3D printing model of a two-link manipulator

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Abstract. Additive manufacturing/ Rapid prototyping is one of the emerging areas in the field of Mechanical Engineering. 3D printing is also known as additive manufacturing. It is a latest and interesting technology used for developing a 3- dimensional solid object from a digital model. Fused Deposition Modeling (FDM) is one of the additive manufacturing techniques used with three linear axes for producing components. A two link (revolute) manipulator consists of two joints separated in space by the links. It provides planned trajectory by programming and relationships between joint variables. The idea of the present paper is to replace and analyze the three mutually perpendicular linear axes of FDM with two link (revolute) manipulator. The complete dimensional, mass data along with the maximum size of the manufacturing component and work volume are selected from the existing FDM. Two link (Revolute) manipulator, work volume and nozzle are modeled in Computer Aided Design (CAD) software. The results have shown that the proposed two link (Revolute) manipulator is used to reduce the number of motors involved in the existing FDM.

1. Introduction

3D printing is one of the process in additive manufacturing, which is an interesting technology and used for developing a 3-dimensional object from a computerized model. It consists of three phases – Modeling, printing and final product. 3D printing utilizes a layering method where an object is printed by continuous layer of materials. Generally, the plastic material is used for 3D printing and alternative materials used are metals of different sorts, mostly carbon is used in present days.

3D printing is developing continuously & it impacts on how various products are built and their view too. 3D printing is having applications in different sectors like education, research, production etc. With the increase of 3D printing technology, the cost of getting 3D printers has been reducing with the development of technology.

A two link (revolute) manipulator consists of two joints separated in space by the link. It consists of a base, two revolute joints, and to follow a planned trajectory an end effecter can be programmed, given connections between joint variables and the position and the direction of the end effecter are figured. Two degrees of freedom robot manipulator resembles like human arms. Total energy is the sum of potential and kinetic energy of the two-link system is defined and used to form Lagrangian equations. Finally, to characterize the torque acting on each link, equations are taken from literature [1, 2, and 3].

Aalim et al. [4] discussed about three PID controller methods. First they have developed kinematics, dynamics using Denavit-Hartenberg notation and derived equations for non-linear motions respectively. Tarun et al. [5] presented kinematics and inverse kinematics of a two link manipulator. Jabbar et al. [6] briefed about the various processes and technologies used for 3D printing. Various applications like medical, nano, automobile etc., of 3D printing are presented in the literature [7, 8, and 9].

1.1. Working Process of 3D Printing

3D printing principle is based on stereolithography, which was defined in 1984 by Charles Hull as a system for producing3-dimensional workpieces by making a object with cross-sectional pattern. 3D software is utilized to develop 3D workpieces which are divided into layers and then the layers are printed by the machine. The first procedure followed in the 3D printing is the preparing of the 3D printable model. The models are fabricated by using computer-aided design software. Then STL format is made from the CAD drawing. A file format STL is developed for the 3D Systems in 1987 for use by its stereolithography apparatus (SLA) machines. Here there is a choice for different aspects of design such as outer finish, layer thickness, temperature, etc. Therefore the product is ready for printing, once the STL file is developed. The STL file data is sent to the printer and according to the STL file data; the machine prints the plastic using layering technique. In 3D printer layers are printed to get the required shape of the workpiece. The final phase consists of output, i.e. finishing the product. 'Figure 1' shows the 3D printing machine using as a reference for this research work.

Figure 1. 3D printer used for reference (Courtesy: Vasavi College of Engineering, Hyderabad)

It is well known that existing 3D printing system consists of motions along the x-axis and y-axis from the top to deposit the material and z-axis motion for a work table for up and downward movement. The idea of the present paper is to replace and analyze the three mutually perpendicular linear axes of FDM with two link (revolute) manipulator. Therefore, it is possible to reduce the number of motors involved from the existing 3D printing.

1.2. Mathematical Modeling of two link (revolute) Manipulator

For a two link manipulator, revolute joints and axis of rotation are perpendicular to the plane of the paper. Kinematics and dynamics linked with two link (revolute) manipulator are as follows and collected from literature [1, 2, and 3].

