# Design analysis and Implementation of a Robotic Manipulator

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***Abstract-*** *Humanoid robotic modules have become indispensable in the engineering sector because of its ability to relieve human workers from performing unpleasant, hazardous or too precise job more recursively. A robotic manipulator is a physical structure that resembles a human arm which functions perfectly when designed according to the requirements taking into consideration all the constraints. Apart from having the exact physical structure like the human arm form it is more important that the manipulator must be efficient enough to have human like behavior regarding the movement and balance. This particular paper discusses in detail the designing perspective of a robotic manipulator including the hardware module of the robotic arm. In addition to the hardware model of a robotic manipulator, the design details are also presented in this paper.*

***Keywords***- Degrees of freedom, End effector, Interlocking, Kinematics, torque.

## I. INTRODUCTION

A robot is a mechanical or virtual agent, usually an electro-mechanical machine that is guided by a computer program or electronic circuitry. Robotics deals with the automated machines which can take the place of humans in dangerous environments or resemble humans in appearance, behavior, and cognition or the manufacturing processes. Three main laws associated with robotics were formulated by Asimov.

Asimov Laws in Robotics:

First law: A robot may not injure a human being or through inaction, allow a human being to come to harm.

Second law: A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.

Third law: A robot must protect its own existence as long as such protection does not conflict with a higher order law.

Manipulators are devices that reduce direct human interaction in the field. Manipulators could be engaged to move heavy weighted objects as well as minute particles based on its degrees of freedom. It consists of arm like structure with series of joints and linkers. These arms could be controlled by pre-programmed software or by compressed air or water. Robotic manipulator consists of four important parts. They are linkers, joints, actuators and end effectors.

Linkers and joints -- Linkers are the solid structural members of a robot, and joints are the movable couplings between them. Joints are the ones which can permit relative movement. Joints are designed to move the robot from one position to another desired position. The basic movements required for the desired motion of the most of the industrial robots is rotational movement, radial movement, and vertical movement. The joints permit only angular motion between the linkers. The joints are mainly classified into linear joints, orthogonal joints, and rotational joint, twisted joint and revolving joint.

Actuators – Actuators are the controlling part of the robots. Actuators work based on the signal from the controller. It actuates the linkers to move to the desired position. Linear actuators have a cylinder and piston for in/out movement. Pneumatic actuators and hydraulic actuators are sub categories of linear actuators. Pneumatic actuators convert compressed air/ vacuum into mechanical energy. It is suitable for engine control since it does not store any power. Hydraulic actuators convert hydro power into mechanical operation. The drawback of this actuators is its limited acceleration.

End effector – End effector, the device at the end of the could be either a gripper to pick and place or a tool to do a specific task. Robotic gripper falls into four categories namely mechanical type, magnetic type, needle and vacuum type. Mechanical type of grippers works with help of pneumatic/hydraulic/servo electrical force. Its action is similar to the human fingers. Magnetic gripper uses magnets to hold the magnetic objects alone. Needle type grippers holds the object by penetrating into the object. This may cause damage to the object it holds, so these type of gripper are used in rare cases. The final vacuum type of gripper uses suction force to hold the object by suction cup.

Several researchers have analyzed the designing aspects of manipulators.

[1] focuses to control the end effector of the robot arm to achieve any accessible point in an amorphous region using LabVIEW, ARM, microcontroller and Dexter ER2 robotic arm. LabVIEW uses analytical method to design the inverse kinematic model of the robot arm.

[2] provides a method to design a robotic arm, synchronized with the working arm performing the task as the working arm does. The work done by the robotic arm would be highly precise, as a digital servo motor is used.

[3] shows the design theory of a robotic arm with 4 degrees of freedom to accomplish accurately simple tasks, such as light material handling, integrated into a mobile platform which serves as an assistant for industrial workforce.

[4] describes the design, fabrication and analysis a five axes articulated robotic manipulator.

