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Design of Delta Robot for Industrial Automation

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Abstract: This paper presents the systematic design, kinematic analysis, and 3D modeling of a high-speed delta parallel robot tailored for precision pick-and-place applications. The robot is engineered to handle a payload of 200 grams and is optimized for lightweight construction and rapid motion. The base platform is designed as an equilateral triangle with a 250 mm side length, serving as a stable foundation for three servo-actuated kinematic chains. Each chain comprises a 130 mm upper arm and a 320 mm passive parallelogram linkage, enabling rigid-body motion while reducing moving mass and inertia. The end-effector, with a 50 mm radius, operates within a defined cuboidal workspace of ±200 mm in the X-Y plane and from -150 mm to +350 mm along the Z-axis, as constrained by the geometric limits and actuator rotation angles of ±60°. The mechanical structure is modeled in SolidWorks with an emphasis on manufacturability and performance. The base frame (450 × 600 mm) is fabricated from aluminum extrusion profiles for structural integrity, while the moving arms are constructed using carbon fiber rods to minimize weight. Spherical joints are incorporated at both ends of the parallelogram links to facilitate smooth and flexible motion. The presented design demonstrates an efficient integration of structural rigidity, lightweight components, and precise kinematic behavior, suitable for industrial automation and research applications

Keywords: Delta Robot, Kinematic Analysis, Pick-and-Place Automation, 3D Modeling, Lightweight Mechanism

I. INTRODUCTION

This Industrial robots play an important role in the modern industrial revolution. The robotic are enabling the global manufacturing [1]. The global market for industrial robots are reached till billions of dollars. In era of Industry 5.0 the human-robot collaboration plays a pivotal role. Industry 4.0 stands for industrial automation. Robots have wide area of applications like automotive, healthcare and logistics. They offer many advantages like improved efficiency, ability to work in challenging environment [2] . Use of theses robots enhances precision, minimize material waste and supports green manufacturing. The AI equipped robots enhances its capabilities. The figure 1 show the schematic diagram of general parallel delta robot [3].

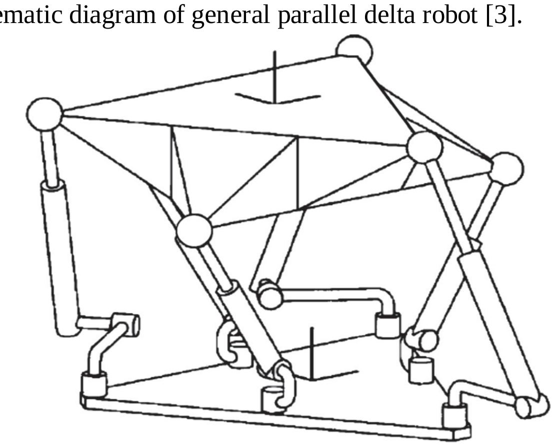

Fig.1 Schematic of General parallel robot [2]

The investment in robots, cobots and digital twins is increasing. The flexibility of robots is responsible for speedy retooling, real time analytics for real-time activation. The robots enable flexible, human-centric manufacturing but also bridge labour and skill shortages while accelerating digitalization [4]. The robots are the soul of global competitive strategy and technological leadership. An industrial robots composed of a mechanical structure which is powered by actuators. These actuators are served as muscles which are responsible for multi axis movement with six degrees of movement. In human body all actions are controlled by brain. In a similar way in robots the controller plays the function of brain which processes data and executes instructions in real time. The sensors are used to provide input data to the robots. This paper describes the designing of delta robot for the industrial automation purpose [5].

II. LITERATURE REVIEW

The delta Robot is a concept which is put in front in mid of 1980s [5,6]. It is a high speed parallel manipulator. It consist of three kinematic linkages and parallelograms. This enables a pure translational motion for its end effector. Few others tried to formulate the analytical inertial (M), Coriolis (c) and gravitational matrices (G) matrices. They used Jacobin-based virtual work principles. CAE-MATLAB workflows is used to identify key dimensions which affects positioning errors. This is used to perform parametric analysis [7,8]

Wu et al. (2024) introduced a model-based iterative learning controller that compensates for flexible-mode mismatches using fuzzy logic combined with input-shaping (barrier energy function), significantly improving trajectory fidelity. Neural-network-based controllers (MDPI, 2022/2023) approximate inverse kinematics in real-time, significantly reducing computation overhead and adapting online to nonlinear dynamics. Table 1 shows the literature review for the designing of delta robots [9].

