DESIGN AND KINEMATIC ANALYSIS OF THE LINEAR DELTA ROBOT WITH SINGLE LEGS FOR ADDITIVE MANUFACTURING

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Abstract: *This paper deals with the design and kinematic analysis of a new structure of the linear delta robot using single legs for Additive Manufacturing (AM)/3D printing. The design is approached through a structured methodology based on a reference model for the mechatronics product development, which consists of three design domains: mechanical, electro-electronics and computational. A new structure for the linear delta robot is proposed using an innovative concept of delta mechanism with single legs and rotational joints. The new structure consists of twelve links (three parallel single legs), three actuated prismatic joints and eleven rotational joints. The inverse and direct kinematics problem are solved for the proposed structure. Finally, a prototype of the robot is developed to validate the design concepts and functionality of the machine.*

Keywords: *linear delta robot, single legs, parallel kinematic, additive manufacturing, 3D printing.*

Introduction

Additive Manufacturing (AM) also referred as 3D Printing or Rapid Prototyping, brings together a set of technologies that allow the fabrication of physical objects by adding successive layers of material from a CAD model, in contrast to subtractive manufacturing processes. e Fused Deposition Modeling (FDM) technique, introduced by Stratasys in 1989, is one of the most popular and used for its simplicity and low cost, becoming attractive to small and medium enterprises. As shown in Fig. 1, this process consists of pushing a filament into an extruder by means of a stepper motor coupled with a gear system, allowing its extrusion through the spout having a smaller diameter than the filament. The extruded filament is deposited on the top of the platform or above the anterior layer.

A new approach being investigated to improve AM quality and reduce build time is the design of FDM machines based on parallel kinematic structures and the Delta robot format, proposed by Clavel in 1985, is perhaps the parallel configuration most famous and recognized in both industry and research community.

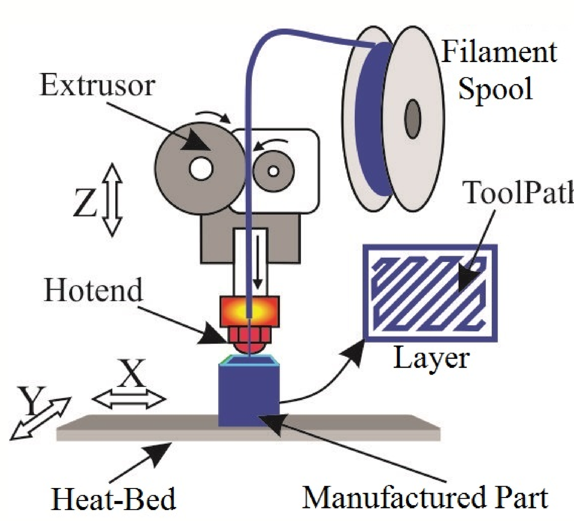

Figure 1. FDM process representation.

Inverse kinematics

The resolution of this problem is essential for position control of the Linear Delta robot for FDM. The kinematic model and geometric parameters of the Linear Delta robot are shown in Fig. 2, where the reference coordinate system *O* is located on the printing platform on the center of the fixed base *A-B-C*, with the z-axis normal to the printing platform and the x-axis in the A direction. The actuated prismatic joints are denoted by $Q_i(x_i, y_i, z_i)$, with i=1, 2, 3, which are located at a distance R_b from the reference system *O* and spaced 120◦ apart from each other (see the top view in Fig. 2). The common-joint pose respect to the reference system is denoted by $P(x, y, z)$. The aim is to determine the (x_i, y_i, z_i) coordinates for the actuated joints.