[5] provides an analysis of a generic articulated robotic arm. A novel joint actuation scheme is described with its implementation is detailed in this paper.

## II. DESIGN THEORY

It's the A robotic arm is made up of similar individual joints. Unless the distance between any two links remains constant, the design of a rigid arm is not feasible. Physical constraints on the relative motion between the links are wholly attributed to the joints. A joint is the one which couples two links. It is responsible to specify how one link moves with respect to another. Several types of joints are used in the design of an arm. They include Prismatic joint, helical joint, spherical joint and planar joint.

### A. Degree of freedom:

One of the major terminologies to be considered for the design of any type of manipulator is the estimation of the number of degrees of freedom. A degree of freedom [DOF] exactly gives the number of co-ordinates that are independent. The minimum number of co-ordinates required to fully describe a pose or configuration of any robotic module is termed as the degree of freedom of that particular module.

Degree of freedom could be determined by various methodologies. The methodology used in common is the Grubler - Kutzbach criterion.

It's given as

$$n = s(r - 1) - c \quad \ldots\ldots (1)$$

Where $c = \sum_{i=1}^{p} Ci$

(-1) in the above equation is given to indicate the fixed link of the system which has a degree of freedom of zero value.

n= DOF of the entire system

s=working space dimension

r=number of links in the entire system

p= number of joints in the system

c=total number of constraints imposed by all joints

$s = ci + ni \quad \ldots\ldots (2)$

ci = number of constraints imposed by each joint

ni = relative degree of freedom of each joint

Now, the total number of constraints is given by,

$$c = \sum_{i=1}^{p} CI = \sum_{1=1}^{p} (S + n_i)$$

$$= Sp - \sum_{i=1}^{p} ni$$

$$n = s\,(r-p-1) + \sum_{i=1}^{p} ni \quad \ldots\ldots (3)$$

The end effector plays a vital role in a robotic manipulator. Whatever be the type of end effector, it is necessary to control the end effector with respect to the base. The relation between the co-ordinate frames attached to the end effector and the base of the manipulator is of very much necessity in order to control the end effector. The co-ordinate transformation between the co-ordinate frames forming the overall description in a recursive manner is the key factor to estimate the relation between the co-ordinate frames and the manipulator frames.

### B. Rigidity and Stability:

The mechanical design of a robotic manipulator is more efficient when the rigidity and the stability of the arm is achieved perfectly. The rigid pose of a robotic manipulator deals with the position and orientation of several bodies or parts that make up the manipulator module. The position is computed from the position vector ‘p’. The orientation could be described in two different ways namely the direct cosine representation and the Euler angle representation.

The four major Denavit and Hartenberg [DH] parameters are joint angle, link length, joint offset, twist angle. The link frames whose position and orientation are specified by using these DH parameters are known as DH frames. Among the above mentioned four DH parameters the link length and the twist angle remain constant and same throughout. The other two parameters define the relative position of the particular link and the link to which it is previously connected to.

The co-ordinate transformation representing the position and the orientation of the end effector is obtained from position vectors. It is given by

$[P]f = [O]f + Q [P'] M$

**C. Dynamics and Kinematics:**

Controlling a manipulator describes precisely controlling each joint. Controlling of each joint is wholly dependent on the knowledge of the forces acting on the joint and the torque developed at these joints.

Generally, for any axial manipulator, the forces on each of the link should be balanced to be equal.

**D. Torque Calculation:**

Torque could be defined as the amount of force acting on any object causing the rotation of that object. It is implied that

$T= F X L$…………………………………. (5)

T= torque
F= calculated force
L= length between two joints.
According to Newton's second law,
$F=M*a$
M=mass of the link
a= Acceleration due to gravity.

Here the force could be considered as the weight
(i.e.) $W=M*a$

Hence the total torque equation is given as
$T= (M*a)*L$

Thus the torque balance at any point is directly dependent on the weight and length of the link. This equation is applied to each joint to estimate the torque at all the joints.

