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TRAJECTORY PLANNING OF 6 DOF ARTICULATED ROBOTIC ARM FOR LOADING AND UNLOADING OPERATIONS

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Abstract - This paper represents the trajectory planning for loading and unloading operations by articulated robotic arm.6-Axes Robotic Arm is a project based on designing of the robot arm with more number of axes. The arm has six axes and six degrees of freedom. The six degrees of freedom allows the robot to move in all the three dimensions. Servo motors are used as controlling elements for providing the different degrees of freedom to the robot arm. 6-axes robotic arm is useful for industrial applications like welding, painting, assembly, pick and place, product inspection and testing with great accuracy. Robotic arm has been widely used in manufacturing industry as part of automation system. Typical applications of robots in industry include welding, painting, assembly pick and place, packaging and palletizing, product inspection and testing.

The effectiveness of the proposed analysis was verified by comparing simulation and experimental results. Ten different scenarios with different number and pattern of obstacles were used to verify the efficiency of the entire path planning algorithm. Overall results confirmed the efficiency of the implemented methods for performing pick-and-place operations with a 6-DOF manipulator.

Keywords: Palletizing, freedom, manipulator, algorithm, servo, packaging, 6-DOF

Introduction: The word ‘robot’ has the origination in Czech dictionary word ‘robota’ meaning work. The perception of a robot as given in science fiction literature in the mid twentieth century is different from the present form of industrial robot which cannot move on its own but their physical pattern resembles the human arm. The industrial application & atmosphere are diverse in nature, frequent, complex, non-reachable or harmful to human being. In all this cases the robot can be an alternative to human hands. In this advanced technological world the skill, perfection, productivity and the speed with which the work has to be done influence the people making decision regarding introducing a robot for manufacture and manipulate efficiently.

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The articulated industrial robot is patterned to look like human hand with upper arm, fore arm and finger at the end. The chest and the arm are corresponded by the links in the manipulator. The robot joints represent the shoulder, elbow and the wrist. The robot fingers are called end-effectors which may be a tool or a gripper which is a holding device. The opening & closing or a movement can be a mechanical mechanism. The movement is programmed by a computer.

The goal of trajectory planning is to describe the requisite motion of the manipulator at a time sequence of point/link/end effectors location and derivatives of locations, which are generated by ’interpolating” or “approximating” the desired path by a polynomial function .The space curve that the manipulator hand moves along from an initial to final location is called path. These time base sequence locations, also called time law history obtained from the trajectory planning serve as reference input or “control set points” to the manipulators control system, in turn assures that the manipulator executes the planned trajectories. A systematic approach to the trajectory problem is to view the trajectory planner as box as shown in fig 1