Nomenclature

a	Link Length
C_1	$\cos\theta_1$
C_2	$\cos\theta_2$

C_{12}	$\cos(\theta_1 + \theta_2)$
d	Joint Distance
g	Acceleration due to gravity
L_1	Length of Link 1
L_2	Length of Link 2
m_1	Mass of Link1
m_2	Mass of Link2
P_x	Linear distance along X axis
P_y	Linear distance along Yaxis
S_1	$\sin \theta_1$
S_2	$\sin \theta_2$
S_{12}	$\sin(\theta_1 + \theta_2)$
ϑ_x	Linear velocity along X axis
ϑ_y	Linear velocity alongY axis
α	Twist angle
θ	Joint angle
θ_1	Joint angle of link1
θ_2	Joint angle of link2
$\dot{\theta}_1$	Joint velocity of link1
$\dot{\theta}_2$	Joint velocity of link2
$\ddot{\theta}_1$	Joint acceleration of link1
$\ddot{\theta}_2$	Joint acceleration of link2
τ_1	Torque of Link 1
τ_2	Torque of Link 2

Table 1. D-H notation table

	a	$\boldsymbol{\alpha}$	**d**	$\boldsymbol{\theta}$
Link 1	L_1	*0*	*0*	θ_1
Link 2	L_2	*0*	*0*	θ_2

For joint variable θ_1:

$$\theta_1 = atan(\frac{S_1}{C_1})$$

$$P_x = (L_1 + L_2C_2)C_1 - L_2S_1S_2$$

$$P_y = L_2S_2C_1 + (L_1 + L_2C_2)S_1$$

Where

$$S_1 = \frac{(L_1 + L_2C_2)P_y \mp L_2S_2P_x}{P_x^2 + P_y^2}$$

$$C_1 = \frac{(L_1 + L_2C_2)P_x \mp L_2S_2P_y)]}{P_x^2 + P_y^2}$$

For joint variable θ_2:

$$\theta_2 = atan(\frac{S_2}{C_2})$$

$$P_x = (L_1C_1 + L_2C_{12})$$

$$P_y = (L_1S_1 + L_2S_{12})$$

$$where\ C_2 = \frac{P_x^2 + P_y^2 - L_1^2 - L_2^2}{2L_1L_2}$$

$$S_2 = \pm\sqrt{(1 - C_2^2)}$$

$$\theta_1 = \frac{P_xC_{12} + P_yS_{12}}{S_2}$$

$$\theta_2 = \frac{-P_x(C_1 + C_{12}) + P_y(S_1 + S_{12})}{S_2}$$

Torques r_1, r_2:

$$r_1 = M_{11}\theta_1 + M_{12}\theta_2 + H_1 + G_1 + C_1\theta_1 - C_2(\theta_2 - \theta_1)$$

$$r_2 = M_{21}\theta_1 + M_{22}\theta_2 + H_2 + G_2 + C_2(\theta_2 - \theta_1)$$

$$Where\ M_{11} = (\frac{m_1}{3} + m_2)L_1^2 + \frac{m_2L_2^2}{3} + m_2L_1L_2C_2$$

$$M_{12} = M_{21} = m_2(\frac{L_2^2}{3} + \frac{L_1L_2C_2}{2})$$

$$M_{22} = \frac{m_2L_2^2}{3}$$

$$H_1 = -m_2L_1L_2S_2\theta_1\theta_2 - \frac{m_2L_1L_2S_2\theta_2^2}{2}$$

$$H_2 = \frac{m_2L_1L_2S_2\theta_1^2}{2}$$

$$G_1 = [(\frac{m_1}{2} + m_2)L_1C_1 + \frac{m_2L_2C_{12}}{2}]g$$

$$G_2 = \frac{m_2 L_2 C_{12} g}{2}$$

2. Modeling of a two link (revolute) manipulator for 3D printing

The basic idea behind this work is to replace three linear motions of regular 3D printing model with 2 revolute joints. As a base work in this paper the various components involved for making the new version of 3D printing with 2 links, are modeled in CAD software and discussed about its procedure.

2.1. Work Volume

The dimensional data of work volume are considered based on the size of an actual component developed from the existing 3D printing. The sequence of steps followed for modeling the work volume is as follows
File→New→modeling→ok

Select YZ -plane for the sketch.

Select rectangle with dimensions of width (365 mm) and height (360 mm). Now sketch is extruded in X- direction to a length of '410 mm'. The modeled work volume is shown in 'figure 2'.

