IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 11, Issue 3 Ver. II (May- Jun. 2014), PP 01-07
www.iosrjournals.org

Simulation of Articulated Robotic Manipulator & It's Application in Modern Industries

Pankaj Kumar[1], Dr. R.K. Gupta[2]
[1](*Mechanical Engineering, GITM, Bilaspur, Haryana, India)*
[2]*((Mechanical Engineering, GITM, Bilaspur, Haryana, India)*

Abstract : *Simulation has been recognized as an important research tool since the beginning of the 20th century. Invention of computers boosted the simulation capability that's why simulation is now a powerful tool supporting the design, planning, analysis, and decisions in different areas of research and development. In the present work, a CAD/CAE integrated system for Cartesian, cylindrical & articulated type robot manipulators are developed. The D–H (Denavit–Hartenberg) coordinate transformation method was used to perform the robot position analysis, according to the transformation matrices; P. Corke Robotic toolbox for MATLAB is used for the robot position analysis. Pro/ENGINEER (Pro/E) is used to construct the robot manipulator parametric solid models; Pro/Mechanica is used for the kinematic simulation and analysis of working envelop. Finally an error model is generated to estimate the positional error in all three manipulator configurations. This integrated system not only promotes automation capabilities for robot manipulator production, but also simplifies the CAD/CAE process for a robot manipulator & provides the idea for selecting the robotic manipulator for a particular application.*

Keywords: *Computer Aided Design/Computer Aided Engineering, Denavit-Hartenberg, Pro/Engineer*

I. Introduction

Robotics is very interdisciplinary, fast growing research field. Robots are introduced in various areas and used for different tasks also the requirements for the simulation tools depend on the particular application. However, all new applications, methodologies and technologies in robotics share the requirement to simulate robot systems and the environment with sufficient sophistication and accuracy. Therefore Simulation is the process of designing a model of an actual or theoretical physical system, executing the model, and analyzing the execution output. Invention of computers boosted the application area of simulation & now it has become a powerful tool supporting the design, planning, analysis, and decisions in different areas of research and development. Simulation is also a strategic tool in many fields, used by many researchers, developers and by many manufacturers. In robotics simulation plays a very important role, perhaps more important than in many other fields and we like to present in the following some insight in the robotics from the simulation point of view.

In many cases simulations are mandatory prior to implementation of any significant new operation, project or process. Manufacturing technologists and engineers need to be familiar with these modern tools and their applications, and to understand when and how to effectively utilize them. The development of the hardware and software required for a robotized work cell can be a long, tedious and expensive process. An interactive graphic simulation system in computer reduces costs and time in the design, analysis and manufacture of Mechanical products. They are now widely used in the industry to build virtual models and analysis schemes. A design model can be refined, modified and simulated virtually using computer tools. Manufacturing pre-processing is also performed using computer techniques. Robotic programs can be debugged and tested without danger to the operator or to the equipment. Reference points of the trajectories, transformed to the joint coordinates, can be directly fed to the robot's controller. The validity of the results obtained with computer graphic simulation systems depends largely on the validity of the kinematic models used in the simulation. The mathematical modeling of robot kinematics is motivated by the complexity of robotic systems, which possess highly nonlinear characteristics. A large number of software & robotic toolboxes are available for this purpose.

II. Solid Modeling, Mechanism Design

The work is done in PRO-E that provides solid modeling, assembly modeling and drafting, finite element analysis, and NC and tooling functionality for mechanical engineers. The parametric modeling approach uses parameters, dimensions, features and relationships to capture intended product behavior.

Steps involved in Pro/E are as shown in figure:

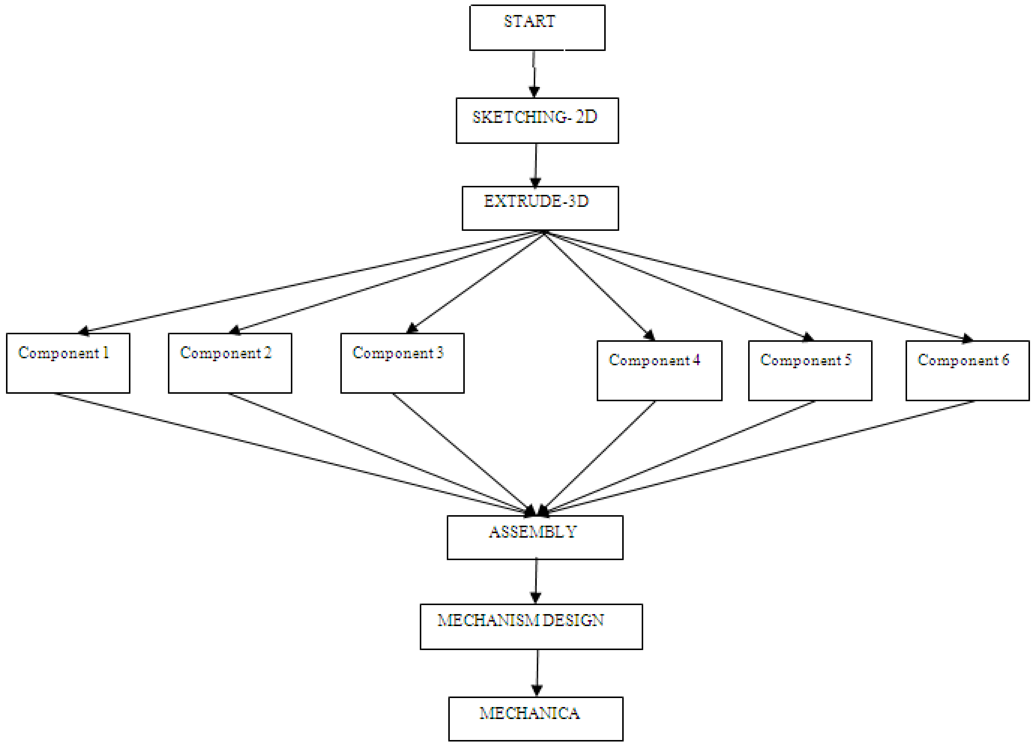


Fig 2.1 Steps followed in Pro- Engineer

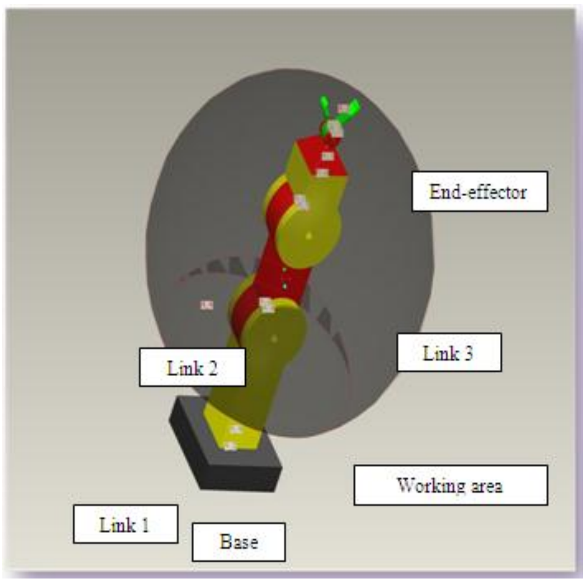
III. Work Envelop

Types of joints-

1. Revolute Joint between link(0) & link(1) along Z_0
2. Revolute Joint between link(1) & link(2) along Z_1
3. Revolute Joint between link(2) & link(3) along Z_2
4. Revolute Joint between link(3) & link(4) along Z_3
5. Revolute Joint between link(4) & link(5) along Z_4
6. Revolute Joint between link(4) & link(6) along Z_5

By providing all joint information to PRO-E the work-envelop of Articulated manipulator is achieved as shown in figure.

Fig.3.1 Work envelop of Articulated manipulator



3.1.1.1 Kinematics: Frame Assignment

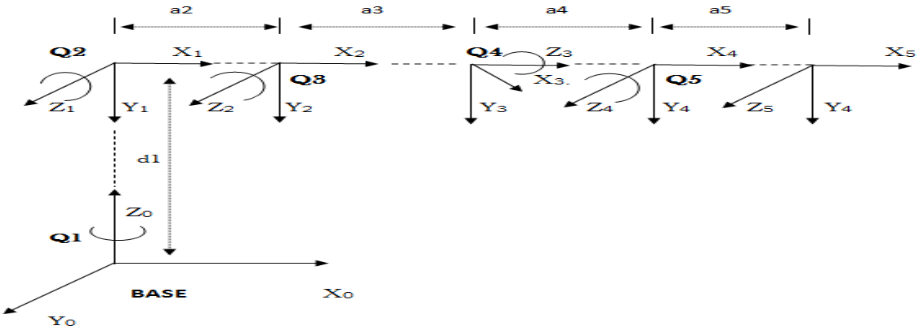


Fig 3.2 Frame assignment for the Articulated Manipulator

On the basis of frame assignment we can tabulate the joint-link parameters.

