Kinematics Analysis of Humanoid Robot Arm using SimMechanics

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Abstract_Today every small and enormous industry use a robotic manipulator to complete various task like picking and placing, welding process, painting, and material handling but to finish these tasks one among the foremost important problems is to induce the specified position and orientation of the robotic manipulators. Humanoid robots have fascinated people ever since they were invented robots. Kinematics of a robot arm deals with the geometry of motion concerning a set reference arrangement without relation to the effect of forces. There are two methods for analyzing the robotic manipulator one is that the forward kinematic analysis and another is inverse kinematic analysis. This project aims to model the forward and inverse kinematic of the 7 DOF robotic manipulator. The inverse Kinematics problem and obtaining its solution is one among the foremost important problems in robotics. it's quite complex, because of its non-linear formulations and multiple solutions. The forward kinematics of 7DOF is calculated using SimMechanics.

Keywords: Humanoid robot arm, Forward kinematics, Inverse kinematics, Simmechanics

1. Introduction

Kinematics studies the motion of bodies inconsiderately of the forces or moments that cause the motion. Robot kinematics refers to the analytical study of the motion of a robot manipulator. Formulating suitable kinematics models for a robot mechanism is incredibly crucial for analyzing the behavior of business manipulators. There are mainly two different spaces employed in kinematics modeling of manipulators namely, Cartesian space and Quaternion space. The transformation between two co-ordinate systems are often decomposed into a rotation and a translation. There are some ways to represent rotation, including the following: Euler angles, Gibbs vector, Cayley-Klein parameters, Pauli spin matrices, axis and angle, orthonormal matrices, and Hamilton's quaternions. of those representations, homogenous transformations supported 4x4 real matrices (orthonormal matrices) are used most frequently in robotics. Denavit & Hartenberg (1955) showed that a general transformation between two joints requires four parameters. These parameters called the Denavit-Hartenberg (DH) parameters became the quality for describing robot kinematics. Although quaternions constitute a chic representation for rotation, they need not been used the maximum amount as homogenous transformations by the robotics community. A dual quaternion can present rotation and translation during a compact kind of transformation vector, simultaneously. The robot kinematics is divided into forwarding kinematics and inverse kinematics. The forward kinematics problem is uncomplicated and there's no complexity in deriving the equations. Hence, there's always a forward kinematics solution for a manipulator. Inverse kinematics may be a far more difficult problem than forwarding kinematics. the answer to the inverse kinematics problem is computationally expansive and usually takes a awfully very long time within the real-time control of manipulators. Singularities and nonlinearities make the matter harder to unravel.
Two main solution techniques for the inverse kinematics problem are analytical and numerical methods. within the first type, the joint variables are solved analytically in keeping with given configuration data. within the second kind of solution, the joint variables are obtained supported numerical techniques.

There are some difficulties to resolve the inverse kinematics problem when the kinematics equations are coupled, and multiple solutions and singularities exist. Mathematical solutions for inverse kinematics problems might not always correspond to the physical solutions and also the method of its solution depends on the robot structure.

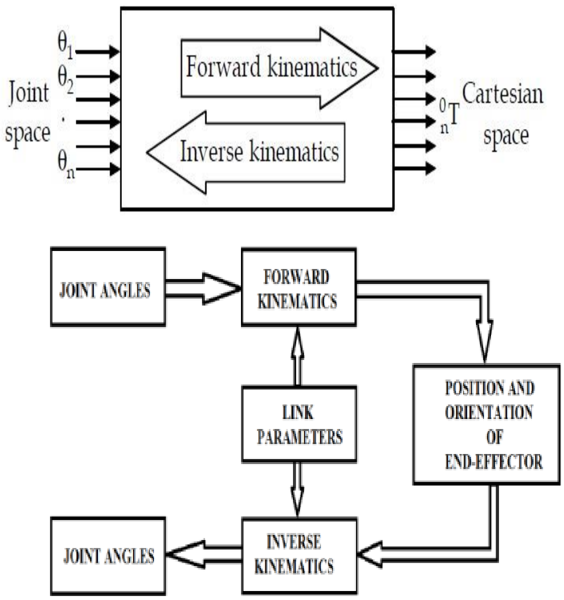


Fig.1: The relationship between forward and inverse kinematics.