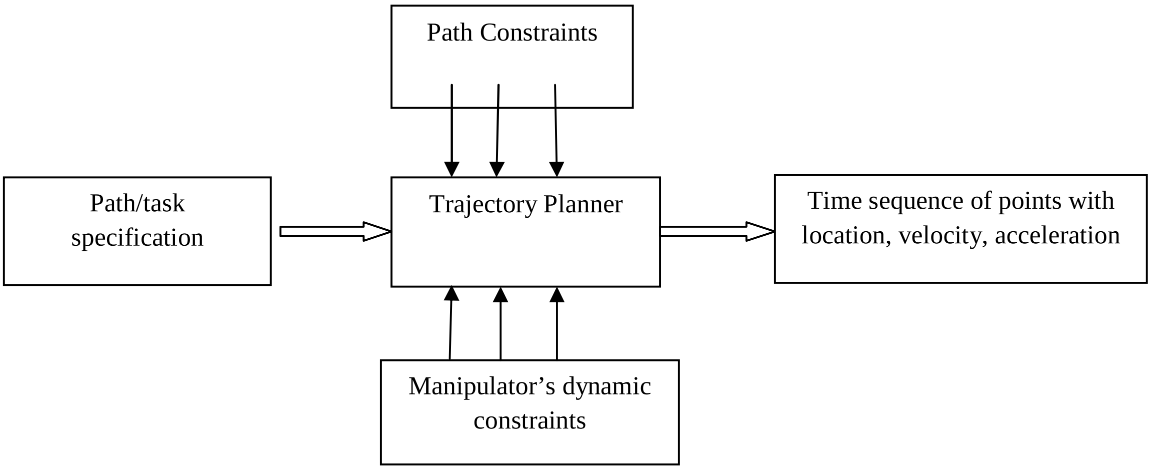

Fig: 1 Trajectory Planning Block Diagram

Overview of Industrial Robotics

There is a common delusion of electrical engineers that mechanical phenomena are simple because they are visible. They also had little training in the industrial engineer's realm of material handling, manufacturing processes, manufacturing economics and human behavior in factories. As a result, many of the experimental tasks in those laboratories were made to fit their robot's capabilities but had little to do with the real tasks of the factory. Modern industrial arms have increased in capability and performance through controller and language development, improved mechanisms, sensing, and drive systems. In the early to mid 80's the robot industry grew very fast primarily due to large investments by the automotive industry. The quick leap into the factory of the future turned into a plunge when the integration and economic viability of these efforts proved disastrous. The robot industry has only recently recovered to mid-80s revenue levels.

Tesla is better known as the inventor of the induction motor, AC power transmission, and numerous other electrical devices. Tesla had also envisioned smart mechanisms that were as capable as humans. These robots do not resemble the romantic android concept of robots. They are industrial manipulators and are really computer controlled "arms and hands". Industrial robots are so different to the popular image that it would be easy for the average person not to recognize one.

Benefits of Robotics: Robots offer specific benefits to workers, industries and countries. If introduced correctly, industrial robots can improve the quality of life by freeing workers from dirty, boring, dangerous and heavy labor. It is true that robots can cause unemployment by replacing human workers, but robots also create jobs for robot technicians, salesmen, engineers, programmers, and supervisors. The benefits of robots to industry include improved management control and productivity and consistently high quality products. Industrial robots can work tirelessly night and day on an assembly line without any loss in performance. As a result, they can greatly reduce the costs of manufactured goods. Because of these industrial benefits, countries that effectively use robots in their industries will have an economic advantage in global markets.

Robot Design Process

- Defining the Problem
- Identifying the purpose of a construction
- Identifying specific requirements

The need to determine what problem you are trying to solve before you attempt to design and build a robot to solve a problem. Take the time to study a number of different situations and once decided what the situation is and understand exactly what the problem is then write a design brief in a log book (this will be your working document as you work on your robot. This log book can be a paper notebook or an electronic document.) This is a short statement which explains the problem that is to be solved.

Research and Designing

- Gathering information
- Identifying specific details of the design which must be satisfied
- Identifying possible and alternative design solutions
- planning and designing a appropriate structure which includes drawings

Creating A Protoype

- Testing the design
- Troubleshooting the design

First ideally think of at least three different ways to solve the problem before concentrate on any one in particular. Sketches and notes are required at this stage. Create prototypes using Lego for this step. Once created a Lego prototype, take a digital picture of it. Print out the picture and notes. Once settled on one solution, go back over the list of specifications you have made. Make sure that each specification is satisfied. Now it the time to produce some working drawings. These are the drawings that will assist for constructing the prototype of your structure. Choose to do your drawings by hand or you might want to use a draw program on the computer to assist you.

Planning for Trajectory

First select the initial & final location of the tool tip, so that the velocity & acceleration can be decided for this particular location. Normally the initial & final locations are considered as zero. Normally there are two types of trajectory planning 1) joint space trajectory planning 2) Cartesian space trajectory planning. In joint space trajectory, trajectory is obtained in desired form by means of set of polynomial equation. In Cartesian space trajectory planning, trajectory is obtained in straight line form.