From Fig. 3, the expressions in Eq. (1) can be deduced to obtain the (x_i, y_i) coordinates of each actuated joints Q_i.

$$x_i = R_b\, cos\theta_i, \quad y_i = R_b\, sin\theta_i, \quad i = 1, 2, 3, \tag{1}$$

where,

$$\theta_i = \frac{2i-2}{3}\pi, \quad i = 1, 2, 3, \tag{2}$$

It is assumed that all the three legs of the Linear Delta robot are identical in length (L_e). The (x_i, y_i) coordinates are used to compute z_i by using Pythagoras through the Eq. (3).

$$z_i = z \pm \sqrt{L_e^2 - (x - x_i)^2 - (y - y_i)^2}, \quad i = 1, 2, 3, \tag{3}$$

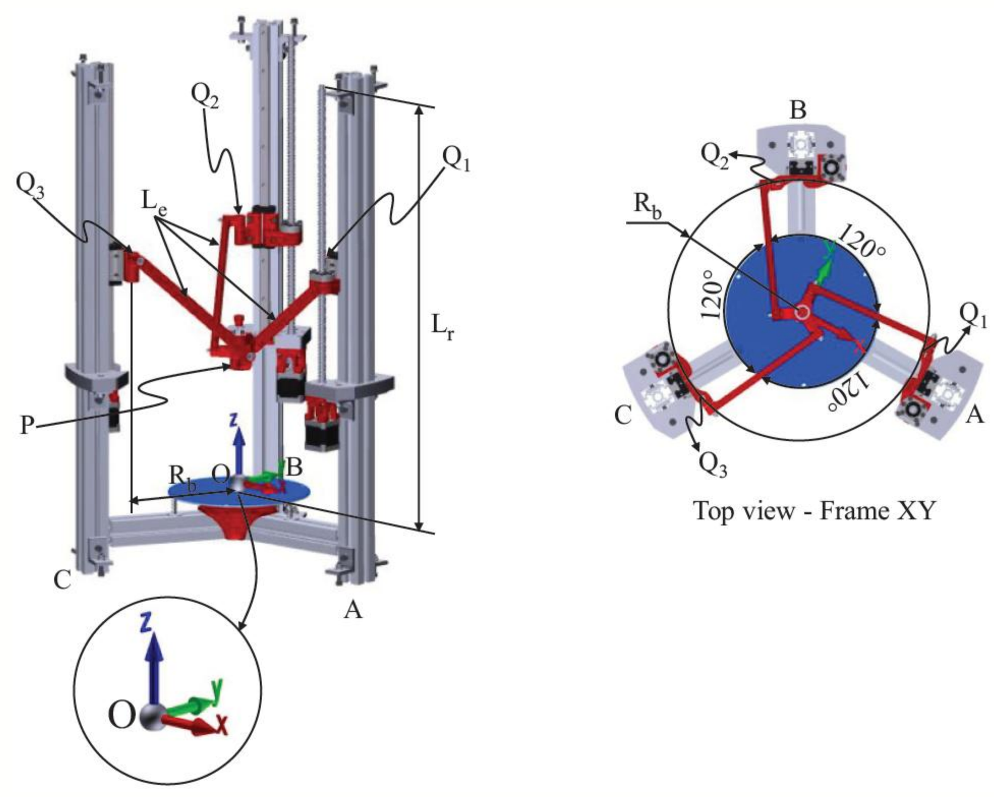

Figure 2 . Kinematics model of the Linear Delta robot

Main struture of the robot

The detailing base structure of the rDL-AM is shown in Fig. 3. It formed basically by plates and aluminum profiles. The two main plates (bottom and top) are attached to three parallel aluminum profile columns. Three smaller plates, referred as central brackets, are fixed to the aluminum profiles at a distance of 500 mm measured from the top-plate. The aluminum plates have a dimensions of 500 mm x 500 mm and thickness of 20 mm, while the profiles are 40 mm x 40 mm x 1000 mm. Figure 5 also shows a detail of the central brackets fixation on the aluminum profiles using aluminum corner brackets, the same one used to fix the main plates. The goal of a structure based on aluminum plates and profiles is to achieve the greatest possible robustness and rigidity.

