IECMA 2026 Conference

The 3rd International Electronic Conference on Machines and Applications

MDPI

12–14 May 2026 | Online

Proposed design of a cube cable-driven parallel robot design for rehabilitation exercises and precision 3D manufacturing

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INTRODUCTION & AIM

The cable-driven parallel robots were identified as one of the significant types of robots according to the mechanical simplicity of the robots, reduction of the moving mass, large workspace capacity, and the precision of the positioning of the robots as compared to the conventional mechanical systems[1, 2]. The parallel cable robot's working mechanism has been identified as the movement of the robot through the cables in tension, which are driven by the motorized actuators to move the platform in the three-dimensional space. This work has been carried out to analyze the 3-D three-degree-of-freedom parallel cable robot that has been designed to move the platform precisely in the three-dimensional space in the x, y, and z axes. The robot has been designed by attaching four cables to the end effector of the robot at points A1, A2, A3, and A4, which enables the movement of the robot through the four motors attached to the moving platform in the x-y plane. The movement of the robot in the z-axis has been achieved by attaching the fifth motor to the moving platform at point A5, enabling the movement of the platform through the vertical sliding mechanism. Figures 1 and 2 illustrate the robot's structural configuration and support the geometric and vector analyses of its main component .

The primary objective of this work is to present a geometric model of the cube cable parallel robot that provides extensive clarification in terms of spatial parameters and points of attachment. This geometric model deals with the basic framework concerning the description of the configuration, workspace, and motion capabilities of the robot, and thus, it comes to form the indispensable base for subsequent approaches to kinematic, dynamic, and control analyses. While developing the model, the present study aims at enhancing understanding of the robot's operational behavior, therefore supporting its effective design and application in precision manipulation tasks.

METHOD

This section describes a 3D cable-driven parallel robot with three degrees of freedom. The robot features a dynamic base with motion along the Z-axis and a platform connected by five cables attached at points A1–A5 (see fig.1). Four motors on the base control movements along the x and y axes, while a fifth motor governs vertical motion based on mentioned in [3-5]. Motor-driven pulleys precisely adjust cable lengths to control the position and orientation of the end-effector. Figs.1 and 2 show the geometric structure of the 3D cable-driven parallel robot as well as the vector analysis of the robot, which can be utilized to create a geometric model that can explain the spatial configuration of the robot.

$$\vec{S}_i = \vec{P}_i + \mathcal{R}^* \cdot \vec{d}_i - \vec{a}_i$$

$$\mathcal{R}^* = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$L_i = \|\vec{S}_i\| = \sqrt{\left(x + d_{i_x} - a_{i_x}\right)^2 + \left(y + d_{i_y} - a_{i_y}\right)^2 + \left(z + d_{i_z} - a_{i_z}\right)^2}$$

The list that follows outlines and elucidates the essential geometric parameters that define the intricate structure and configuration of the robot:

- $\vec{d}_i$: vector $(\overline{a, \delta})$.
- R: side length of the robot base (The shape of the robot base is square);
- A_i: exit point of the cables from the base;
- $\mathcal{R}*$ Unitary matrix;
- $\vec{P}_i$: vector $(\overline{\delta, o})$;
- $\vec{a}_i$: vector $(\overline{A_i, o})$;
- $\vec{S}_i$: vector $(\overline{a, A_i})$;
- L_i: length of the cable;
- k: is the side length of the end-effector (The shape of the end-effector is square);

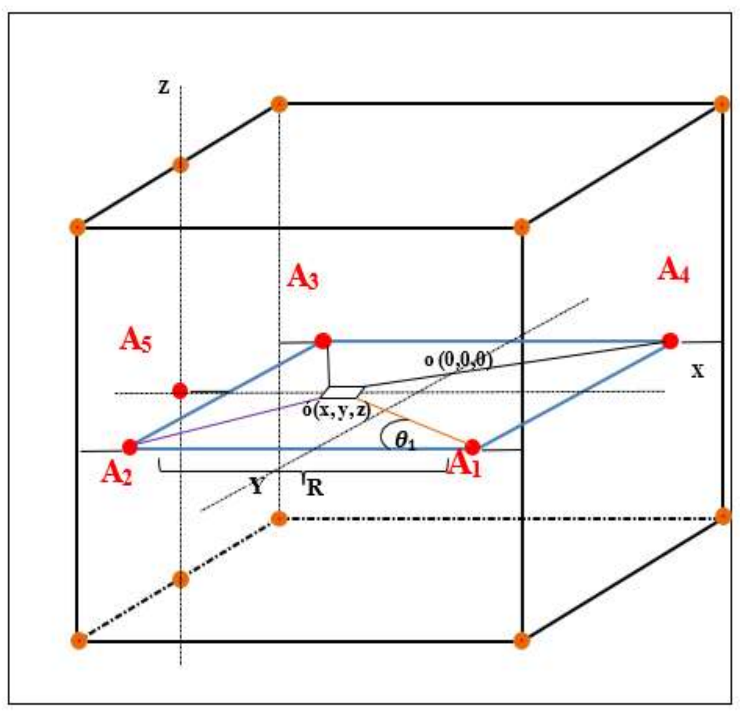

Fig. 1 The general geometrical.