- **Degree of Freedom**

Defined because the number of independent relative motions of all parts within the body. Unconstrained rigid body in space describes 6 DOF. they're 3Translational and three rotational. An unconstrained rigid body in a very plane has 3 DOF. they're 2-Translational (about x, y-axis). and one Rotational (about z-axis).

- Degrees of Freedom of planar systems:

- A line in the plane.
- A rigid body in a plane.
- A rigid link in the plane.
- A system of links in the plane.

To calculate Degrees-of-freedom of links in the plane:

- Mobility:

Mobility (m) = DOF

a) $$\boldsymbol{m = 3 \times (n-1) - 2J_1 - J_2}$$

- m= Mobility.
- n = Number of links.
- J_1= Number of 1DOF joints (lower pair).
- J_2= Number of 2DOF joints (higher pair).

2. Forward Kinematics

The Forward Kinematics problem: is worried with the connection between the individual joints of the robot manipulator and therefore the position and orientation of the tool or end-effector. Stated more formally, the forward kinematics problem is to see the position and orientation of the end-effector, given the values for the joint variables of the robot. The joint variables are the angles between the links within the case of revolute or rotational joints and also the link extension within the case of prismatic or sliding joints.

There are two methods to solve the Forward Kinematics problem:

• Geometric (Graph) solution.

• Algebraic solution.

The geometric solution has been used in simple problems and the Algebraic solution in complex problems.

we use the SimMechanics solution to solve Forward kinematics 6 DOF, 3 DOF & 7 DOF.

2.1. <u>SimMechanics</u>

Robots present considerably complicated electromechanical systems with mutual interactions of robot mechanics and drives, the planning of which the mechatronic approach should be taken into consideration. Computer modeling presents a basic tool for mentioned mechatronic approach. When designing the control of a robot, we'd like to understand the mandatory torque and angle of rotation of every motor, to visualise the behavior of the robot, and acquire a mathematical model of every part.

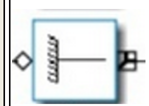
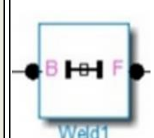
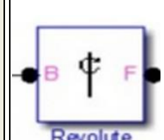
The physical modeling within the SimMechanics environment considerably facilitates simulation efforts of complex mechanical systems irrespective of their complication by elastic and damping elements and by several degrees of freedom. The SimMechanics program scheme having the shape of interconnected blocks shows how the physical components with geometric and kinematic relationships of the robot are mutually interconnected. The SimMechanics program enables one to model mechanical systems by bodies and joints, simulate their motion, change easily the structure, optimize system parameters, and analyze results all within the Simulink environment.

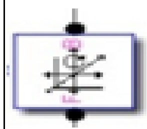
The SolidWorks models will be simulated within the Simulink environment to research forces and torques in mechanical joints, plot accelerations and displacements of every a part of the system, to visualise the motion of the CAD assembly while taking into consideration the masses of individual objects. This facility is enabled by installing an appropriate plug-in in SimMechanics which imports the 3D CAD model of the total system with bodies, joints, couplings, and much from the SolidWorks program into the SimMechanics for further work with the model.

➢ Employed SimMechanics blocks

SimMechanics contains a collection of block libraries and special simulation interfaces (Sensor and Actuator blocks) for interconnection of the SimMechanics scheme with the Simulink environment. The SimMechanics blocks present elements enabling to model of mechanical systems consisting of rigid bodies connected by joints that represent translational and rotational degrees of freedom.

Table 1 Description of functions of the used blocks in the SimMechanics program.

