Design, Development and Kinematic Analysis of a Low Cost 3 Axis Robot Manipulator

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Abstract: The monotonous tasks carried out in the industry require the need for a cost effective system that simplifies the work in material handling of complex parts. The main focus of this work is to design, develop and carry out the kinematic analysis on the low cost 3 axis robot to check its feasibility for the above mentioned requirement. The robot arm is designed with three degrees of freedom and intended to carry out simple tasks like material handling of complex shaped parts stationary or moving in a conveyor. The robot arm is equipped with several servo motors which will perform the required arm movements. The proposed model makes it possible to control the manipulator to achieve any reachable position and orientation in the structured environment. The forward kinematic model is predicted based on Denavit Hartenberg (DH) parametric scheme of the robot arm position placement. The Inverse kinematic equation is used to calculate the workspace of the robot arm. The robot is designed in such a way that it can safely lift the load up to 0.5 kg.

Keywords: 3 Axis Robot, Interchangeable Two fingered gripper, Complex Parts, Low cost automation

1. Introduction

The robot arm was designed with four degrees of freedom and talented to accomplish accurately simple tasks, such as light material handling, which will be integrated into a mobile platform that serves as an assistant for industrial workforce. The robot is controlled using Lab VIEW, which performs inverse kinematic calculations and communicates the proper angles serially to a microcontroller that drives the servo motors with the capability of modifying position, speed and acceleration. [1]. A 5-axes articulated robot was designed with indigenous components and a brief kinematic modeling was performed and using this kinematic model, the pick and place task was performed successfully in the work space of the robot. A user friendly GUI was developed in C++ language which was used to perform the successful robotic manipulation task using the developed mathematical kinematic model. The developed kinematic model also incorporates the obstacle avoiding algorithms also during the pick and place operation [2].Forward kinematic model has been presented in order to determine the end effector's position and orientation. The analysis is useful for path tracking of an industrial manipulator with 'pick-and-place' application. The path tracking is possible to predict the behavior of an end Effector in complicated work space [3]. The forward kinematic model has been validated using Robotics Toolbox for MATLAB while the inverse kinematic model has been implemented on a real robotic arm [4]. A creative approach to designing industrial grippers by using the kinematic structure database, which contains general information about the robot gripper mechanism, kinematic structures, function, type of drive mechanism and application is presented [5-6]. A classification system for grippers has been developed based on factors such as size, position and orientation of gripping force. This method is used to determine additional design constraints based on the final installation and activities that the robot would be performing under different load conditions [7-8].

2. Conceptual Design

The Robot is designed with simple mechanical elements having 3 DOF provided with interchangeable mechanical gripper. The robot linkages are independently operated by servo motor interfaced with the suitable software like LabVIEW. The payload capacity of the robot is around 0.5 kg.

2.1. Free Body Diagram of the Robot Structure

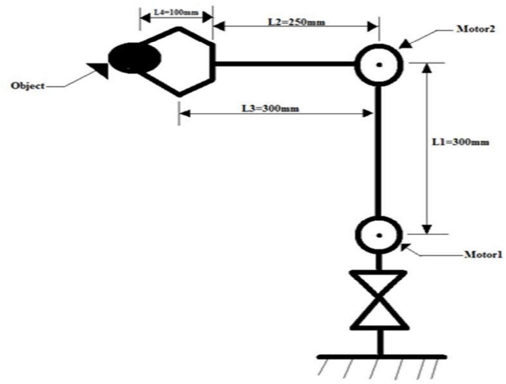

Figure.1. Free Body Diagram of the Robot Structure

2.2. Robot Arm 3d Model

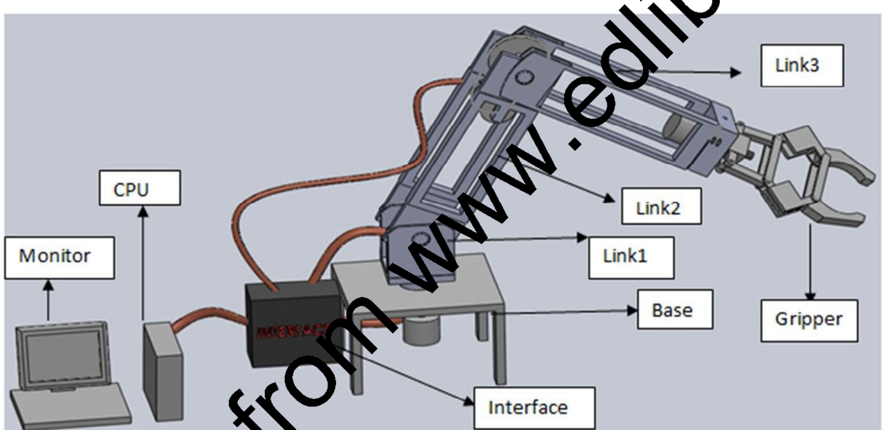

Figure.2. 3D Model of the developed 3 Axis Robot

3 Kinematic Analysis of the Robot Arm

The robot is modelled considering the kinematics involved in the robot movement. The maximum limit movements for each arm is assumed and based on that values, the work space with in which the robot can be operated is calculated for its effective functioning in the expected working environment

3.1. Kinematic Parameter Values of the Developed Robot

Table 1: DH Parameters

Link	Angular Movement (θ_i)	Length of the Arm a_i (mm)
1	θ_1=270°	0
2	θ_2=90°	300
3	θ_3=90°	200

 ISBN : 978-81-929742-0-0

3.2. Work Region of the Developed Robot Arm

Based on the degrees of the freedom and the limits up to which the arms can be moved along with the gripper, the maximum working space is calculated in 2D and 3D environment.