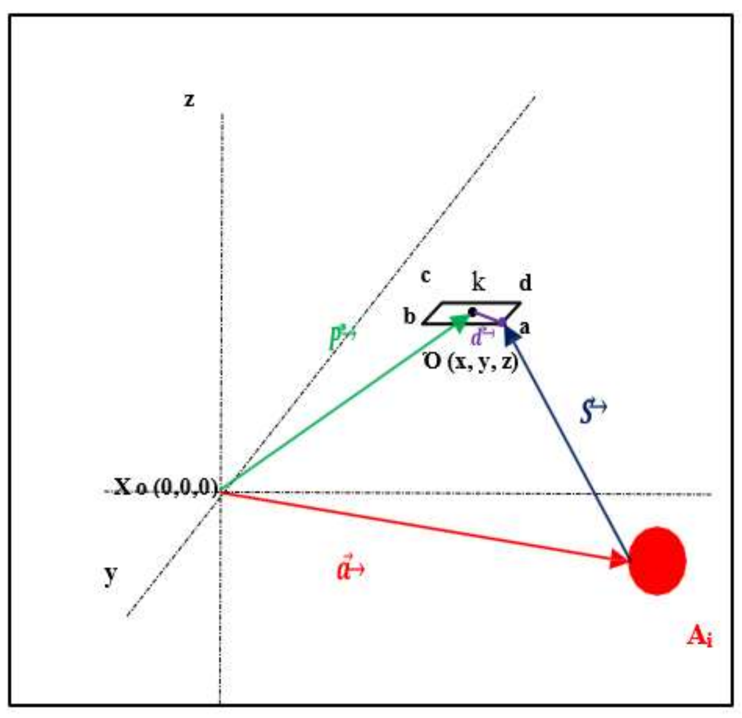

Fig. 2 the vector analysis that applies to a part of the robot.

RESULTS & DISCUSSION

In this section, a series of trajectories were selected for simulation using MATLAB, including both simple point-to-point trajectories and complex continuous trajectories for drawing letters and geometric shapes, as illustrated in Figs. 3 to 8. These simulations were implemented based on the models presented in second Section. The study employed a combined geometric and kinetic modeling approach to accurately capture the robot's behavior.

Simulations conducted on the MATLAB platform enabled a comprehensive evaluation of the system's dynamic response and trajectory-tracking performance, with continuous trajectory simulations providing particular insight into the system's precision and operational capabilities.

The obtained results confirm the accuracy and reliability of both the geometric and inverse kinematic models, demonstrating their suitability for the development of robust control algorithms aimed at optimizing the robot's performance. In addition, these models provide a comprehensive framework for understanding the system's behavior and serve as a fundamental basis for the design, implementation, and evaluation of subsequent experimental studies.

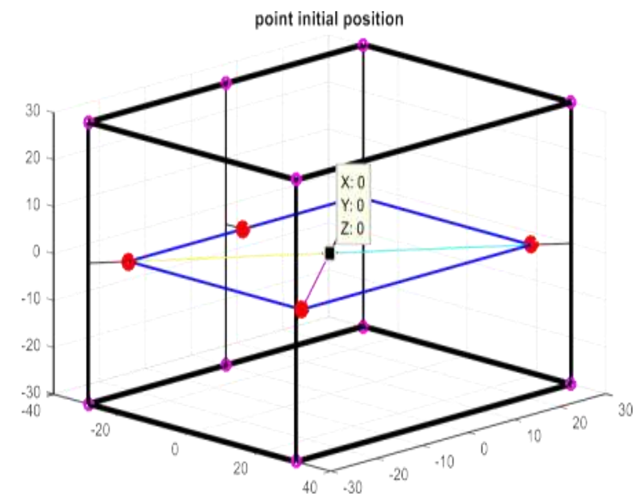

Fig. 3. Plot the end effector to initial point position.

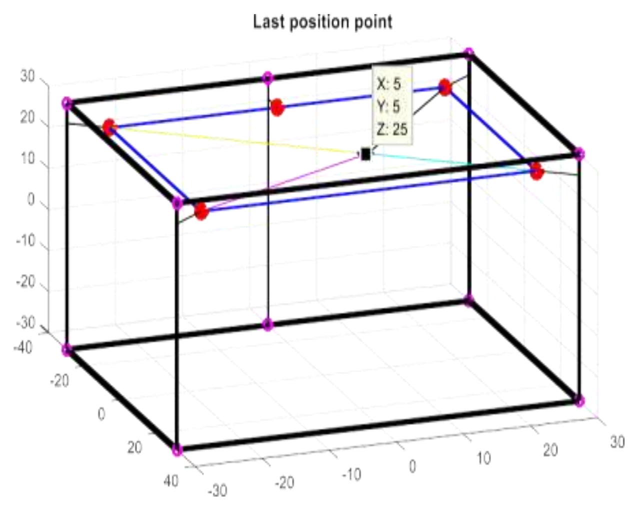

Fig. 4. Plot the end effector to second point position.