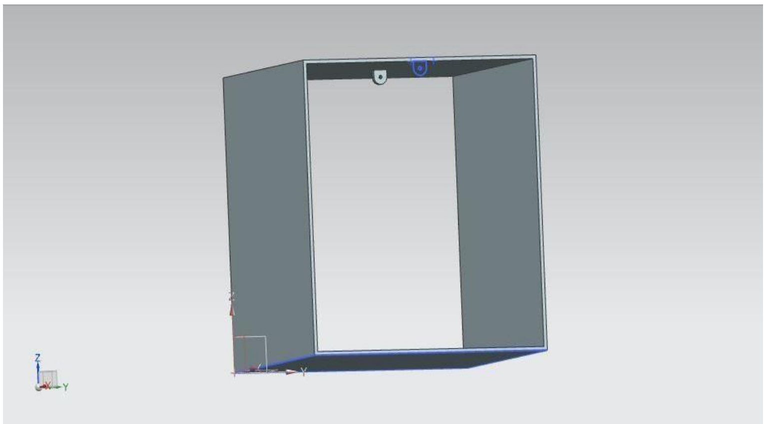

Figure 2. Work volume

2.2. Link-1

The sequence of steps followed for modeling the link-1 is as follows
File→New→modeling→ok

Select YZ -plane for the sketch.

Select rectangle with dimensions of width (40 mm) and length (210 mm) is drawn with an angle theta_1.Chamfer the end of the sketch to a radius of '20 mm'. Now sketch is extruded in X-direction to a thickness of '15 mm'. The modeled link-1 is shown in 'figure 3'. (The sizes of links are assumed based on work volume).

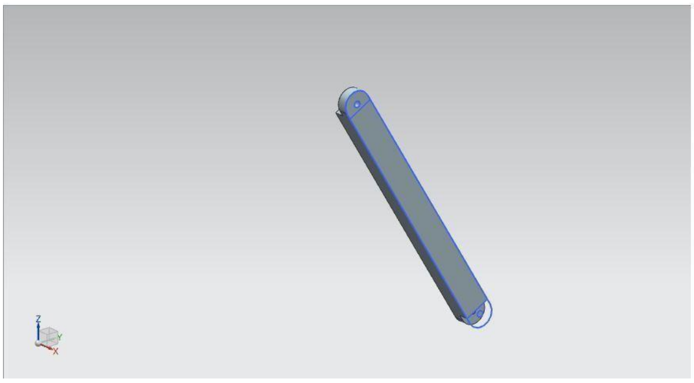

Figure 3. Link-1

Select rectangle with dimensions of width (40 mm) and length (210 mm) is drawn with an angle theta_2. Chamfer the end of the sketch to a radius of '20 mm'. Now sketch is extruded in X-direction to a thickness of '15 mm'. The modeled link-2 is shown in 'figure 4'. (The sizes of links are assumed based on work volume).

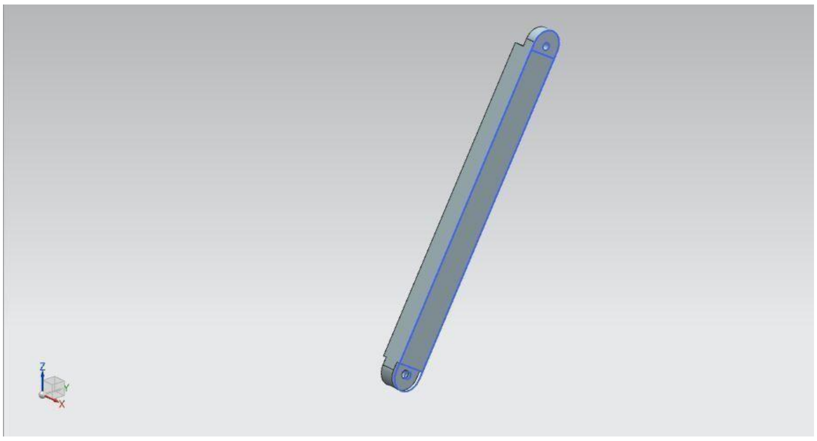

Figure 4. Link-2

2.3. Gripper:

The sequence of steps followed for modeling the gripper is as follows
File→New→modeling→ok

Select YZ-plane for the sketch.

Select rectangle dimensions of width (100 mm) and height (25 mm). Now sketch is extruded in X-direction to a length of '25 mm'. Subtract the rectangle with dimensions of width (50 mm) and height (10 mm) from the extruded part along the X-direction to a length of '25 mm'. Subtract the rectangle with dimensions of width (20mm) and height (10 mm) from the extruded part along the Z-direction to a length of '25 mm'. Subtract circle of radius '5 mm' from the body along X-direction to a length of '25 mm'. The modeled gripper is shown in 'figure 5'. (The sizes of links are assumed based on work volume).

