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Dynamic modeling of a 3D printer based on a four arms SCARA mechanism

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Abstract

This work presents the dynamic simulation of a four arms SCARA mechanism used in 3d printers using a free multidisciplinary software. Different conditions were simulated to show their impact on the construction of a layer of a printed part.

Nowadays, companies are facing shorter and shorter time-to-market cycles. Their success is strictly related to their ability to conceive new products and services and deliver them rapidly. In this environment, the application of new tools to accelerate the innovation process is fundamental to develop new products. The computational tools for product development linked to the manufacturing design helped to forge the "digital fabrication" concept. The basis of this concept is to apply software for three-dimensional modeling (CAD), computational simulation (CAE), the code generation (g-code) for CNC machines (CAM - computer aided manufacturing) and rapid prototyping process.

One of the most popular methods of rapid prototyping is the fused deposition method (FDM). It was developed at the end of the 1980s. Its basic operation is to add melted plastic direct to the model through an extrusion head. The prototype is built by the successive deposition of layers of material. Therefore, the extruder head must perform a series of repetitive motions until the layer is finished to start the next one. The deposition process must be relatively fast, to assure the adhesion of the new layers on top of the former ones. The control of the motion of the deposition head and of the extrusion speed is fundamental to make the process accurate.

The most common mechanism employed to move the deposition head is the gantry (Cartesian) mechanism. However, other types of mechanism such as the Delta and SCARA [1, 2] have been adopted in open source 3D printers because their fabrication and assembly is usually simpler and faster than those of Cartesian mechanisms, which always require a more complex support frame. The reduced inertia of the mechanism is another advantage over gantry mechanisms, since it increases the deposition head speed and allows the construction of thin wall parts.

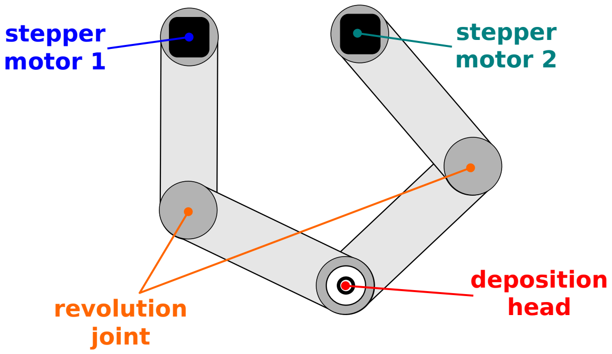

Figure 1: Deposition mechanism composed by four arms.

The four arms design (five bar mechanism) as shown in Figure has been chosen to be more rigid and stable compared to the traditional two arm concept. Another interesting feature of the four arms design is that both motors can be attached to the support structure, whereas in a traditional two arms configuration one of the motors must be attached to the elbow of the robotic arm.

The SCARA concept (Selective Compliance Articulated Robot for Assembly) was first introduced in Japan in 1979 [3]. This robot arm was designed to move fast in the horizontal plane with some compliance, but with high stiffness with respect to transverse loads. It has a small footprint compared to Cartesian robots, which renders it very useful for operations in restricted spaces.

On a 3d printer, the arms are driven directly by stepper motors, reducing the need of feedback control, particularly in low speed operation. This solution is cheap compared to servomotors, which are most commonly applied to industrial robots.

To simulate the behavior of the SCARA mechanism associated with a set of steeper motors, a model of the robot was assembled using the software MBDyn [4], and the motor model proposed by Morar [5] was implemented in a user-defined module and further integrated into the model of the complete mechanism. MBDyn can perform inverse kinematics and dynamics analysis [6]. This feature is particularly interesting for the study of this kind of mechanisms, since it requires one to transform the desired trajectory of the deposition head into the corresponding rotations of the arms.

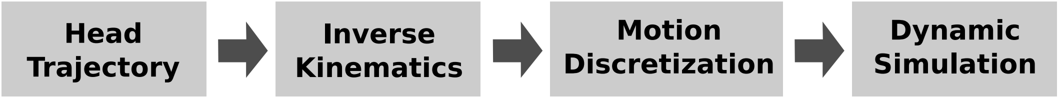

Figure 2: Workflow of the dynamic analysis of the mechanism.

Figure shows the workflow of the simulation performed to analyze the mechanism.

The first step is to model the part that is going to be fabricated in a solid modeler. Then, a slicing software, such as Slic3r, is employed to generate the g-code program. This program tells the printer how it should move to build the part layer by layer. This slicing software takes into consideration some limits of the machine, such as the maximum printable dimensions, the number of extrusion heads, and the maximum speed and resolution.

Normally, the firmware of the printer has to translate the desired motions of the deposition head into a sequence of motor steps. In this work, a Python script interprets the g-code generated, and provides the correct displacement, velocity and acceleration of the deposition head to the inverse kinematics analysis of MBDyn.

At the end of the inverse kinematic analysis, a file is generated, which contains the rotation of each arm. The latter can be directly translated into the stepper motor motion. Another script interprets the continuous movement provided by the former analysis into discrete steps that are going to be performed by each of the motors. This phase is called motion discretization; it yields a file with time and direction of each step.

The dynamic simulation of the model considers rigid arms, but the stepper motors are modeled to show their influence on the dynamic behavior of the deposition mechanism. Even though the discrete motions are relatively close to the actual trajectory to be followed by the deposition head, the inertia of the components and the stepper motor behavior deviates the motion of the deposition head regarding the desired path. A feedback control is required to minimize such deviations.

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