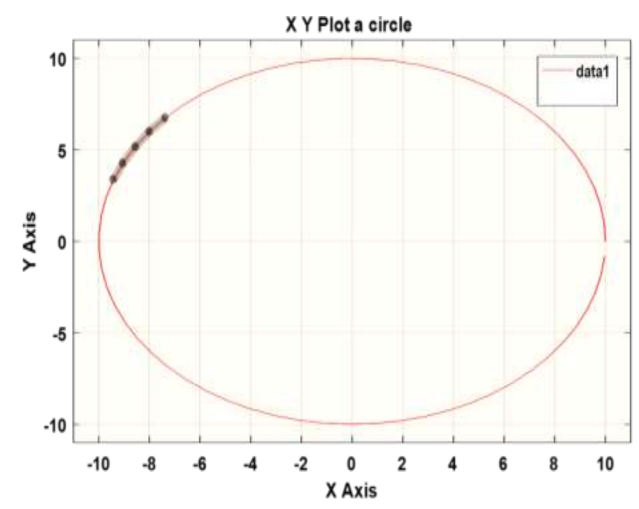

Fig. 5. Simulation of a circle in MATLAB.

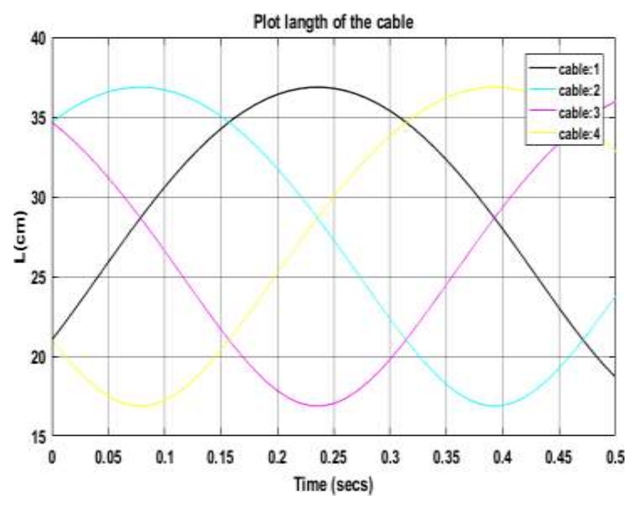

Fig.6. The cables lengths (L1, ...L4).

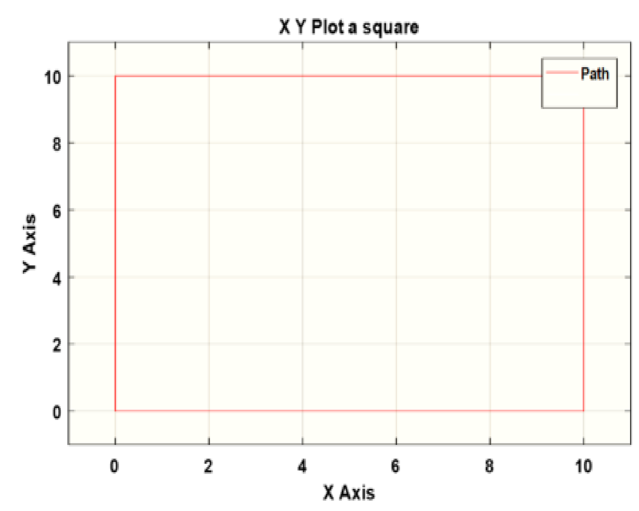

Fig.7. Simulation of a square in MATLAB.

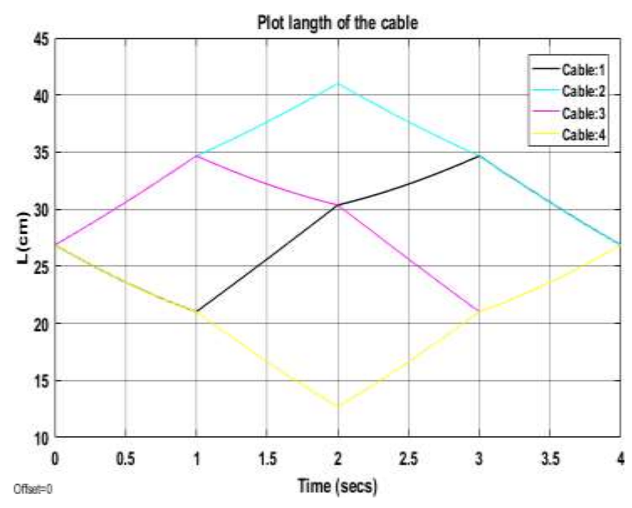

Fig. 8. The cables lengths (L1,..L4).

CONCLUSION

In conclusion, this study has provided a clear geometric basis for a cube cable-driven parallel robot with 3 Dofs. The model has defined the structure, cable, and role of the motors in the robot, providing a clear basis for understanding the movement and spatial capabilities of the robot. This framework is essential for further kinematic, dynamic, and control analyses and supports the effective design and implementation of cable parallel robotic systems for precise positioning applications.

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