TABLE 1 LITERATURE REVIEW FOR DESIGNING DELTA ROBOTS

Reference Sr No	Aim of the work	Key findings	Imiations
[5]	Model kinematic errors due to link non-parallelism	Model kinematic errors due to link non-parallelism	Model kinematic errors due to link non-parallelism
[6]	Control-based geometric design optimization	Optimized geometry and camera placement for visual-servo controllers; co-simulation validated positional accuracy	Requires integrated visual feedback; hardware validation pending
[7]	Formulate a direct explicit dynamic model of Delta robot	Derived M, C, G matrices explicitly via virtual work; validated with experiments showing accurate torque prediction	Doesn't address real-time control integration or structural flexibilities
[8]	Suppress vibration via iterative learning + fuzzy input shaping	Derived dynamic model incorporating flex; proven stability via Lyapunov; simulations show strong tracking improvement	Only tested in high-fidelity simulation; no physical prototype validation
[9]	Develop a 9-DOF Delta for object catching	Modeled kinematics/dynamics; implemented vision-sensor feedback with PID + current limit, suitable for real-time catching	Simulation-heavy; lacks full hardware implementation; complex mechanical setup
[10]	Simplify inverse kinematics using lightweight ANN	Achieved ~97.5 % accuracy; trained with small dataset in <1 min; fast IK mapping via ANN	Dataset limited; tests confined to XY motion without 3D paths or payload variation

The above table showcases important aspects of delta robots. The researchers has worked on structural design, precision modelling of delta robot in detail. Some of them also put control system fabrication to develop delta robots [10]. Now days AI algorithms are also contributing in may robots for adaptability for industrial automation. But still there is a gap that the work is not experimentally validated in special cases of complex and real-world applications [11].

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III.KINEMATICS OF DELTA ROBOT

An easy way to comply with IJRASET paper formatting requirements is to use this document as a template and simply type your text into it. Kinematics of delta robot involve finding the joint angles (θ1,θ2,θ3) given a desired position (x, y, z) of the end effector. Figure 2 shows the stepwise approach for designing delta robot [12].