3.2.1. Predicted Workspace of Robot Arm in 2D

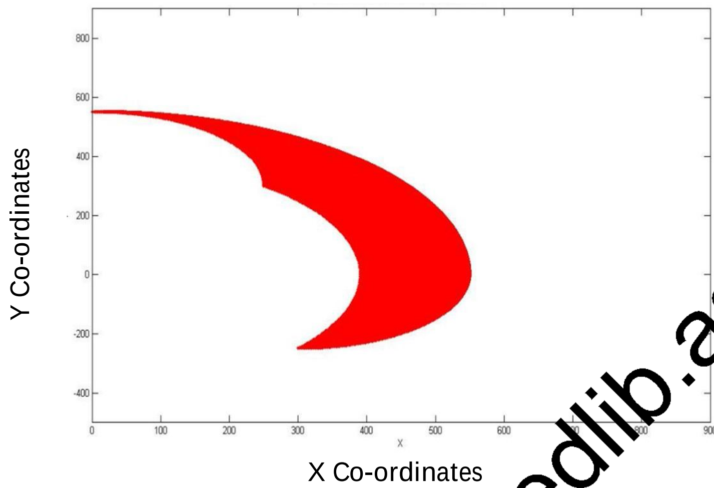

Figure.3. 2D Workspace of the Robot

3.2.2. Calculation of Work Space for the Robot Arm

To calculate the position of the End effecter, Inverse Kinematics is used. θ_1, θ_2 are the limits of the Link1 and Link2. When θ_1& θ_2 values are given in the Equation (1), respective X values are calculated during the movement. Similarly when θ_1& θ_2 values are given in the Equation (2), respective Y is calculated. The increment values for θ_1 and θ_2 are done by 0.01.

θ_1 = (0): 0.01: (1.57) [in radians]
θ_2 = (-1.57):0.01: (0) [in radians]

$$X = l_1 * \cos(\theta_1) + l_2 * \cos(\theta_1 + \theta_2) \quad (1)$$

$$Y = l_1 * \sin(\theta_1) + l_2 * \sin(\theta_1 + \theta_2) \quad (2)$$

3.2.3. Predicted Workspace of Robot Arm in 3D

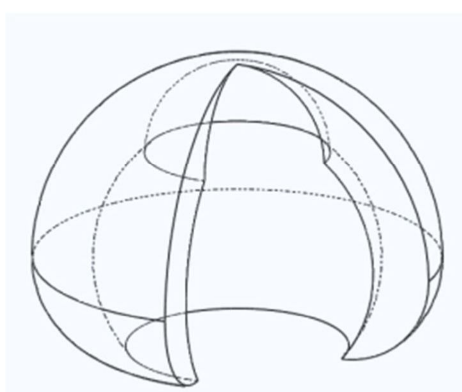

Figure.4. 3D Workspace of the Robot

3.3. Anatomy of the Robot Arm with Load Condition

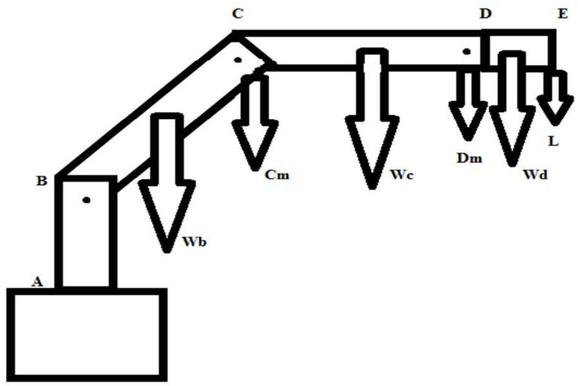

Figure 5.Various Loads acting in the Robot Arm

3.4. Calculation of Moments and Forces Acting on Various Locations of the Robot Arm and Selection of Motor Drive System

Expected Load Carrying Capacity =0.5kg

3.4.1. Assumptions

Weight of the motor 1 (W_1) = 0.3Kg;
Weight of the motor 2 (W_2) = 0.3Kg;
Weight of the motor 3 (W_3) = 0.3Kg;
Weight of the object along with gripper (W_4) = 1.25Kg
Motor speed (N) =10rpm
Angular Velocity (w) =2πN/60 = ((2*3.14*10)/60) = 1.05 rad/s
Link angle (θ) = 90° = 1.57 rad

3.4.2. Calculation of Torque for Motor 2

$M_2 = (L_2/2) * W_3 + L_3 * W_4$
= (0.3/2)*0.3+0.35*1.25
= 0.4825Kgf m
= 4.9215Nm

3.4.3. Calculation of Torque for Motor1

$M1 = ((L_1/2)*W_1) + (L_1*W_2) + ((L_1 + (L_2/2))*W_3) + ((L_1+L_3)*W_4)$
= (0.15*0.3) + (0.3*0.25) + (0.45*0.3) + ((0.3+0.35)*1.25)
=1.0675Kgf m
=10.888Nm

3.4.4. Calculation of Additional Torque required to Move Gripper along with Maximum Load

T = I*α
Where, I – moment of Inertia, α – acceleration, w -angular velocity, T_a – Additional Torque
I = (m*r*r)/2 = (0.3*0.3*0.3)/2 =0.0135Kg.m^2
α= w / 2θ = (1.05/2*1.57) = 0.325

T_a=4.39 X10^{-3} Nm
T_1=11Nm (Approx)
Similarly, for motor2
T_2=5Nm (Approx)

4. Conclusion

In this work a low cost 3 axis robot is designed and proposed to justify its suitability for carrying out simple material handling of complex shape parts. The robot working behaviour is predicted for its payload capacity, work space flexibility and the movement of various arms within the work zone based on the kinematics model. Based on the load conditions and forces acting on the robot, the proposed robot has the capability of handling the complex components stationary or moving in a conveyor with a payload capacity of around 0.5 kg.

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