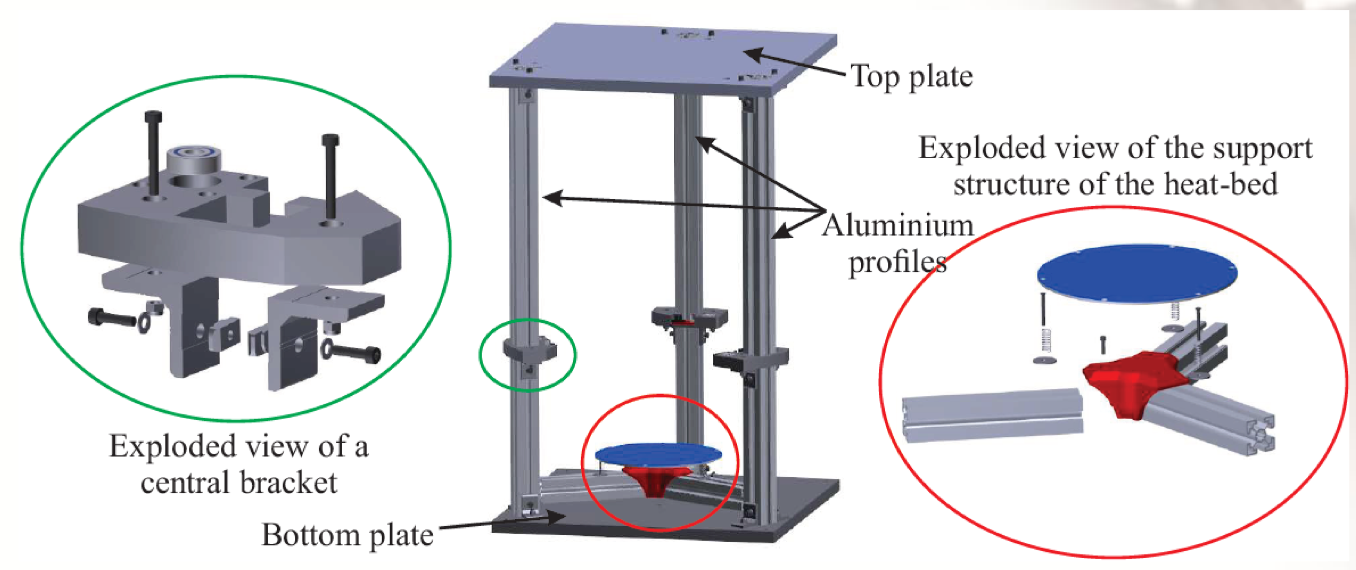

Figure 3. Detailing the main struture.

Delta mechanism description

Figure 4 presents the delta mechanism designed for the linear delta robot, which has as a differential feature the use of single legs and rotational joints. This feature was conceived by the designing team in a stage of design principles formulation and selection. Each leg is formed of three links: the primary link, which connects the delta mechanism to the motion transmission system; the main arm, which transmits the movement generated by the linear actuators to the end-effector (hotend); and, the secondary link, that constitutes the mechanism common-joint where the hotend is coupled.