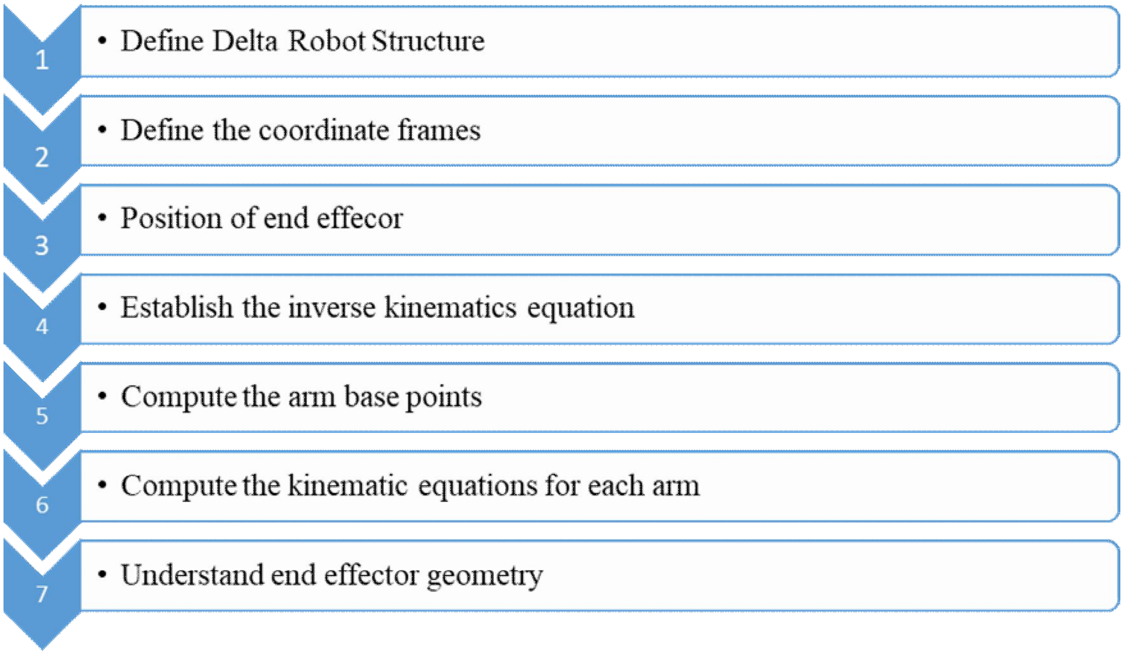

Fig. 2 Stepwise Approach foe designing Delta Robot

The delta robot consist of a base, arms and end effector. On the base actuators are mounted. There are generally three arms. Two of them are driven by motors and Lower arm is a passive arm. End effector is a triangular platform that moves in 3 D space. The base frame is fixed at the origin o (0,0,0) with Cartesian coordinates (x,y,z) . The end effector frame is attached to the 3 D platform. Each motor at the base is positioned B_1, B_2 and B_3 forming an equilateral triangle [13]. The end effector's position is defined as P (x, y, z) is measured from the global frame. Each lower arm is attached at points K_1, K_2, K_3 on the moving platform. Each upper arm (servo driven) rotates around its respective base joint (Bi) and controls the motion of lower arms. For each arm, the joint angle θ required to reach the desired end effector position is found. The following equation shows the mathematical equations to design the delta robots [14,15].

$$(x + R_p - R_b)^2 + y^2 + z^2 = L^2$$

$$(x - \frac{R_p}{2} + \frac{R_b}{2})^2 + (y + \frac{\sqrt{3}R_p}{2} - \frac{\sqrt{3}R_b}{2})^2 + z^2 = L^2$$

$$(x - \frac{R_p}{2} + \frac{R_b}{2})^2 + (y - \frac{\sqrt{3}R_p}{2} + \frac{\sqrt{3}R_b}{2})^2 + z^2 = L^2$$

Define the known parameters:

R_b- Radius of the base triangle
R_p- Radius of the end-effector triangle
L- Length of the upper arm
P(x, y, z) - Desired end-effector position

The fixed base platform of a delta robot is an equilateral triangle where the three actuators (motors). The angle between any two sides is 120° [16].

The end effector is an equilateral triangle with center at (x,y,z) – this is the position of moving platform. Radius (*Rp*) – Distance from center of the platform to each attachment joint. The above equations are the pivotal role in designing delta robot [17, 18, 19].

IV. CAD MODELING FOR PRECISION APPLICATIONS

All This research focuses on the systematic design, kinematic analysis, and 3D modeling of a delta parallel robot with a payload capacity of 200 grams, optimized for high-speed pick-and-place operations. The robot's base platform is configured as an equilateral triangle with 250 mm side length, providing a stable mounting structure for three servo-actuated arms. Each kinematic chain consists of an upper arm (130 mm) connected to a passive parallelogram linkage (320 mm), ensuring rigid-body motion while minimizing inertia. The end-effector, designed with a 50 mm radius, operates within a rectangular cuboid workspace of ±200 mm (X-Y plane) and -150 mm to +350 mm (Z-axis), determined through geometric constraints and actuator rotation limits (±60°). For Solid-Works modeling, the mechanical components are designed with manufacturability in mind the base frame (450 × 600 mm) is constructed from aluminum extrusion profiles for rigidity actuated arms use carbon fiber rods to reduce weight while maintaining stiffness. Spherical joints are implemented at both ends of the parallelogram linkages to ensure smooth motion. Fig. 3 shows the design of delta robot in CAD Model.

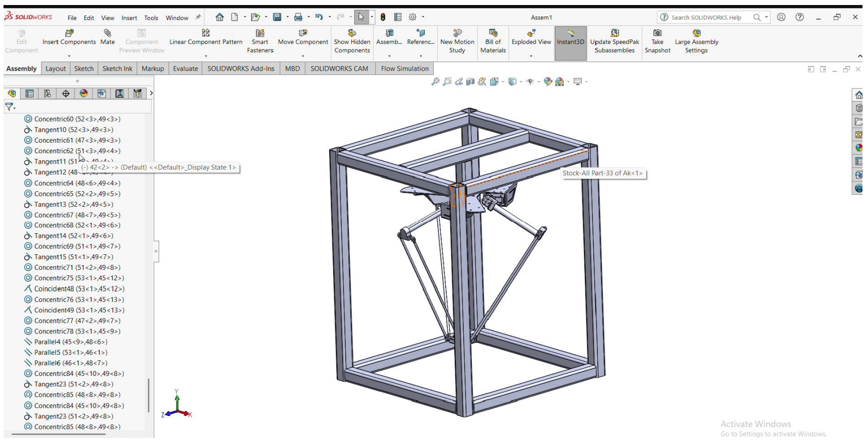

Fig 3. Delta Robot CAD Model

V. RESULTS AND DISCUSSIONS

The CAD-based design successfully generated a delta robot with the specified 200 g payload capacity and structured geometry. The equilateral base platform (250 mm side) and servo-actuated arms in the SolidWorks model resulted in a predicted rectangular cuboid workspace of ±200 mm in the X–Y plane and from –150 mm to +350 mm in Z—closely matching the calculated actuator limits and geometry constraints. The 50 mm radius end-effector demonstrated sufficient reach and clearance for high-speed pick-and-place tasks.