Group	Block	Name	Description
Bodies		Env	The block Machine Environment defines the environment for the calculation of the scheme. Each SimMechanics model contains one such block that's connected with the block Ground.
		Ground	The Ground block represents a set point having infinite mass. a minimum of one block of Ground connected with the Machine Environment must be involved.
		Body	The block Body in SimMechanics replaces all fixed rigid bodies among which the degrees of freedom are added.
Joints		Weld	The blocks Joints interconnect blocks of the body-build and that they are added degrees of freedom. The blocks determine the direction and sort of motion.
		Revolute	The Revolute block from the Joints group represents one degree of freedom (rotation)

		Custom Joint	The Custom Joint is developed by the user using so-called primitives (Joint Primitives) that make degrees of freedom.
Drivers & Constraints		Linear Driver	Linear Driver – is employed to define the gap between Base and Follower following the x, y, or z axis of the globe.
		Parallel Constraint	The Parallel Constraint block ensures that vectors of axes of two bodies are parallel.
Sensors & Actuators		Driver Actuator	Sensors and Actuators are the blocks used as interfaces between non-SimMechanics Simulink blocks and SimMechanics blocks. By the Actuators, it's possible to remodel a Simulink signal into a physical one actuating the bodies within the SimMechanics diagram.

➢ Robot model development

Development of a dynamic model of a robot starts by identifying its parameters: supported technical specifications from the producer and completing them by own measurement of dimensions and distribution of masses betting on the shape of robot arms. Modeling of separate bodies and joints in SolidWorks is way more advantageous because supported animation in SolidWorks one can simultaneously verify the correctness of kinematics of the mechanical model. The imported model also contains masses of the bodies, centers of inertia, tensors of the inertia, and graphics which will be used for visualization.

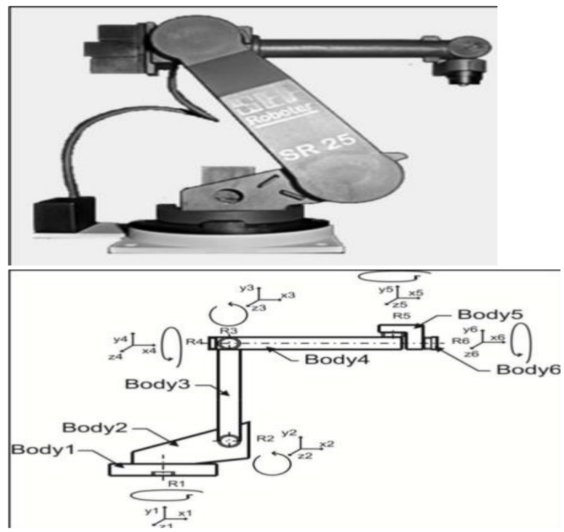


Fig. 2: SEF Roboter SR25 (6DOF).

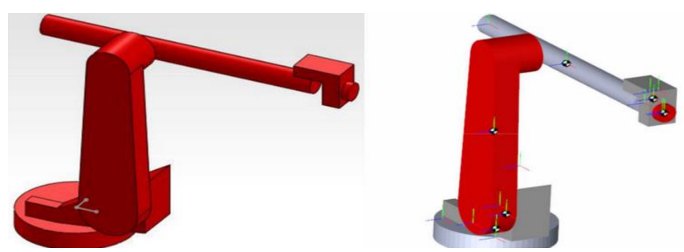


Fig.3: SEF Roboter SR25 in SolidWorks program.

➢ The model in SimMechanics is built in the following steps:

1) Specification of body inertial properties, degrees of freedom, and constraints, together with coordinate systems attached to bodies to live positions and velocities.
2) Applying forces/torques and completing the model by sensors and actuators to initiate and record body motions.

3) Starting the simulation, calling the Simulink solvers to seek out motions of the system, while maintaining any imposed constraints.
4) The 3D CAD model developed within the SolidWorks program is imported into the SimMechanics suitable format using the link that makes a basic mechanic chain completed by system parameters.