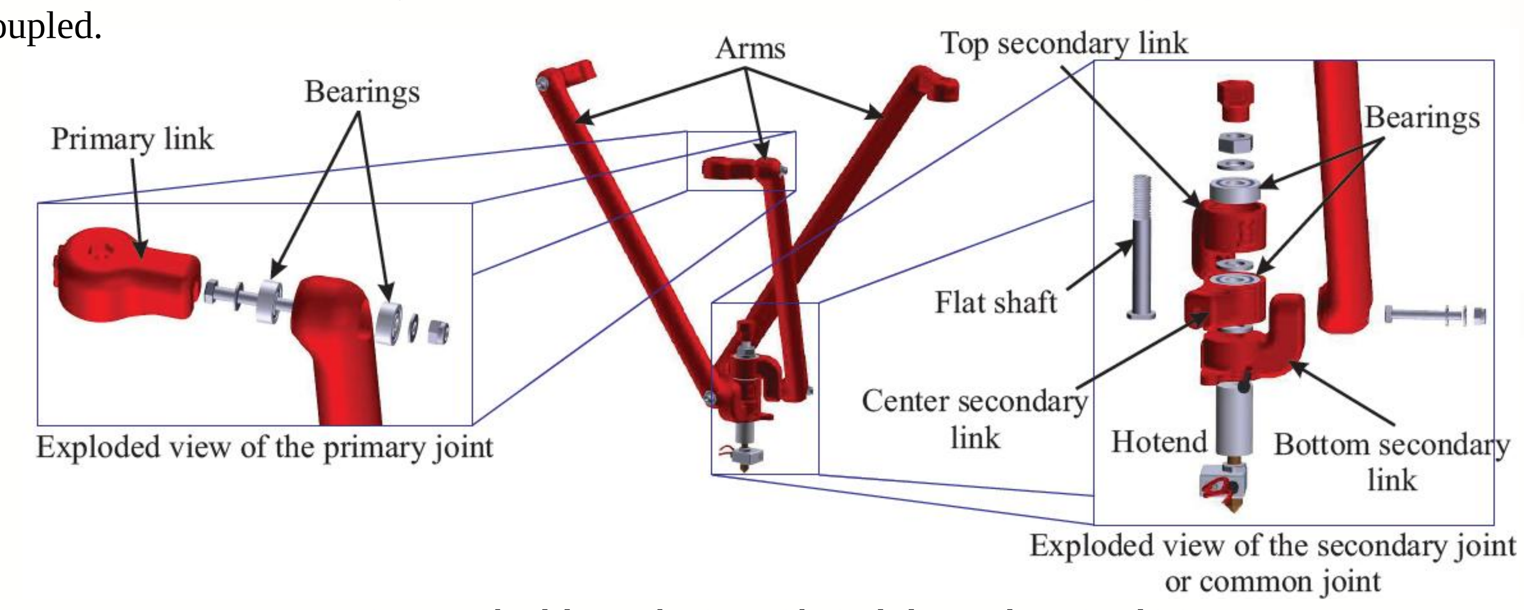

Figure 4. The delta mechanism with single legs and rotational joints.

The extruder mechanism

The extruder mechanism adopted in this project is bowden type. That is, the extruder body is fixed in the base structure of the robot, while only the hotend is assumed as end-effector. Thus, the plastic filament is pushed by the extruder and guided through a teflon tube/hose to the hotend. This type of extruder, presented in Fig. 5, allows to remove weight from the robot mechanism, since extruder body weight is supported on the base structure.

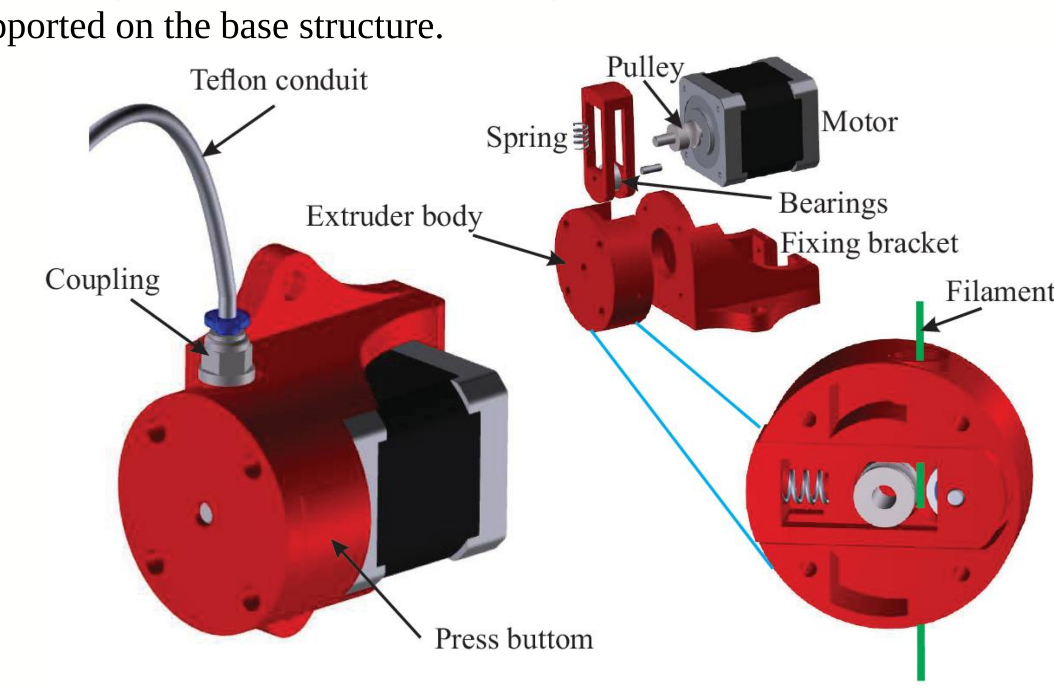

Figure 5. Detailing the extruder mechanism.

