown as snap shot from the ANSYS for every part in all the three different case. The result obtained is then compared with the analytical result that is obtained by using the basic formulas of the strength of material. The result is calculated for lifting a load of say 10N, on comparing the result from both the process is tabulated and the % error obtained is not more than 5% for any part hence it is accepted.

To calculate maximum payload of robot

The above result shown is calculated for carrying a load of 10N and for this the robot is safe. Hence to calculate the maximum load for which the robot will not fail gives the maximum load carrying capacity of robot in other terms it is also called as the payload of the robot. By varying the load from 10-60N the robot will not fail for any cases.

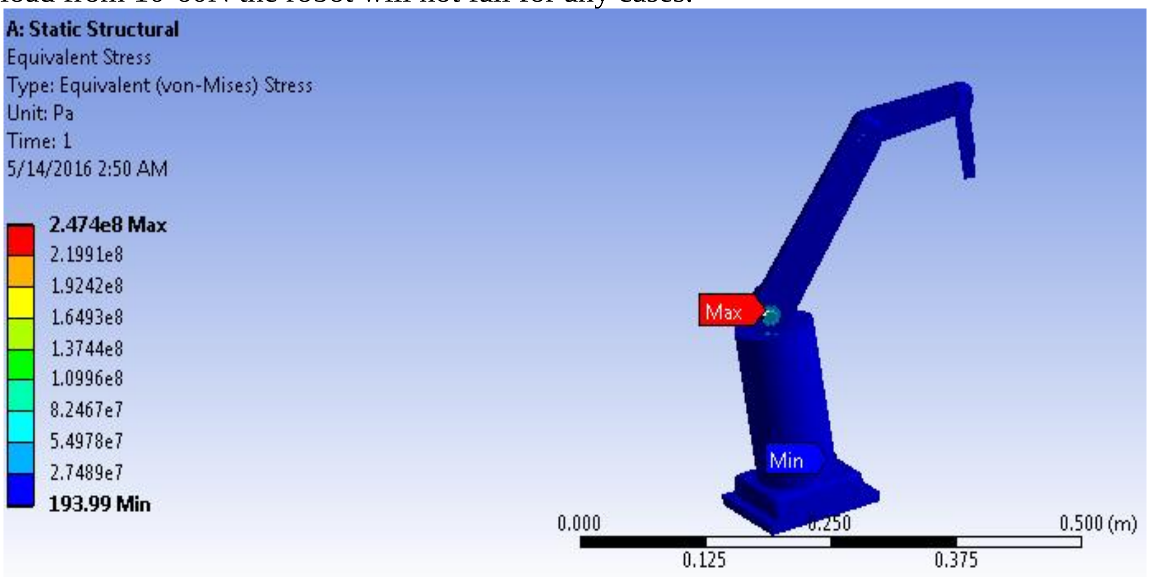

Fig. 4: Stress distribution for max. Payload

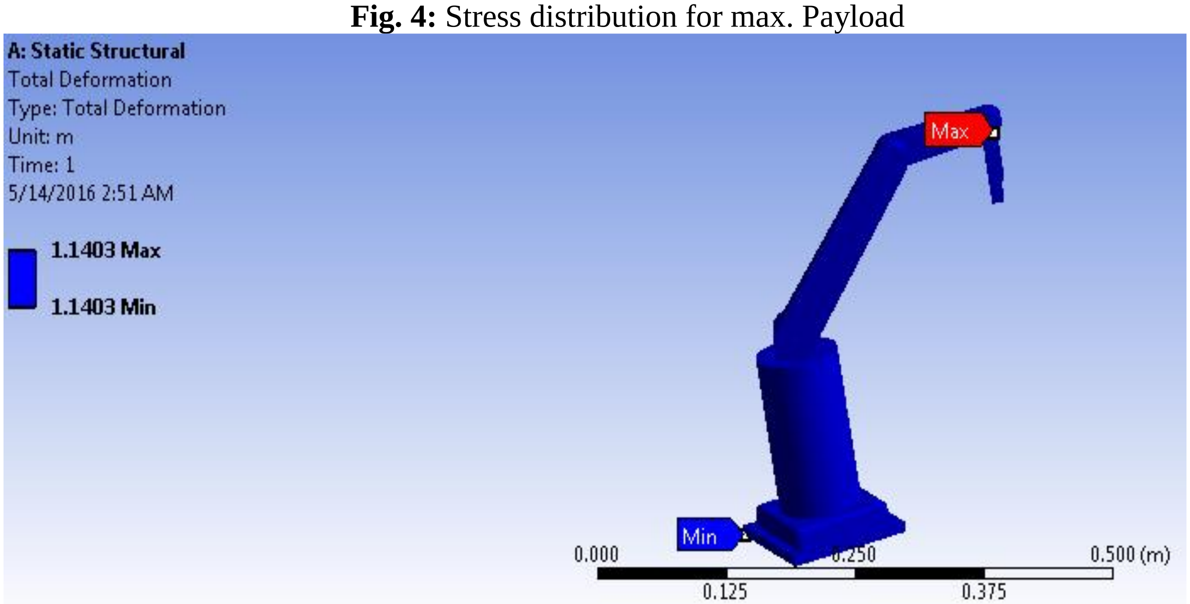

Fig. 5: Deformation for maximum payload

- Maximum stress generated for case-3 i.e. approx. 247MPa for the load of 60N.
- For structural steel - A36 steel plate.