LINK No.	Ai	a_i	θ_i	d_i
1				
2				
3				
-				
-				
n				

Table 3.1 Joint-link parameter of Articulated Robot

IV. Generation Of Homogeneous Transformation Matrix

Articulated Robot is having 6-DEGREES OF FREEDOM because end effector is also attached, end effector is having 3-DOF; all joints are rotating.

<u>Start Transformation</u>.

Transformation from frame (0-1)

$$ {}^{0}_{1}T = \mathrm{Rot}(Z, Q_1)\ \mathrm{Trans}(0,0,d_1)\ \mathrm{Rot}(X, 90^\circ) $$

$$ \begin{bmatrix} cQ_1 & -sQ_1 & 0 & 0 \\ sQ_1 & cQ_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \mathrm{x} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \mathrm{x} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{0}_{1}T = \begin{bmatrix} cQ_1 & 0 & sQ_1 & 0 \\ sQ & 0 & -cQ_1 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Transformation from frame (1-2)

$$ {}^{1}_{2}T = \mathrm{Rot}(Z, Q_2)\ \mathrm{Trans}(a_2, 0, 0) $$

$$ \begin{bmatrix} cQ_2 & -sQ_2 & 0 & 0 \\ sQ_2 & cQ_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \mathrm{x} \begin{bmatrix} 1 & 0 & 0 & a_2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{1}_{2}T = \begin{bmatrix} cQ_2 & -sQ_2 & 0 & a_2 cQ_2 \\ sQ_2 & cQ_2 & 0 & a_2 sQ_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Transformation from frame (2-3)

$$ {}^{2}_{3}T = Rot(Z,Q_3)\ Trans(a_3,0,0)\ Rot(Y,-90^\circ) $$

$$ \begin{bmatrix} cQ_3 & -sQ_3 & 0 & 0 \\ sQ_3 & cQ_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & a_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} X \begin{bmatrix} 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{2}_{3}T = \begin{bmatrix} 0 & -sQ_3 & -cQ_3 & a_3cQ_3 \\ 0 & cQ_3 & -sQ_3 & a_3sQ_3 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Transformation from frame (3-4)

$$ {}^{3}_{4}T = Rot(Z,Q_4)\ Trans(0,0,a_4)\ Rot(Y,90^\circ) $$

$$ \begin{bmatrix} cQ_4 & -sQ_4 & 0 & 0 \\ sQ_4 & cQ_4 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & a_4 \\ 0 & 0 & 0 & 1 \end{bmatrix} X \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{3}_{4}T = \begin{bmatrix} 0 & -sQ_4 & cQ_4 & 0 \\ 0 & cQ_4 & sQ_4 & 0 \\ -1 & 0 & 0 & a_4 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Transformation from frame (4-5)

$$ {}^{4}_{5}T = Rot(Z,Q_5)\ Trans(a_5,0,0) $$

$$ \begin{bmatrix} cQ_5 & -sQ_5 & 0 & 0 \\ sQ_5 & cQ_5 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & a_5 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{4}_{5}T = \begin{bmatrix} cQ_5 & -sQ_5 & 0 & a_5cQ_5 \\ sQ_5 & cQ_5 & 0 & a_5sQ_5 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Final Transformation Matrix from frame (0-5)

$$ {}^{0}_{5}\mathbf{T} = {}^{0}_{1}\mathbf{T} * {}^{1}_{2}\mathbf{T} * {}^{2}_{3}\mathbf{T} * {}^{3}_{4}\mathbf{T} * {}^{4}_{5}\mathbf{T} $$

With the help of above equation one can get the exact position & orientation of end-effector corresponding to the different values of angles Q1, Q2, Q3, Q4, and Q5.

V. Result & Conclusion

5.1 Simulation Results

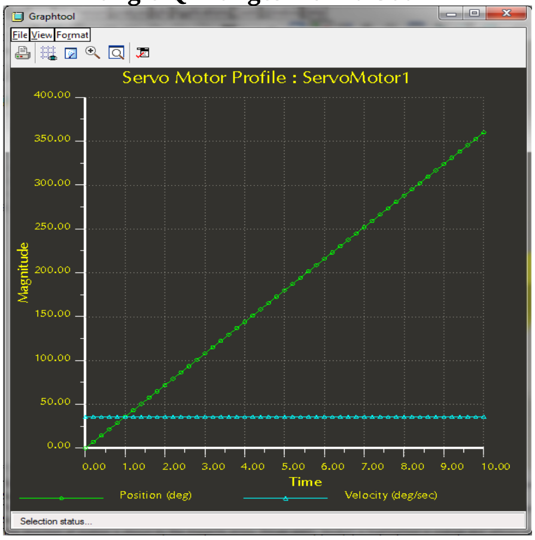
By the result of simulation the work envelops of each manipulator configuration is achieved. Motion simulation provides the graphical representation of motion at each joint. The graph between (time & position) & (time & velocity) is obtained with the help of PRO-E MECHANISM as shown.

