Design and Fabrication of a Delta Robot for Pick and Place Applications

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Abstract— ***this*** **work presents the design, fabrication and implementation of a delta robot for pick and place automation. The main goal of the project is to provide a modular, bench-top robotic platform for demonstrating principles of parallel kinematics. The system utilizes an acrylic frame, 3D printed arms and end-effector, carbon fiber rods and metal components sourced commercially. The main microcontroller used for executing the control system is Arduino Uno with a PID-based control algorithm. The robot provides hands-on experience in additive manufacturing, robot control programming, and mechatronic system integration. It is an educational robot designed for learning purposes.**

Index Terms— **Delta robot, pick and place, parallel kinematics, motion control, industrial automation.**

I. INTRODUCTION

The Delta Robot, a parallel manipulator, was first introduced by Raymond Clavel in 1985 [5]. With the actuation system situated at the base, the links experience less inertia, enabling high precision and speed in performing repetitive pick-and-place operations. These properties have led to wide applications in industrial automation. However, commercially available Delta Robots are expensive and often not suitable for educational environments where safety, cost, and accessibility are primary concerns.

The educational delta robot project was initiated to bridge this gap by designing a scaled-down, safe manipulator that retains the essential kinematic characteristics of industrial systems while being suitable for classroom and laboratory demonstration.

II. DESIGN OBJECTIVES

The main objectives of this project were:

- To design a 3D-printed Delta robot with full 3-DOF control and 1 kg payload capacity.
- To develop a safe, low-voltage (≤12 V) system for classroom demonstration.
- To implement inverse kinematics control for precision pick-and-place motion.
- To integrate optional AI-based object recognition for intelligent sorting.
- To make the system fully reproducible for undergraduate education and robotics research.

III. SYSTEM OVERVIEW

A. General Specifications

Table I shows the general specifications of the delta robot system.

TABLE I. GENERAL SPECIFICATIONS

Parameter	Specification
Total Height	0.6 m
Degrees of Freedom	3 translational (X, Y, Z)
Power Supply	LRS (Mean Well)
Controller	Arduino Uno R3
Motor Drivers	DRV8825
Workspace (Cylindrical)	Ø400 mm × 200 mm
Material	Acrylic, PLA+, PETG, Carbon Fiber

IV. MECHANICAL DESIGN

A. Structure and Components

Base Frame: Houses the motors and provides fixed anchors for upper arms.

Upper Arms: Equal-length 3D-printed arms connect to the stepper motor via a metal shaft.

Forearms: Equal-length pultruded carbon-fiber rods connected via rod-end ball joints to the moving end-effector.

B. Geometry

TABLE II. GEOMETRIC PARAMETERS

Parameter	Value
Upper Arm Length	200 mm

Forearm Length	320 mm
End-Effector Diameter	70 mm
Working Volume	Ø400 mm × 200 mm height

Each pair of upper and lower arms forms a parallel kinematic chain, maintaining the orientation of the end-effector while moving along translational axes.

C. Material Description

TABLE III. MATERIAL DESCRIPTION

Component	Material Used	Quantity
Base Frame / Structure	Acrylic	1
Upper Arms, Motor Brackets	PLA+	3, 3
Forearms	Pultruded Carbon Fiber	6
Active Gripper	PET-G	1
Rod-End Ball Joints	Aluminum	6
End-Effector Tool	PET-G	1