The torques at each point is given by the vector cross-product of the forces and the link vectors 'r'.

Thus for any given force vector, F= (Fx, Fy), each joint needs a torque to generate that force. Thus torque for a two axial manipulator could be given by the following equations.

$T1 = [L1\cos\theta1 + L2 \cos(\theta1 + \theta2) +$
$L1 \sin\theta1 + L2 \sin(\theta1 + \theta2)] * (fx, fy)$ …………………. (6)
$T2= L2\cos(\theta1 + \theta2) * Fx – L2 \sin(\theta1 – \theta2) *F$……… (7)

Thus the forces generated at the tip of the arm provided with the above mentioned torques at the joints are given by

$$Fx = \frac{T1\, L2 \cos(\theta1 + \theta2) - T2\,(L1 \cos\theta1 + L2 \cos(\theta1 + \theta2))}{L1\, L2 \sin\theta2}$$

$$Fy = \frac{T1\, L2 \sin(\theta1 + \theta2) - T2\,(L1 \sin\theta1 + L2 \sin(\theta1 + \theta2))}{L1\, L2 \sin\theta2}$$

These equations have been formulated after performing the trigonometric calculations. Inertia of a robotic arm depends upon the position and orientation of the links with respect to the base.

## III. DESIGN CONSIDERATIONS

The major part of pick and place robot is its end effectors. There are three major types of end effectors usually employed for pick and place action. The vacuum type and magnetic type has same appearance - both grasp the product from the top and moves it to another place. The mechanical type end effector act like human hand. Controlling a mechanical gripper requires proper motors with high accuracy and can be applicable for any type of application irrespective of type of product. Thus, in this design, mechanical gripper is chosen as the end effector.

The next consideration is the number of fingers needed. In general, two fingers are used more than three fingers can also be 7used based on the application. Basically fingers are for holding actions and they can be easily removed or replaced. The power produced from the actuators can be sent to the fingers for opening and closing in addition a significant force is need for holding action.

Poly methyl methacrylate is also known as acrylic sheet. It is a light weight and cost effective material. The acrylic sheet is used as an alternative to glass because of its advantages. There are various other materials available that can be opted for arm construction like metal, metal alloy, plastic, glass etc. depending upon the area of application.

The acrylic sheet chosen here is 3mm transparent sheet. The acrylic sheet is used because of its easy handling, processing and cost. This sheet is similar to polycarbonate except the absence of harmful Bisphenol-A. Acrylic sheet can be scratch and impact resistant. This type of sheet is used in order to reduce the load on the motor so that the efficiency of the entire manipulator is increased. Also the manipulator built using this can be put in to use at different areas irrespective of the environment.

The next important part of the manipulator is actuator. As discussed earlier there are various kind of actuator in which electrical type actuators is chosen for this design. In electrical type there are several motors suitable for this application like DC gear motor, servo motor, stepper motor, etc. The motor will vary depending upon the area of application and type of product it is going to lift. Important consideration for motor selection is the weight, force and torque it produces. Depending upon the necessity this project considered two servo motors with model number S3003 and SG90 micro servo motors.

S3003 servo motor is a plastic gear type servo motor with pulse width modulation. The minimum torque is 3.17kg-cm and maximum torque is: 4.10kg-cm for the voltage supply of 4v and 6v respective. The weight of the motor is 37.2g and it has the maximum rotation of 180'. This motor is used in the design for base and linkers movement.

SG90 micro servo motor is a plastic gear type servo motor with pulse width modulation. The torque is 2.5 kg-cm for the supply voltage of 4.8v to 6v. The weight of the motor is 14.7g and its can rotate up to 180'. The gripper movement is actuated with this motor.