Yield strength- 250MPa and Ultimate tensile strength - 400-550MPa.
So, while designing the robotic arm the load should be less than 60N calculated at maximum speed based upon yield strength criteria for robot. Hence from the above result the model is best suited for Lifting a load of 50N. The payload of robot at normal speed calculated as 50N.

Results of Kinematic Analysis

Inverse Kinematic modelling of Robotic Arm

Analysis is done for two link, 2 dimensional arm mechanism. For this simple mechanism the angle reducing for each joint will be as per the desired location of the tip of the end arm. Let θ1 be the angle between the first arm and the ground. Let θ2 be the angle between the first and second arm. Let the length of first arm is L1 and that of second arm is L2. Assume the limited rotation of arm hence, 0<=θ1<=pi/2 and 0<= θ2<=pi

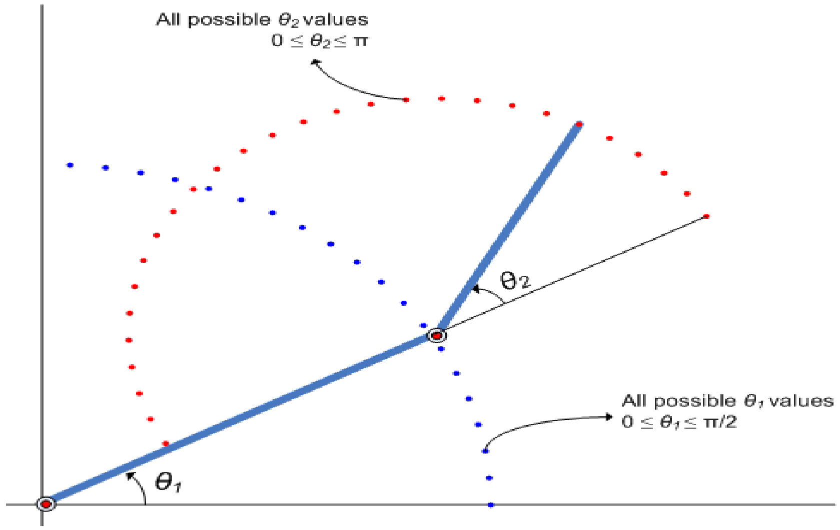

Fig. 6: All possible joint values of θ1 and θ2

The plot shows the generated X-Y data point for different combination of θ1 and θ2 and reducing x and y co-ordinate for each joint. The plot has been generated by using the forward kinematics.

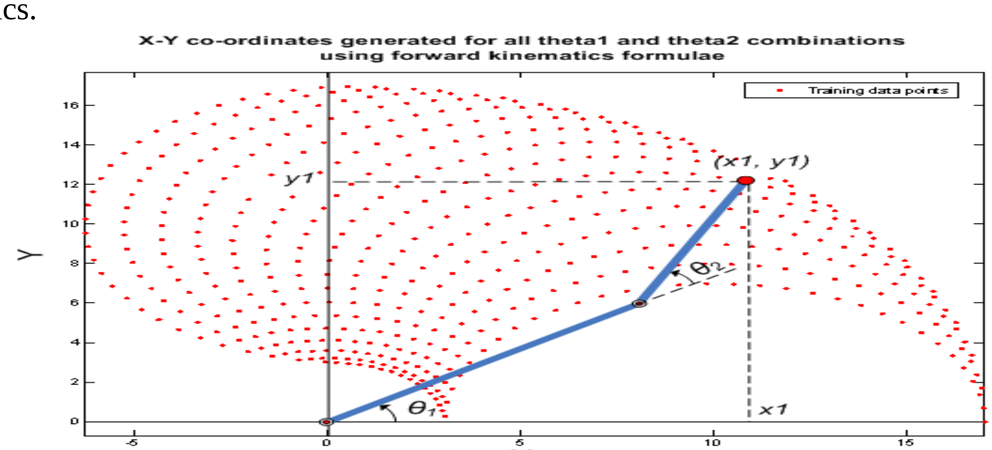

Fig. 7: X-Y coordinate generated for all θ1 and θ2 combinations using forward kinematics Formulae

Formula. Since the forward kinematics formulae for two joint robotic arms are known, X and Y co-ordinates of the tip of the arm can be calculated by moving it to desired range of angle rotation.