For Articulated Manipulator which consists of end-effector, the graphs show that the rotation of links at joints with respect to time. As the **Rotation vs. Time** is straight line so the joint velocity will be constant. Equation of position followed by Servo Motor is

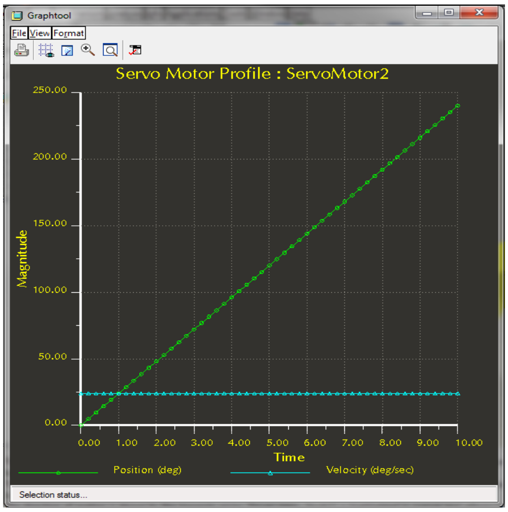
$$ \mathbf{Q= A + B^{t}} $$

Where **A** is coefficient & **B** is slopping (linear coefficient) & **t** is time

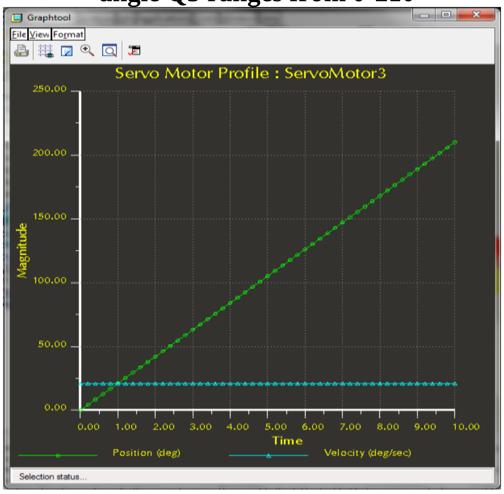
1. Servomotor-1 at Joint-1, angle Q1 ranges from 0-360^0



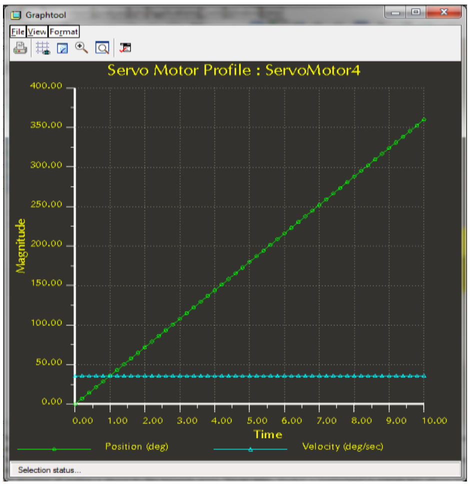
2. Servomotor-2 at joint-2, angle Q2 ranges from 0-240^0



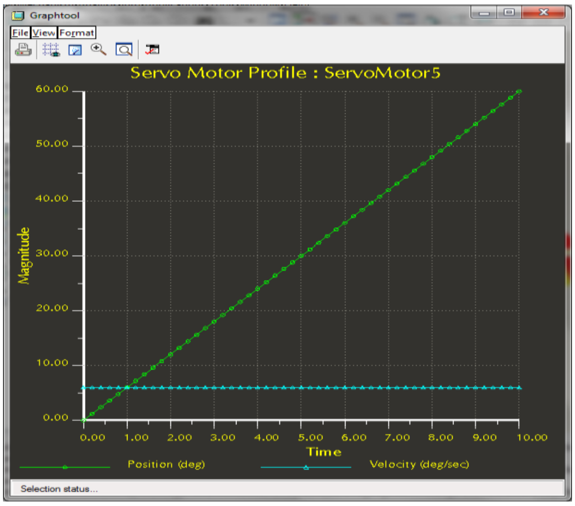
3. Servomotor-3 at Joint-3, angle Q3 ranges from 0-210^0