In order to validate the design feasibility of the proposed Linear Delta robot for AM, a prototype of the machine has been developed. Fig. 6 shows such a prototype of the linear delta robot with aluminum base structure and, also some printed parts using the robot.

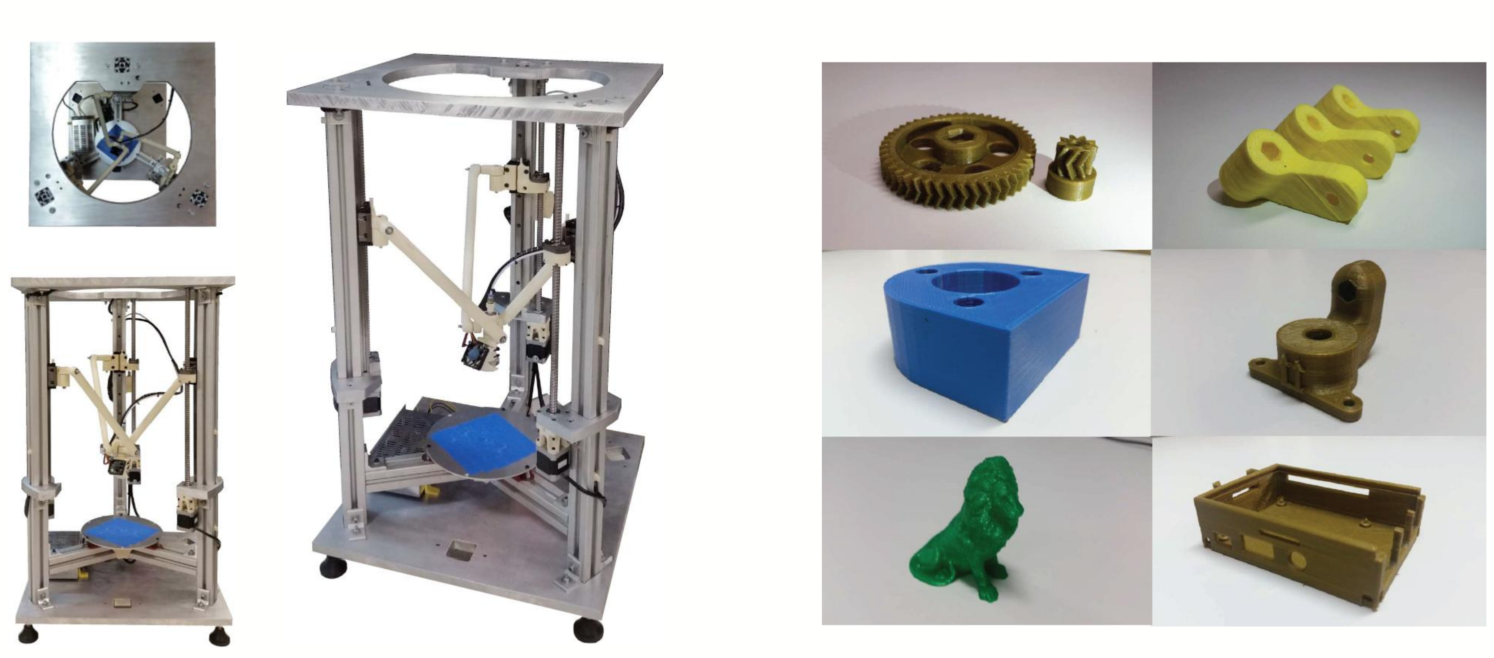

Figure 6. Prototype of the Linear Delta robot for AM and some printed parts.

Conclusion

In this work, the design and kinematic analysis of a robot with linear delta parallel kinematics for additive manufacturing was presented. The rDL-AM has as main differential the use of an innovative concept of delta mechanism with single legs and rotational joints. This solution is also different from the conventional delta architectures that have a mobile platform, while the rDL-AM has a common joint where the end-effector is directly coupled. In order to validate the design feasibility of the proposed Linear Delta robot for AM, a prototype of the machine has been developed. The URL (https://tinyurl.com/y734fwes) presents a prototype video of the delta linear machine in operation: printing of a part with complex geometry.