The final part of this manipulator is controller i.e. a control system that sends PWM signal to the motor based on the requirement. There are various types of controller available like Arduino, raspberry pi, LabVIEW, scilab, etc. in market. Based on the memory and application controller is selected.

## IV. DESIGN DESCRIPTION

The basic design drafted was aimed to rotate the base to 180o, two linkers to move up and down and to have a mechanical gripper as the end effector. The two linker were designed to be of 5 inches each. A joint of 1-inch length was used to connect these linkers. A two fingered mechanical gripper with pivot movement and screw actuator was used. The motors for the respective movement of these linkers were placed in the corresponding linkers. Pivot movement of the manipulator is done through the linkage mechanism. The respective screw actuation is given through two screws at either side. The major issues in this design were the position of each linker, the gripper and the motors. Movement of one of the linkers should not affect the other linkers or joints. If not, there arises the issue of interlocking of motors. Interlocking is a state in which the connection should be in such a way that the latter motor must not start until the motor preceding it starts. This problem of interlocking was found to be predominant due to the placing of motors in the respective linkers.

This issue of positioning the motor was well solved when the decision was made to place the motors of all linkers in the base itself. The control action was performed with the help of joints.

This proposed design after implementing the solutions to these design problems is built using five servo motors. The design of the base and the linkers remain the same as the previous one except for changes in the position of controlling motors. The base and the servo motors are connected with a help of a ball bearing for smooth turning. Thus, the rotation of the base causes the entire manipulator along with all the linkers and gripper to have free rotational movement. Separate motors have been fixed in the base for the linkers movement. Thus each linker is aimed to move up to 180o. All the motors are set at the base of the manipulator as shown in Fig 1 and joints for the linkers are given as extra accessories.

Fig 1: Designed manipulator

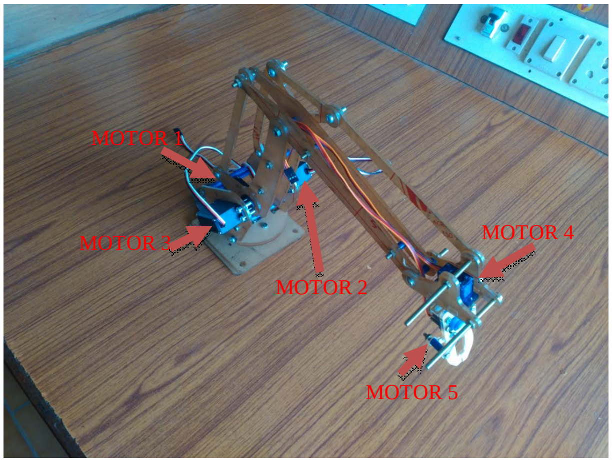


Fig 2: Positioning of motor

Mechanical gripper is used as the end effector in order to pick and place objects. Two servo motors are used for the gripper action alone. One for the finger movement and the other for the circular rotation of the gripper.The opening and closing of the finger of the gripper requires pulses applied in opposite directions to each other to accomplish the action. The rotational movement of the gripper is effected through the second motor which aids in pick and place action. The up-down movement of the gripper could be accomplished by the usage of an additional motor. This becomes mandatory only in circumstances where it is required to hold the objects from top too. The positioning of the motors as explained has been shown in Fig 2.

Simulation design of this manipulator is built using an open source software named Qcad, a computer Aided Design software developed by Ribbionsoft.

## V. CONCLUSION

The major constraints involved in designing a manipulator have been detailed in this paper clearly. This manipulator is designed to have a mechanical gripper for pick and place option. This manipulator could be employed in the industrial sector when interfaced with a suitable controller. This paper thus provides reliable solutions to all the constraints of load calculation, torque calculation, weight reduction, rigidity and stability, kinematics of the manipulator and finally the interlocking of motors. This manipulator is mainly aimed to aid the small scale industrial sectors which demand heavy cost reduction. Future enhancement could be the automation of this arm for various picking and placing option using a suitable controller.

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