Problem Description

Pick-and-place operations can be performed by separating such operations into several tasks to be solved individually. It is also the number of independent inputs required to drive all the rigid bodies in the mechanical system. Examples:

- A point on a plane has two degrees of freedom. A point in space has three degrees of freedom.
- A pendulum restricted to swing in a plane has one degree of freedom.
- A planar rigid body (or a lamina) has three degrees of freedom. There are two if you consider translations and an additional one when you include rotations.
- The mechanical system consisting of two planar rigid bodies connected by a pin joint has four degrees of freedom. Specifying the position and orientation of the first rigid

body requires three variables. Since the second one rotates relative to the first one, we need an additional variable to describe its motion. Thus, the total number of independent variables or the number of degrees of freedom is four.

- A rigid body in three dimensions has six degrees of freedom. There are three translator degrees of freedom. In addition, there are three different ways you can rotate a rigid body. For example, consider rotations about the x, y, and z axes. It turns out that any rigid body rotation can be accomplished by successive rotations about the x, y, and z axes. If the three angles of rotation are considered to be the variables that describe the rotation of the rigid body, it is evident there are three rotational degrees of freedom.
- Two rigid bodies in three dimensions connected by a pin joint have seven degrees of freedom. Specifying the position and orientation of the first rigid body requires six variables. Since the second one rotates relative to the first one, we need an additional variable to describe its motion. Thus, the total number of independent variables or the number of degrees of freedom is seven.

Objective: Although up to eight joint configurations can be found for specific positions and orientations of the end-effector for the 6-DOF robotic arm, locations with singular configuration exist. Such singular configurations are known as singularities and are characterized by the loss of degrees of freedom in the system. The knowledge of these singular configurations is critical because these configurations may represent not just the boundary of the workspace, but also regions in which the end-effector presents motion difficulties. As such, the primary objective of the design is to have an instrument with a wrist, an 8 mm diameter instrument shaft to be able to fit in between the ribs, an actuated needle holder as the end-effectors, and an embedded 6 DOF force/torque sensor to measure the end-effectors' forces and torques. Suturing is the target surgical task for the system.

Formulation of Work

The aim of this project is to design the trajectory of 6 DOF robotic arm used for milling machine loading/unloading the part with better control & accurate positioning of the part. These equations are force-mass-acceleration and torque-inertia-angular acceleration relationship. These equations are also used to see the effect of different inertial load on the robot so, the dynamic equations allow us to investigate the relationship between different elements of the robot & design its component appropriately.

In this project work, the stages of robot trajectory design are carried out as follow:

1) Selection of mechanical design of links and joint: To design a robot which has to follow the pick & place activities, the robot has 6 rotary joint J1, J2, J3, J4, J5, J6 viz. base joint, shoulder, elbow, wrist1,pitch & wrist 2 and 6 links.
2) Calculation of joint torque at each joint: To calculate the joint torque at each joint we have to form Jacobean matrix at each joint by using the equation of arm dynamics and also we have to form force matrix which include the mass of each link, using these two matrix we calculate joint torque
3) Selection of 4-3-4 trajectory segment: It means we divide the trajectory in three segments, first segment is denoted by fourth order polynomial equation, second segment is denoted by third order polynomial equation & last segment is denoted by fourth order polynomial equation.
4) Calculation of velocity and acceleration at each joint: By considering joint space trajectory planning by knowing the joint angle and time required to reach this position at each joint we calculate the velocity & acceleration at each joint with the equation of 4-3-4 trajectory.

5) Development of program on c++: By using the equation of velocity, acceleration & torque we developed a program to calculate it. In this program the input is joint angle and the output is velocity, acceleration & torque.

