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Kinematic analysis and model development of TRL: R mechanism

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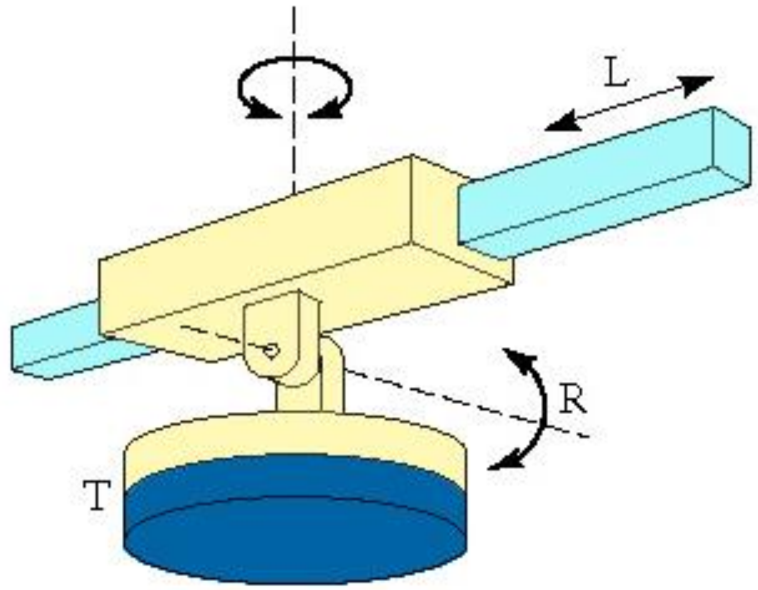
Abstract: A robotic arm is a mechanical arm which is designed to perform a function similarly as a human arm does. It is usually programmable and arm may be a sum total of the mechanism or can be part of a complex robot. To design a robot, various links are being connected by joints allowing either a translational (linear) motion or a rotational motion in various planes. In many cases sensors are used in the arm that usually indicates the controller about the hardness by which the gripping is done by arm or directs the arm in directions in which it should move to perform the task or it tells the system about presence of object in front of it. The selection of electrical components used in the robotic arm is also taken into account by calculating the inverse kinematic and forward kinematic of this robotic arm movement. Besides that, the forces exerted on the robotic arm are also calculated to ensure the mechanical components of the robotic arm is not easily broken or damaged. Referring to the result obtained, a robotic arm resistance depends on the motor used. Therefore, the compatibility of motor torque with the robotic arm design is made is important because it affects the stability of the robotic arm. Testing and validation of the robot arm was carried out and results shows that it work properly.

Key words: Robot arm, TRL: R configuration, Kinematic analysis, Four degree of freedom

I. INTRODUCTION

The term robotics is practically defined as the study, design and use of robot systems for manufacturing. Robots are generally used to perform unsafe, hazardous, highly repetitive, and unpleasant tasks. They have many different functions such as material handling, assembly, arc welding, resistance welding, and machine tool load and unload functions, painting, spraying, etc. There are mainly two different kinds of robots: a service robot and an industrial robotic. Service robot is a robot that operates semi or fully autonomously to perform services useful to the well-being of humans and equipment, excluding manufacturing operations. Industrial robot, on the other hand, is officially defined by ISO as an automatically controlled and multipurpose manipulator programmable in three or more axis. Industrial robots are designed to move material, parts, tools, or specialized de- vices through variable programmed motions to perform a variety of tasks. An industrial robot system includes not only industrial robots but also any devices and/or sensors required for the robot to perform its tasks as well as sequencing or monitoring communication interfaces.

Figure shows a TRL configuration. This is also known as the polar co-ordinate robot. A robot with this geometry has three axes of motion that trace the shape of a sphere. It has a base unit that rotates, a main body that tilts, and arm that slides in and out.



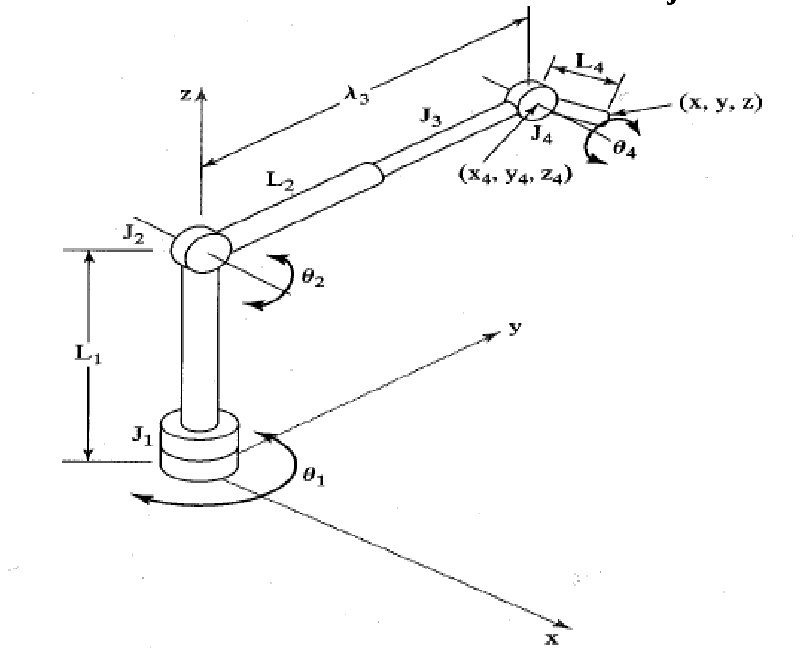
"Figure 1 TRL: R mechanism"