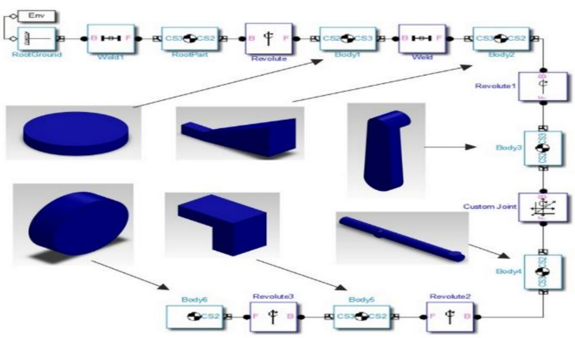


Fig. (4): 6DOF robot in SimMechanics.

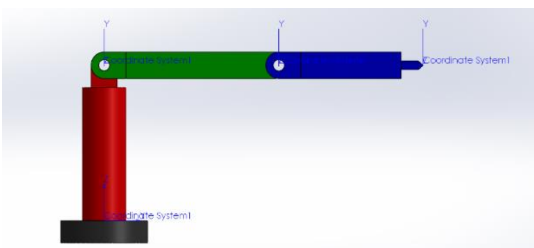


Fig. (5): 3DOF.

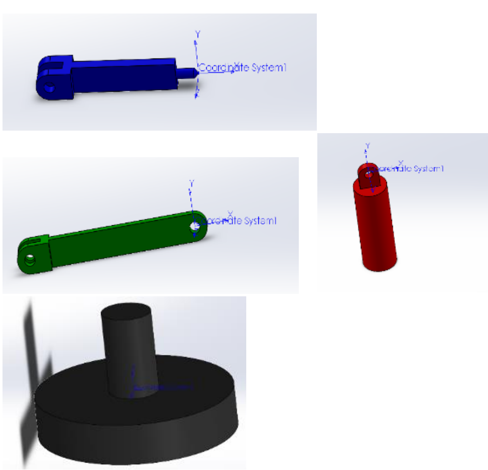


Fig. (6): parts in SolidWorks.

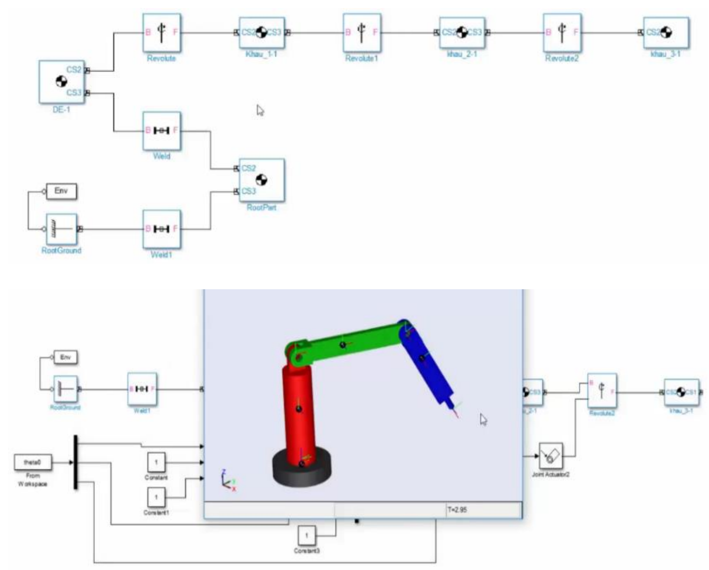


Fig. (7): In SimMechanics.

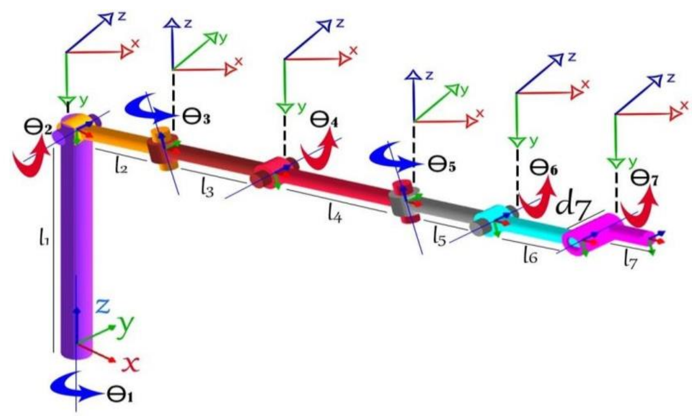


Fig. (8): 7DOF.