Mechanical Description Of 6 Dof Robotic Arm

From fig 2, the stand point of load, the major joint of robot will be J1 since it carries the entire robot's mechanism in addition to the gripper & payload. J1 is the base joint of robot, it is the rotary twisted joint. This joint will require large servo motor to drive it. First axis it can revolve to 300° from -150° to +150°.The power transmission is carried out by timing belt drive through joint 1. J2is the second joint called as shoulder joint. it is rotary joint being the second axis, it can play an angle between 0 to150° J3 is the third joint called as the elbow joint, and it is a rotary joint, being third axis play 0 to 150°. Joint J4 is fourth joint called as wrist 1 joint. It can perform rotation up to 340° from 0 to 340°. Joint J5 is fifth joint called as pitch joint. An angle of 180° can be obtained from fifth axis which makes the robot flexible to pick & place the objects. Joint J6 is the sixth joint called as wrist 2 joint. The small additional wrist in place of the sixth axis will revolve up to 330° which gives much more flexibility to handle job.

Joint No.	Joint name	Joint type	Joint axis	Link length (mm)
1	Base	Twisted	Major	170
2	Shoulder	Rotary	Major	308
3	Elbow	Rotary	Major	320
4	Wrist 1	Twisted	Minor	89
5	Pitch	Rotary	Minor	80
6	Wrist 2	Twisted	Minor	78

Table1: mechanical description of robot ARM

Kinematic Parameters of 6 DOF Robotic Arm

The design of 6 DOF robot requires to develop arm equation for this link coordinate diagram is constructed. Once a set of link coordinates is assigned using the DH algorithm, we can then transform from coordinate transformation matrix by multiplying several of these coordinate transformation matrices together, we arrive at a composite coordinate transformation matrix which transforms or maps tool coordinate into base coordinates. This composite homogenous coordinate transformation matrix is called the arm matrix.

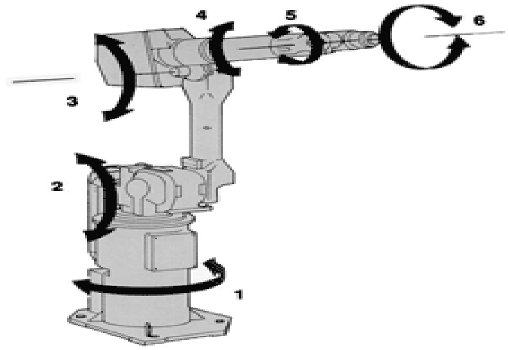

Fig: 2 Kinematic parameter of 6 DOF robot

The Arm Matrix

There are 4 steps involved in constructing the homogenous transformation matrix which maps frame i coordinates into frame i-1 coordinate as given below by transferring frame i-1 to frame i.

Operation	Description
1	Rotate L_{i-1} about by θ_i
2	Translate L_{i-1} about by d_i
3	Translate L_{i-1} along by a_i
4	Rotate L_{i-1} about by α_i

The composite homogenous transformation can be expressed follow:

$$T_{i-1}(\theta_i, d_i a_i, \alpha_i) = screw(d_i \theta_i, 3) screw(a_i, d_i, 1)$$

$$T_{i-1}^{i} = \begin{bmatrix} C\theta_i & -C\alpha_i S\theta_i & S\alpha_i S\theta_i & a_i C\theta_i \\ S\theta_i & C\alpha_i S\theta_i & -S\alpha_i C\theta_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & \alpha_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Where $C\theta_i = cos\theta_i, S\alpha_i = sin\alpha_i, C\alpha_i = cos\alpha_i, S\theta_i = sin\theta_i$

Where T_{i-1}^{i} denotes the transformation from coordinates frame to coordinate from i-1. In general, t denotes a homogenous coordinate transformation, the superscript being the index of the source coordinates frame and subscript being the index of destination. Since the robot is articulated robot, the vector of joint variable is θ.

Derivation of Arm matrix Equation of 6 DOF articulated loading/Unloading Robot:

Using above transformation matrix & kinematic parameters table we get the arm matrix of the 6 DOF loading/unloadingrobots by multiplying the six matrices representing the transformation between successive joints.