Figure shows a schematic diagram of TRL: R mechanism. It Consider four joints which are, Joint 1 (T type) provides rotation about Z-axis, Joint 2 (R type) provides rotation about a horizontal axis whose direction is determined by joint 1, Joint 3 (L Type) is a piston that allows linear motion in a direction determined by joints 1 and 2. In this configuration there are two types of joints, one is a active joints and second is a passive joints. Active joints are those joints which are driver of the system and passive joint means which are driven of the system. Here first and second joints are an active joint and other two are passive joints.

1.1 What do you mean by Kinematic Analysis?

Kinematics is the description of motion without regard to the forces that cause it. It deals with the study of position, velocity, acceleration, and higher derivatives of the position variables. The kinematics solutions of any robot manipulator are divided into two solutions, the first one is the solution of Forward kinematics, and the second one is the inverse kinematics solution. Forward kinematics will determine where the robot's manipulator hand will be if all joints are known. Where the inverse kinematics will calculate what each joint variable must be if the desired position and orientation of end-effector is determined. Hence, Forward kinematics is defined as transformation from joint space to Cartesian space where as Inverse kinematics is defined as transformation from Cartesian space to joint space.

1.1.1 Forward and backward transformation for a robot with four joints in three dimensions



"Figure 2 schematic diagram of TRL: R configuration"

Consider the four degree-of-freedom robot shown below. Its configuration is TRL: R. Joint 1 (T type) provides rotation about Z-axis, Joint 2 (R type) provides rotation about a horizontal axis whose direction is determined by joint 1, Joint 3 (L Type) is a piston that allows linear motion in a direction determined by joints 1 and 2, Joint 4 (R type) provides rotation about an axis that is parallel to the axis of joint 2.

Solving forward kinematic for TRL: R mechanism:
In the above figure, we want to find out what the coordinates of end effector are a simple geometric method, the values of the four joints are, respectively,.θ1, θ2, λ3, and θ4.

$X=\cos\theta_1 (\lambda_3\cos\theta_2+L_4\cos\alpha)$ (1)

$Y=\sin\theta_1 (\lambda_3\cos\theta_2+L_4\cos\alpha)$ (2)

$Z= L_1+ \lambda_3\sin\theta_2+L_4\sin\alpha$ (3)

Where $\alpha = \theta_2+ \theta_4$ (4)

1.2 Inverse Kinematics

Inverse kinematics is the opposite of forward kinematics. This is when you have a desired end effector position, but need to know the joint angles required to achieve it. In contrast to the forward problem, the solution of the inverse problem is not always unique: the same end effector pose can be reached in several configurations, correspond position vectors. Although way more useful than forward kinematics, this calculation is much more complicated too.

The problems in IK:
- There may be multiple solutions,
- For some situations, no solutions,
- Redundancy problem.

Solving the Inverse Kinematics for TRL: R mechanism:-
Although way more useful than forward kinematics, this calculation is much more complicated. In the backward transformation, we are given the world coordinates X, Y, Z, and α. Where α specifies orientation. To find the joint values, we define the coordinates of joint 4 as follows:
For finding an orientation of end effector, first find out the base angle,
$\tan\theta_1 = \frac{Y}{X}$ (5)
After that we find out the position of joint 4,
$X_4 = X - \cos\theta_1 (L_4 \cos\theta_4)$ (6)
$Y_4 = Y - \sin\theta_1 (L_4 \cos\theta_4)$ (7)
$Z_4 = Z - L_4 \cos\theta_4$ (8)
Now, the total link length between the joint 2 and 4,
$\lambda_3=\sqrt{X_4^2 + Y_4^2 + (Z_4 - L_1)^2}$ (9)
Now, the final calculation for find out the orientation angle of joint 2 and joint 4.
$\sin\theta_2 = Z_4 - L_1 / \lambda_3$ (10)
For θ_4 we know that, from the eq. (4)
$\alpha = \theta_2 + \theta_4$
Therefore, $\theta_4 = \alpha - \theta_2$