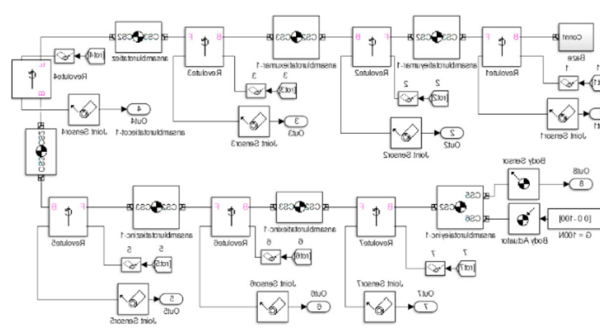


Fig. (9): Program scheme of the 7-DOF robot in SimMechanics with appropriate bodies.

Forward Kinematics of 2DOF Robot Manipulator

Kinematics is that the studying of movement concerning a reference framework inconsiderately of forces or different parameters that affect the movement. The analysis of the robot arm's spatial movement as a time function is that the fundamental worry of the kinematics, especially the connection between the position and direction of the arm with the estimations of the joints' directions. A robot arm, as referenced previously, comprises "inflexible bodies" called links associated by joints. The links and joints of the controller structure a kinematics chain that's open toward one side and related to the bottom on the opposite. The end-effector, or hand, or gripper, is related to the free end, the arm's extreme, and therefore the control goal of the robot framework is to situate the end-effector at a particular area. the matter of the forward kinematics is to make a decision the position and direction of the arm's extreme. employing a transformation matrix T that relates the position and direction of the arm's extreme with the coordinates of joints.

$$Px = l_1 cos\theta_1 + l_2 cos\,(\theta_1 + \theta_2)$$

$$Py = l_1 sin\theta_1 + l_2 sin\,(\theta_1 + \theta_2)$$

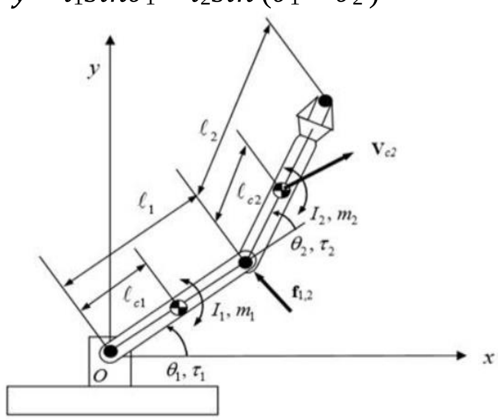


Fig. (10): Mass properties of 2 DOF planar robot.

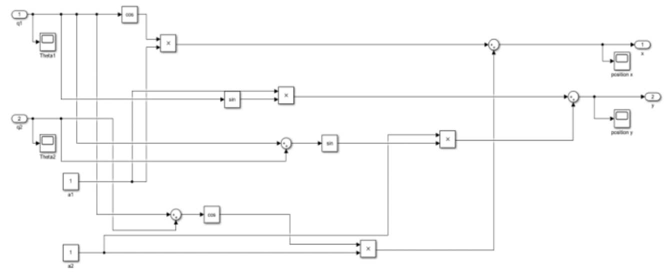


Fig. (11): Simulation model of the forward kinematics.

3. Inverse Kinematics

The inverse kinematics is that the opposite process to the forward kinematics whereby given the specified position for the arm and so found the joint angles that give these locations. the matter here there's over one solution to finding these locations different angles at different times can give the identical position.

There are two solutions of Inverse Kinematics:

- Analytical Solution.
- Numerical Solution.