Therefore, final arm equation 6 DOF loading/unloading Robot is given by

$^{0}T_{6} = {}^{1}T_{0} \times {}^{2}T_{1} \times {}^{3}T_{2} \times {}^{4}T_{3} \times {}^{5}T_{4} \times {}^{6}T_{5}$

$= A_1 \times A_2 \times A_3 \times A_4 \times A_5 \times A_6$

Substituting all kinematics parameters of 6 DOF loading/unloading robot in homogenous Transformation matrix, we get following results.

$$A_1 = \begin{bmatrix} C_1 & 0 & S_1 & 0 \\ S_1 & 0 & -C_1 & 0 \\ 0 & 1 & 0 & 140 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} C_2 & -S_2 & 0 & 170C_2 \\ S_2 & C_2 & 0 & 170S_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_3 = \begin{bmatrix} C_3 & 0 & S_3 & 0 \\ S_3 & 0 & -C_3 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_4 = \begin{bmatrix} C_4 & 0 & -S_4 & 89C_4 \\ S_4 & 0 & C_4 & 89S_4 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_5 = \begin{bmatrix} C_5 & 0 & S_5 & 0 \\ S_5 & 0 & -C_5 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_6 = \begin{bmatrix} C_6 & -S_6 & 0 & 0 \\ S_6 & C_6 & 0 & 0 \\ 0 & 0 & 0 & 78 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

To get final matrix, we will multiply all matrices

$^{0}T_{6} = {}^{1}T_{0} \times {}^{2}T_{1} \times {}^{3}T_{2} \times {}^{4}T_{3} \times {}^{5}T_{4} \times {}^{6}T_{5}$

$= A_1 \times A_2 \times A_3 \times A_4 \times A_5 \times A_6$

$$\begin{bmatrix} C_{123} - C_1S_2S_3 & S_1 & C_{123} + C_1S_2C_3 & 170C_{12} \\ S_1C_2C_3 - S_1S_2S_3 & -C_1 & S_1C_2S_3 + S_{123} & 170S_1C_2 \\ S_2C_3 - C_2S_3 & 0 & S_{23} - C_{23} & 170S_2 + 140 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} C_{456} - S_{456} & -C_4C_5S_6 - S_4C_6 & C_4S_5 & 78C_4S_5 + 89C_4 \\ S_4C_5C_6 + C_4S_6 & -S_6S_4C_5 + C_4C_6 & S_4S_5 & 78S_5S_4 + 89S_4 \\ -S_5C_6 & S_5S_6 & C_5 & 78C_5 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Above equation is the final kinematics equation of 6 DOF articulated loading/unloading milling robot which give position & orientation and coordinate frame with respect to base coordinate frame of robot or reference coordinate frame of the robot.

Joint/axis	θ_i(Degree)	d_i(mm)	a_i(mm)	α_i
1	θ_1	140	0	90
2	θ_2	0	170	0
3	θ_3	0	0	90
4	θ_4	89	0	-90
5	θ_5	0	0	90
6	θ_6	78	0	0

Table: 2 Kinematic parameter of 6 DOF robotic ARM

Static Force Analysis

Robot may be under either position control or force control, Imagine a robot that is following a line , say, on the flat surface of a panel, and is cutting a groove in the surface. If the robot follows a prescribed path, it is under position control. So long as the surface is flat and as long as the robot is following the line on the flat surface. The groove will be uniform. However, if the surface has a slight unknown curvature in it, since the robot is following a given path, it will either cut deeper into the surface , or not cut deep enough

To relate the joint forces and the torque to forces and moment generated at the hand frame of the robot. We will define,

$[F] = [f_x\, f_y\, f_z\, m_x\, m_y\, m_z]$..................(1)

Where fx ,fy, fz are the forces along the x, y , z axes of the hand frame and mx, my, mz, are the moment about the x, y, z axes of the hand frame, similarly, we define,

$[D] = [d_x d_y d_z \delta_x \delta_y \delta_z]$..................(2)

Which, express displacement and rotation about x, y,z axes of the hand frame. We can also define similar entities for the joint as

$[T] = [T_1\ T_2 T_3\ T_4\ T_5\ T_6] \dots\dots\dots\dots(3)$

Which are the torque (for revolute joints) and forces (for prismatic joints) at each joint, and

$[D_\theta] = [d_{\theta 1} d_{\theta 2} d_{\theta 3} d_{\theta 4} d_{\theta 5} d_{\theta 6}]$……………..(4)

Which describe the differential movements at the joint, either an angle for revolve joint, or a linear displacement for a prismatic joint.