1.3 The values used for the torque calculations:-

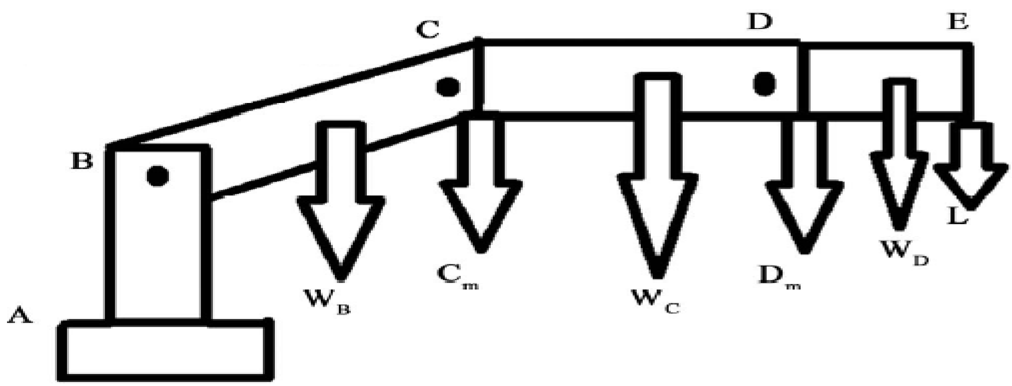


Figure 3 Force diagram for robot arm

Where, the values used for the torque calculations:
W_D = weight of link DE
W_C = weight of link CD
W_B =weight of link CB
L = load
$C_m = D_m$ = weight of motor
L_{BC} = length of link BC
L_{CD} = length of link CD

L_{DE} = length of link DE

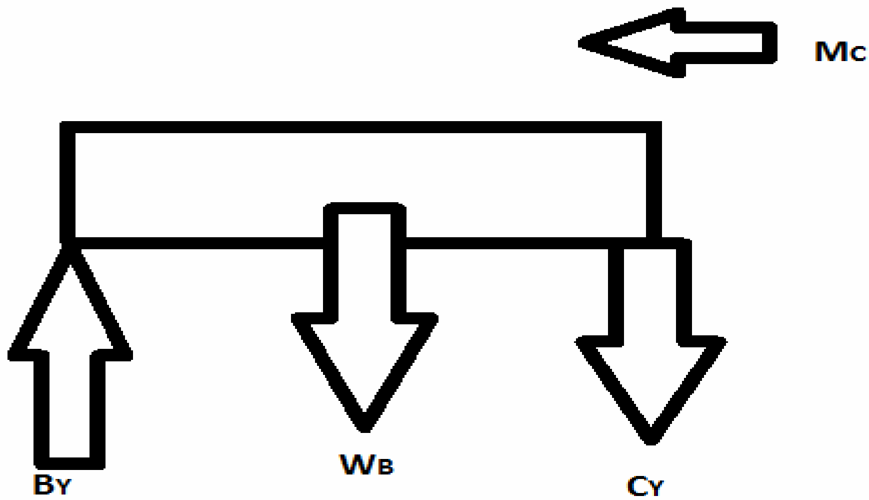


Figure 4 Force diagram of link CB.

Performing the sum of forces in the Y axis using the loads as shown in Figure.

$$\sum F_y = (L + W_d + D_m + W_e + C_m)g - C_y = 0 \quad (1)$$

$$\sum F_y = (L + W_d + D_m + W_e + C_m + W_b)g - C_b = 0 \quad (2)$$

$$\sum M_C = -(\frac{W_e L_{CD}}{2}) - W_d\left(\frac{L_{CD} + L_{DE}}{2}\right) - L\,(L_{CD} + L_{DE}) - D_m(L_{CD}) + M_e = 0 \quad (3)$$

$$\sum M_B = -L(L_{BC} + L_{CD} + L_{DE}) - W_d\left(\frac{L_{BC} + L_{CD} + L_{DE}}{2}\right) - D_m(L_{BC} + L_{CD}) - W_e\left(\frac{L_{BC} + L_{CD}}{2}\right) - C_m(L_{BC}) - W_b\frac{(L_{BC})}{2} + M_b = 0 \quad (4)$$

Solving for C_Y and C_B, see Equations (1)-(2). Similarly, performing the sum of moments around point *C*, Equation (3), and point *B*, Equation (4), to obtain the torque in *C* and *B*, find M_C and M_B respectively. The servo motor that was selected based on the calculations.

II. CONCLUSION

A complete analytical solution to the forward and inverse kinematics of 4 DOF Robotic arm is derived in this paper. The selection of electrical components used in the robotic arm is also taken into account by calculating the inverse kinematic and forward kinematic of this robotic arm movement. Besides that, the forces exerted on the robotic arm are also calculated to ensure the mechanical components of the robotic arm is not easily broken or damaged. Referring to the result obtained, a robotic arm resistance depends on the motor used. Therefore, the compatibility of motor torque with the robotic arm design is made is important because it affects the stability of the robotic arm. The mathematical model is prepared and solved for positioning and orienting the end effectors by preparing an actual model of TRL: R mechanism. The result of the Kinematic analysis can be crossed checked by the measured result of actual model of TRL: R mechanism.

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