VI. CONCLUSION

There is an increased demand for specifically designed delta robots for pick and place operations. The work is an attempt to design a Delta robot. The design of Delta robot is carried out with a designed workspace. The forward and inverse kinematics analysis is crucial and fundamental step in understanding and controlling the movement of the Delta Robot's end-effector.

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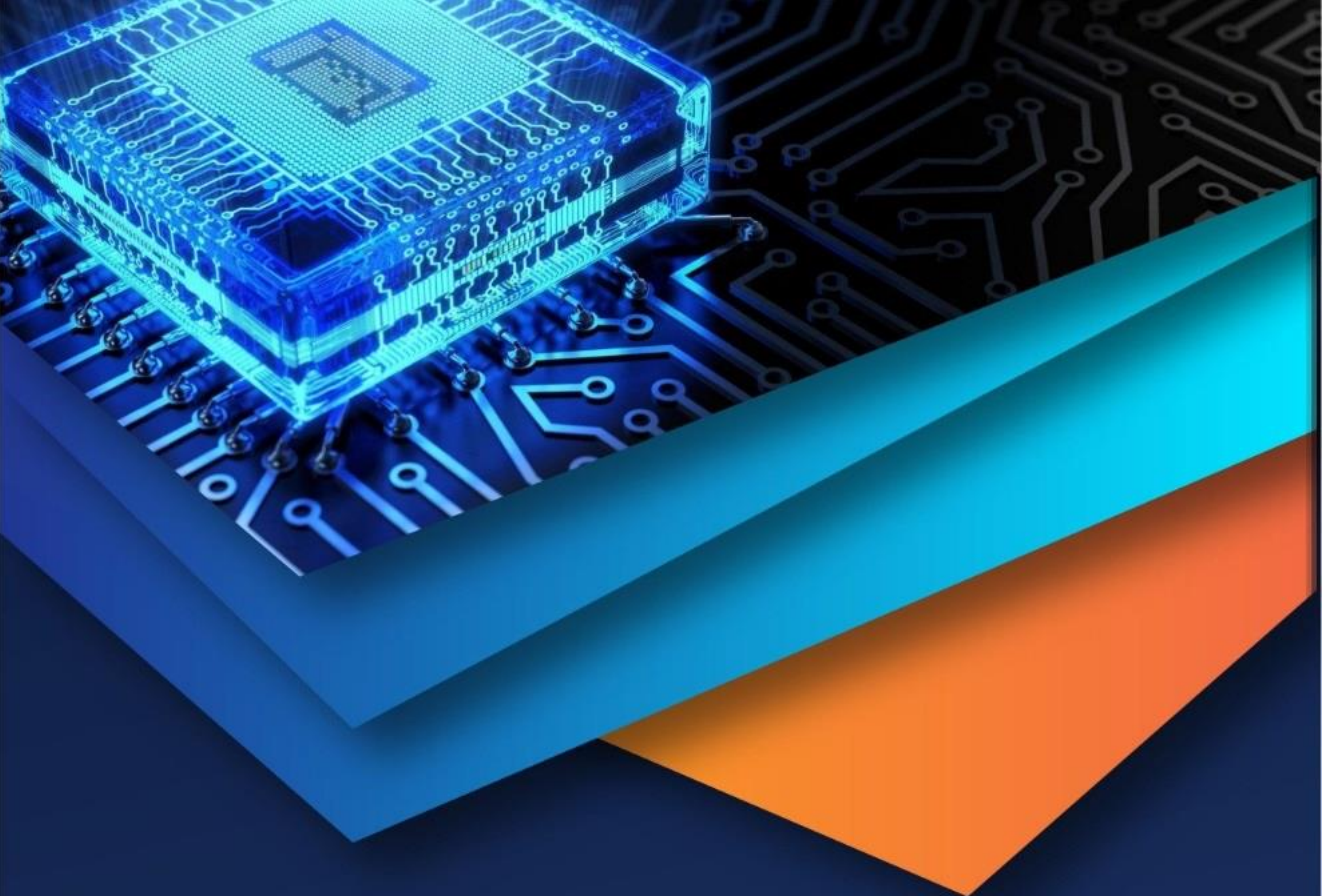

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