Using the method of virtual work , which indicate that the total virtual work at the joint must be the same as the total work at the hand frame, we get

$\delta w = [F][D] = [T][D_\theta]$……………….(5)

Or that force times the displacement at the hand frame is equal to the displacement at the joints.

Substituting this into equation (5) gives

$[F][J][D_\theta] = [T][D_\theta]$……………..(6)

$Thisequationcanberewrittenas$

$[T] = [F][J]$…………………(7)

This indicates that the joints force and the moment can be determined from the desired set of forces and moment at the hand frame.

Calculation of Mass at Each Joint:

To calculate the torque at each joint we have to calculate mass of each joint &Jacobean matrix for each joint. To calculate the mass of each link following procedure is followed:

For plain aluminum ρ=7800 kg/m^3

Volume=l.b.h=170x140x10= 2.38$\times 10^{-4} m^3$

Mass =$m_1 = \rho.v = 7800 \times 2.38 \times 10^{-4} = 1.85kg$

Same calculation can be done to calculate mass of each remaining link, which is summarized in following table:

Link length	Breadth of link	Height of link	Mass of link
170	140	10	1.85
308	128	10	3.07
320	156	10	3.89
89	50	10	0.34
80	50	10	0.312
78	50	10	0.304

Table: 3 Masses of each link

Calculation of Jacobean for 6 DOF robotic arm

A Jacobean is a vector derivative with respect to another vector. If we have a vector valued function of a vector of variables **f**(**x**), the Jacobean is a matrix of partial derivatives- one partial derivative for each combination of components of the vectors. The Jacobean matrix contains all of the information necessary to relate a change in any component of **x** to a change in any component of **f.** The Jacobean is usually written as J(**f**,**x**), for 6 DOF robotic arm Jacobean can be written as follow,

The complete Jacobean matrix is written as follow:

After placing the value of joint angle in above equation we get the value of final Jacobean matrix as,

$$J = \begin{bmatrix} -43.99 & -28.51 & -28.08 & 0 & 0 & 0 \\ 7.64 & -161.71 & -159.25 & 0 & 0 & 0 \\ 0 & -43.99 & -7.64 & 0 & 0 & 0 \\ 0 & -0.98 & -0.98 & -0.98 & -0.116 & -0.116 \\ 0 & 0.17 & 0.17 & 0.17 & -0.66 & -0.66 \\ 1 & 0 & 0 & 0 & -0.31 & -0.672 \end{bmatrix}$$

The force matrix for 6 DOF robotic ARM is written as:

$$F = \begin{bmatrix} 1.85 \\ 3.07 \\ 3.89 \\ 0.3471 \\ 0.312 \\ 0.3042 \end{bmatrix}$$

The torque at each joint is calculated by using the following equation

$[T] = [J] \times [F]$

$$\begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \\ T_6 \end{bmatrix} = \begin{bmatrix} -43.99 & -28.51 & -28.08 & 0 & 0 & 0 \\ 7.64 & -161.71 & -159.25 & 0 & 0 & 0 \\ 0 & -43.99 & -7.64 & 0 & 0 & 0 \\ 0 & -0.98 & -0.98 & -0.98 & -0.116 & -0.116 \\ 0 & 0.17 & 0.17 & 0.17 & -0.66 & -0.66 \\ 1 & 0 & 0 & 0 & -0.31 & -0.672 \end{bmatrix} \times \begin{bmatrix} 1.85 \\ 3.07 \\ 3.89 \\ 0.3471 \\ 0.312 \\ 0.3042 \end{bmatrix}$$

$$\begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \\ T_6 \end{bmatrix} = \begin{bmatrix} -278.13 \\ -1101.79 \\ -164.95 \\ -7.45 \\ -0.47 \\ 1.54 \end{bmatrix}$$