4. Servomotor-4 at Joint-4, angle Q4 rages from 0-360^0



5. Servomotor-5 at Joint-5&6, angle Q5 Q 6 ranges from 0-45^0



Pro-Mechanica Results for end-effector

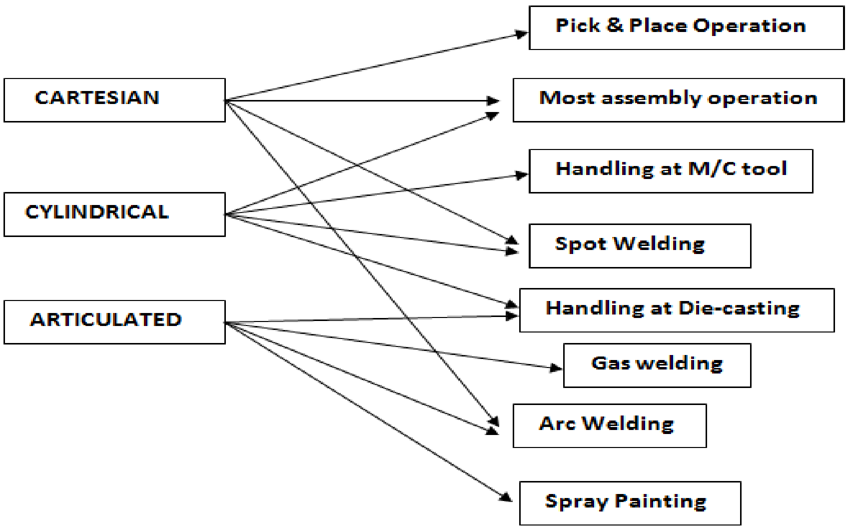
5.2 Error Modeling Results

The common point selected for the error analysis is (X, Y, Z), corresponding to this point the error values are tabulated as follows-

Serial No.	Random Number	Cartesian	Cylindrical	Articulated
1	1.8339			
2	-2.2588			
3	0.8622			
4	0.3188			
5	-1.3077			
6	-0.4336			
7	0.3426			
8	3.5784			
9	2.7694			
10	-1.3499			
11	3.0349			
12	0.7254			
13	-0.0631			
14	0.7147			
15	-0.2050			
16	-0.1241			
17	1.4897			
18	1.4090			
19	1.4172			
20	0.6715			
	Mean Error			

By the table we come to know that the Cartesian Robot Manipulator have minimum error. As a result of which it has maximum accuracy.

5.3 Applications of Robotic manipulator



References

Journal Papers:

[1] Bhavesh kumar P. Patel, Dr. J. M. Prajapati "*A Review on Kinematics of Hydraulic Excavator's Backhoe Attachment*", IJEST 2011.
[2] Chettibi, T., "*Synthesis of dynamic motions for robotic manipulators with geometric path constraints"*, Mechatronics, 2006.
[3] D. Y. Yang, D. G. Ahn, C. H. Lee, C. H. Park, T. J. Kim "*Integration Of CAD/CAM/CAE/RP for the development of Metal Forming Process*" Journal of Materials Processing Technology (2002).

[4] Dolgui A., and A. Pashkevich, "*Manipulator motion planning for high-speed robotic laser cutting"*, International Journal of Production Research, 2009.

[5] Dr. Agustin Jimenez and Dr. Basil M. Al Hadith "*Robot Manipulators, Trends and development*" In-Tech, March, 2010.

[6] H.S. Lee, S.L. Chang "*Development of CAD/CAE/CAM integrated system for a robot manipulator*" Journal of Materials Processing Technology 2003.

[7] Han Sung Kim, "*Kinematic Calibration of a Cartesian Parallel Manipulator*", International Journal of Control, Automation, and Systems, 2005.

[8] Hayati S, Mirmirani M. "*Improving absolute accuracy of robot manipulators, J Robotic Systems"*, 1985.

[9] Henry W. Stone *"Kinematic Modeling, Identification, and Control of Robotic Manipulators",* 1987.

Books:

[10] Nagrath I. J. & Mittal R. K., *Robotics & Control*, TMH, 2005

[11] http://www.google.co.in

[12] http://www.wikipedia.org