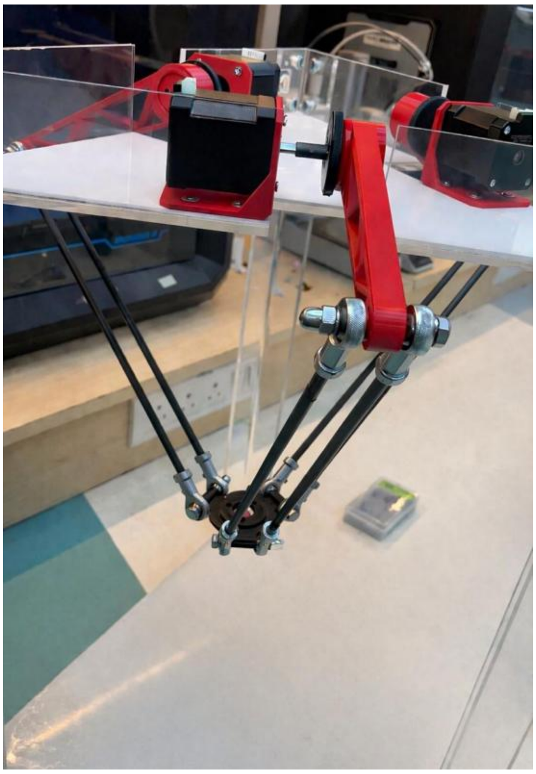

Figure1. Assembled Model of the educational table-top Delta Robot.

V. KINEMATIC MODEL

A. Inverse Kinematics

The Delta robot's motion is defined by the intersection of three rotational arms forming a common end-effector position. Each arm moves in a vertical plane, controlled by an angle θ_i. For a given target position (x, y, z), the inverse kinematics equations for each arm are derived from geometric constraints:

$$(x+a_i)^2 + (y+b_i)^2 + (z+L_2^2 - \sqrt{(x+a_i)^2-(y+b_i)^2})^2 = L_1^2$$

Where: L_1 = Upper Arm Length, L_2 = Forearm Length, (a_i, b_i) = Base joint coordinates for motor i.

VI. CONTROL SYSTEM ARCHITECTURE

A. Hardware Layout

Power Flow: LRS → Arduino UNO R3 → CNC-Shield → Steppers

Signal Flow: Arduino UNO R3 → CNC-Shield with motor drivers → 3 Stepper motors.

Communication: USB serial link to PC Dashboard.

B. Software Architecture

TABLE IV. SOFTWARE ARCHITECTURE

Layer	Description
Low-Level	Timer-driven pulse generation with motion planning
Mid-Level	Inverse kinematics solver
High-Level	Pick-and-place sequence controller

PID Control Loop:

$\Delta\theta = K_p e + K_i \int e + Kd(de/dt)$,

where e is the position error between the target and actual joint angles.

C. Motion Planning

Trajectory Interpolation: Smooth path generation between source and destination using cubic spline interpolation.

Pick and Place Sequence: The pick-and-place operation begins by positioning the end-effector over the target object, followed by activating the gripper. The end-effector then lifts vertically and translates to the designated drop point, where the object is released to place it at the desired location.

Safety Envelope: Automatic motion limiters prevent over-extension or joint collision.

VII. GRIPPER AND END EFFECTOR

The robot features an active servo-driven gripper on the end-effector, 3D-printed from PETG with rubber pads and powered by an SG90 micro servo. The design also accommodates modular end-effectors for future suction or magnetic gripping options.

VIII. DISCUSSION

A. Educational Relevance

The 3D-printed Delta Robot serves as an ideal educational platform for teaching: Kinematics and Dynamics of Parallel Robots; Inverse Kinematic Computation; Embedded Control; 3D Printing and Mechatronics Integration; and Industrial Automation Principles.

The project provides students with hands-on exposure to CAD modelling, control coding, and physical system debugging, aligning with AICTE's project-based learning (PBL) framework.

IX. FUTURE WORK

- Integration of AI-driven trajectory optimization using reinforcement learning.
- Replacement of PLA links with carbon-fiber reinforced PETG to increase stiffness.
- Addition of force/torque sensors for delicate handling.
- Integration with ROS2 and Gazebo simulation for digital twin modelling.
- Expansion to a 4-DOF configuration for orientation control.
- Integration into a mini smart factory cell with conveyor sorting.

X. CONCLUSION

This paper demonstrated the design and development of a table-top Delta Robot suitable for educational and light research applications. The system combines parallel kinematic modelling, additive manufacturing, mechanical components and embedded control to create a low-cost, safe, and effective teaching platform. By balancing simplicity with precision, the project enables students to gain practical insight into robotics design, control theory, and industrial automation, providing a strong foundation for advanced robotics and AI integration.

ACKNOWLEDGMENT

The authors thank the uGDX School of Technology, Atlas Skilltech University, for providing fabrication and testing resources, and acknowledge faculty advisors and student collaborators for their contributions to design, programming, and analysis.

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