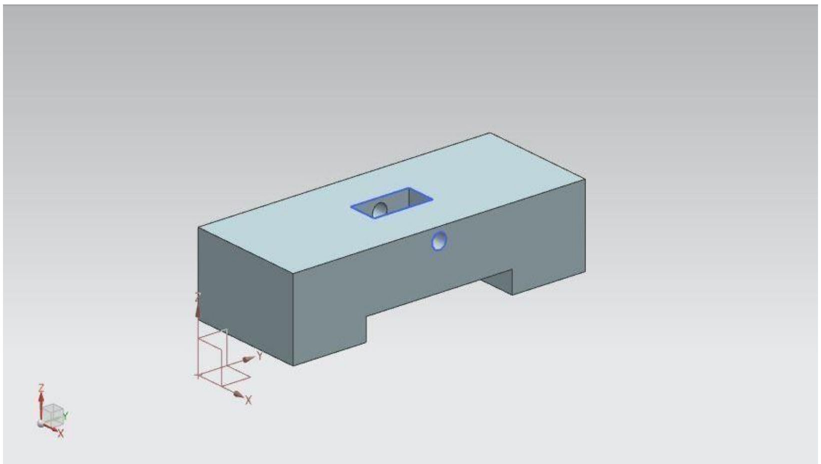

Figure 5. Gripper

3. Assembly:

The sequence of steps followed for assembling the modeled parts are as follows
File→New→assembling→ok.

Work volume:

Add→select the work volume→ok. Next Move→click on work volume→positioning the object at the correct position→ok.

Link-1:

Add→select the work volume→ok. Next Move→click on work volume→positioning the object at the correct position→ok. Now by using the constrain place the link -1 in work volume.

Link-2:

Add→select the work volume→ok. Next Move→click on work volume→positioning the object at the correct position→ok. Now by using the constrain place the link-2 is attached to end of the link-1 in work volume.

Gripper:

Add→select the work volume→ok. Next Move→click on work volume→positioning the object at the correct position→ok. Now by using the constrain place the gripper is attached to the end of the link -2 in work volume.

'Figure 6' depicts the assembly of the proposed 3D printing

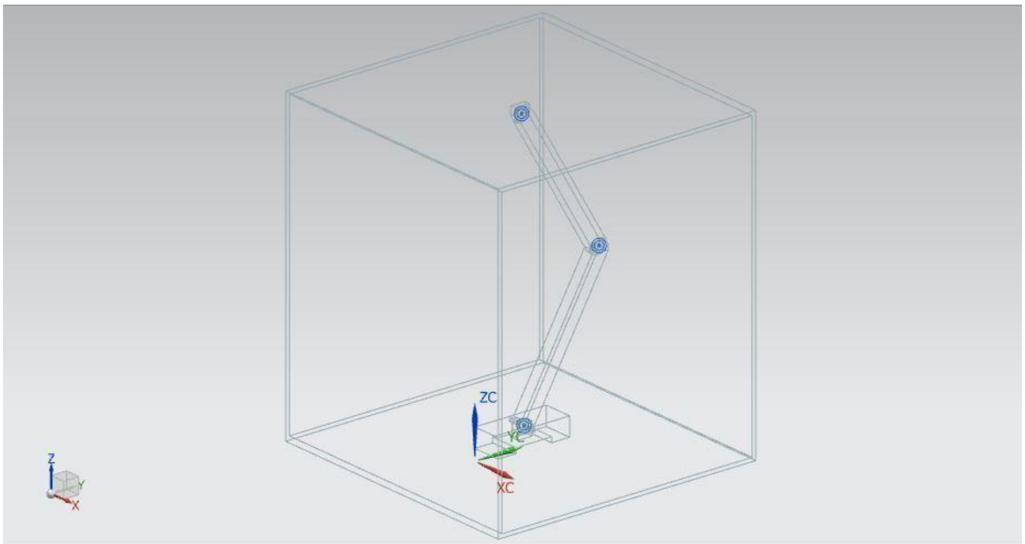

Figure 6. Assembly

4. Conclusion:

The following conclusions are observed from this work:

CAD software is used to model two link (Revolute) manipulator. The following considered data such as complete dimensional, mass data along with the maximum size of manufacturing component and work volume are used for modelling and analysis. Kinematic and dynamic equations of the 2R manipulator are discussed. These equations are used to optimize the power consumption of motor requirements in FDM. The result concluded that the proposed two link (Revolute) manipulator is used to carry the nozzle of FDM and provides moment of three axes such as X, Y and Z directions. This

Proposed and modeled two link (Revolute) manipulator can eliminate one axis motor involved in the existed FDM. The future advantage of this modeled parts are used to optimize the link lengths for minimizing the power consumption and stress analysis.

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