$T_{1=} -278.13\ NM$, $T_{2=} -1101.79\ NM$, $T_{3=} -164.95\ NM$, $T_{4=} -7.45\ NM$, $T_{5=} -0.47\ NM$, $T_{6=} 1.54\ NM$

Joint No.	θ 8	d_i	a_i	α_i	Torque(Nm)
1	80	140	0	90	-278.13
2	75	0	170	0	-1101.79
3	80	0	0	90	-164.94
4	45	89	0	-90	-7.45
5	20	0	0	90	-0.47
6	50	78	0	0	1.54

Table: 4 joint and torque at each angle

Result & Discussion: In this project to design the trajectory of 6 DOF robotic arm, mechanical design of joint & link is selected and static force analysis is performed to calculate the Torque of each Joint. To calculate the Torque, we developed the Jacobean matrix is developed at the robotic arm similarly force matrix is calculated by observing the value of torque we select the suitable rating servo motor at each joint.

Discussion: From control point of view, the movement of a robot arm is usually done in two distinct control phases. The first is gross motion control in which the arm moves from an initial position to the vicinity of the desired target position/orientation along the planned trajectory. The second is the fine motion control in which the end effector of the arm dynamically interacts with the object using sensory feedback information to complete the task. This program is very useful for 4-3-4 trajectory segment to calculate the velocity, acceleration & torque at each joint directly by entering the value of position of each joint which will minimize the time of calculation at each joint. This program is also useful for precise & accurate result of trajectory planning for 6 DOF robotic arm. We can also use this program while microcontroller programming.

Conclusion

In the trajectory planning of 6 DOF robotic arm, the most important thing is the smoothness of the path, because, if the path of the robot makes robot tilt or crash, or if the robot makes dangerous movements, there is no meaning to make trajectory planning or path generation. In the method used, the smoothness is the key point. Besides starting and ending points, via points are determined and the robot has to be passed from these points. In this trajectory planning method, we used the 4-3-4 trajectory segment time must be given as the input to it, the value of velocity, acceleration & torque are calculated and we get maximum torque at joint 1108.40 NM and hence by using specification chart of motor catalogue for servomotor we select the Aneheim Automation Model,34K2 motor for this joint. The stability of the polynomial decreases when the value of degree of the polynomial increases. The programmed developed in C++ is also useful for calculation of velocity, acceleration & torque at each joint. The value of torque at different joint & motor selected are as follow:

Joint	Maximum torque required	Motor selected(Aneheim Automation Model)	Motor maximum rating
1	278.137.45	42N3	308.26
2	1101.79	34K2	1108.40
3	164.95	23L1	168.89
4	7.45	17Y4	8.06
5	0.47	17L1	0.68
6	1.68	14Y1	1.76

Table:5 Joint Motor selection

Scope of Future Work: The future work of this project includes trajectory planning Cartesian space. By considering Cartesian space we can plan the desired path trajectory by considering boundary condition, and same trajectory can be shown by using simulation software which will provide actual working of the trajectory.. The optimization is considered in the trajectory planning. In fact, some optimization criteria may be considered, such as, minimum time or minimum energy. This criterion avoids us to apply minimum energy optimization. Time optimization in this method is also very lengthy subject for this trajectory planning method and it can be the future work. The robot joints are driven by the actuator which acts on the command signal issued to follow the desired input & to produce the required output. This process is known as robot control problem. The joint forces are equated to the differential equation representing the control law with mass, friction damping & stiffness partitions. Based on the control law, the system response & the performance are determined.

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