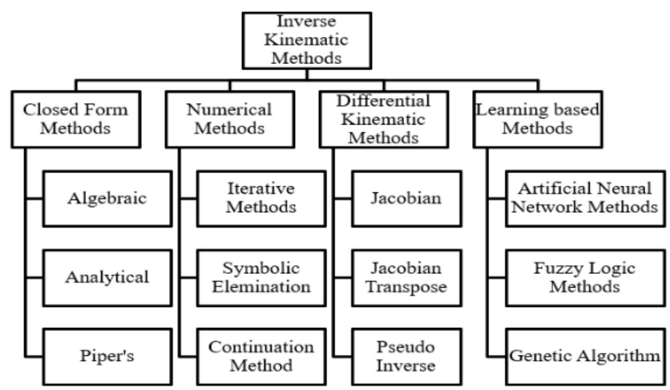


Fig. (12): Broad classification of inverse kinematic methods.

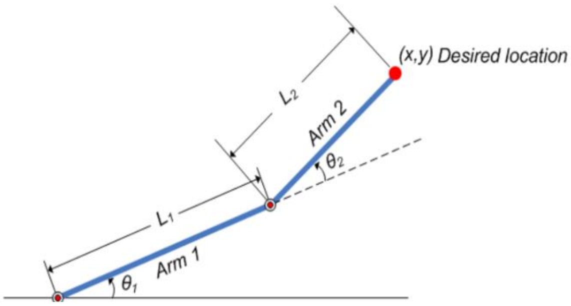


Fig. (13): Two-joint robotic arm with the two angles, theta1 and theta2.

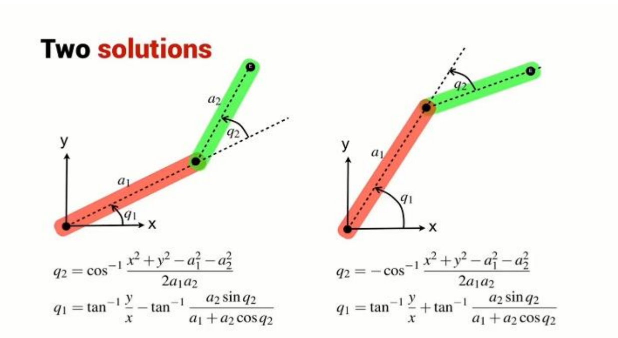


Fig. (14): The inverse kinematic equations.

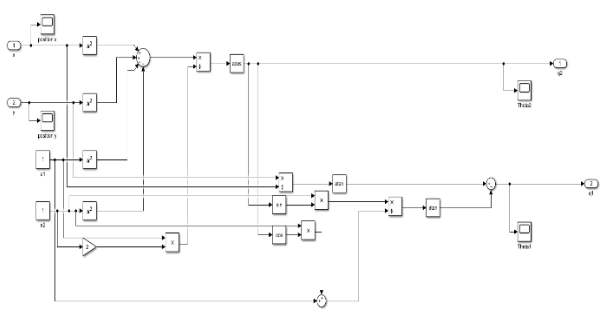


Fig. (15): Simulation model of the inverse kinematics position 1.

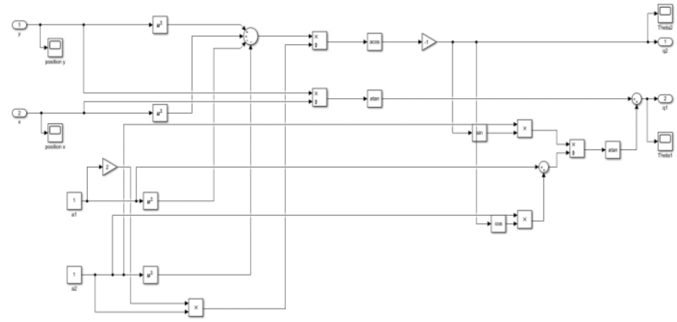


Fig. (16): Simulation model of the inverse kinematics position 2.

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