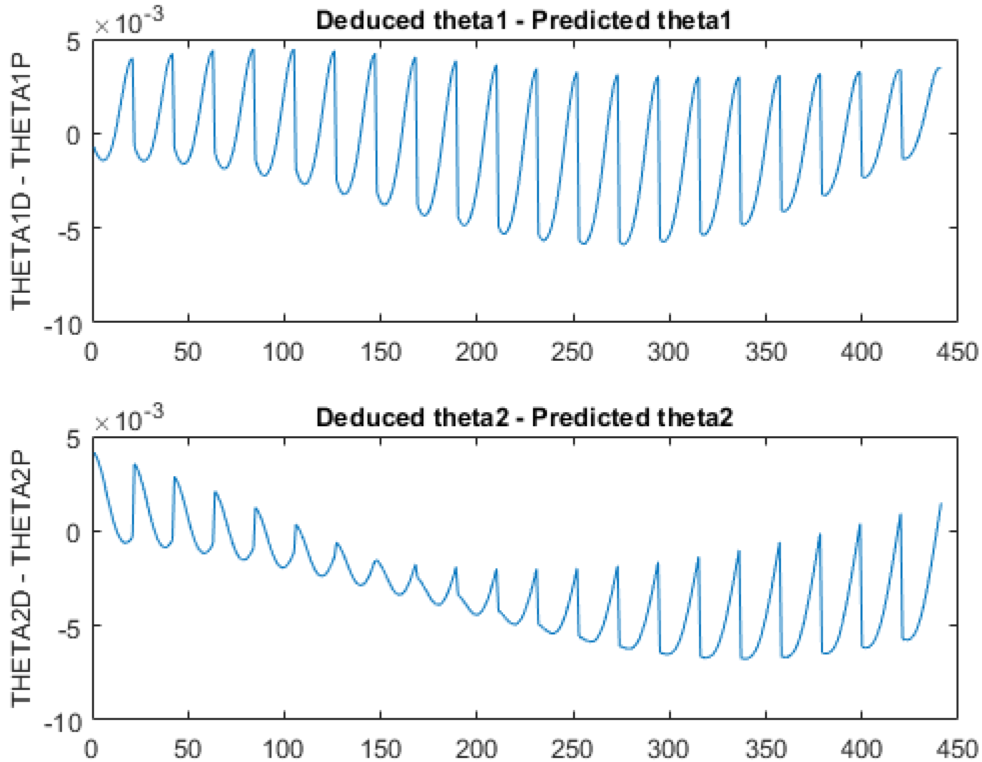

Fig. 8: Variation between actual and predicted theta values.

THETA1D and THETA2D are the variables that hold the values of θ1 and θ2 reduced using the inverse kinematics formulae. The errors are in the range of 1e-3 which is a fairly good number for the different application.

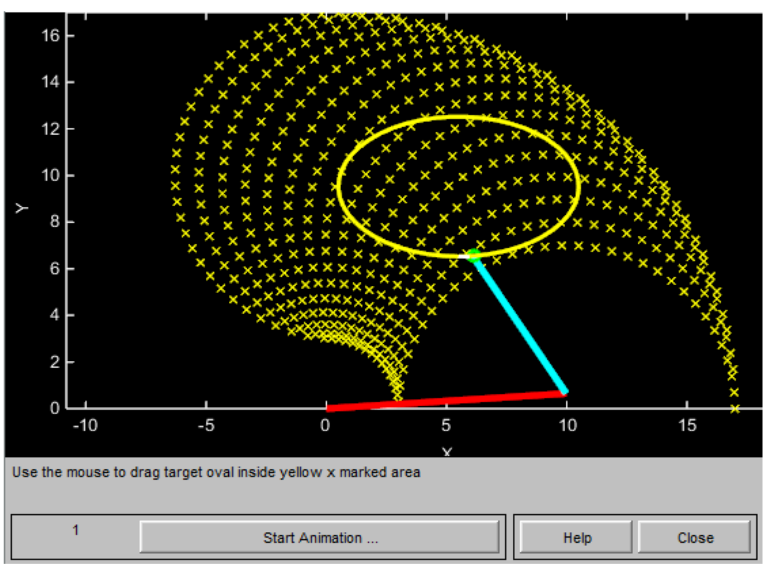

Fig. 9: GUI for inverse kinematics modelling

Conclusions

After getting results the paper can be concluded to its result in a way that, the work is completely based on theoretical approach to follow certain design criteria. To avoid failure of parts the stress value find should be lower than the yield point limit for the material. Maximum stress (Von Misses Theory) criteria used to define the payload of the robots. On the basis of payload the robots can be used for different applications. At maximum payload the robots will not follow the predefined path hence normal payload is always used for the robots. As from the result obtained the normal payload of the robot is 50N which the model can lift within the yield stress limit of the material.

In the second part, motion planning result containing graph which shows the error between the predicted angle variations with the actual variation of the angle. This type of error is found because of the joint constraints of the robotic manipulator. The estimated errors are in the range of 1e-3 which is fairly good number and can
be used for the applications where the very high accuracy is not desired.

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