

# Robot Arm Platform for Additive Manufacturing: 3D Lattice Structures

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## ABSTRACT

A conventional 3D printer utilizes horizontal plane layerings to produce a 3D printed part. The printing process is based on the slicing of the designed part where it is then 3D printed by depositing a material layer upon layer. A 3D printed part built using 3D lattice structures has a restriction on the minimum size of the struts on the 3D lattice structure design using the FDM process. To overcome this conventional 3D printing method limitation, an industrial robot arm platform is proposed as an additive manufacturing platform. The concept being explored is the integration of existing additive manufacturing process technologies with an industrial robot arm to create a 3D printer with a multi-plane layering capability. The objective is to perform multi-plane toolpath motions that will leverage the increased capability of the robot arm platform compared to conventional gantry-style 3D printers. This approach enables print layering in multiple planes whereas existing conventional 3D printers are restricted to a single toolpath plane (e.g. x-y plane). This integration combines the fused deposition modeling techniques using an extruder head that is typically used in 3D printing and a 6 degree of freedom robot arm. Here, a Motoman SV3X is used as the platform for the robot arm. The integration of the robotic arm and extruder enables multi-plane toolpaths motions to be utilized in the production of 3D lattice structure parts. Using this integrated system, a 3D lattice structure test block with an overhang structure has been 3D printed without using support material. The printing toolpaths are based on the geometric features of the lattice structure.

**Keywords:** 3D printing, Robotic arm, Lattice structure, Multi-plane layering

## 1. INTRODUCTION

Additive manufacturing (AM) is a process of joining materials to make a 3D part [1]. The AM process is usually performed by depositing or curing a material layer upon layer. The material can be in the form of liquid, powder, or filament. AM process is also known as a 3D printing technique. The AM process enables the fabrication of complex geometric structures such as three-dimensional (3D) lattice structures which usually have limitations in fabrication using conventional manufacturing processes.

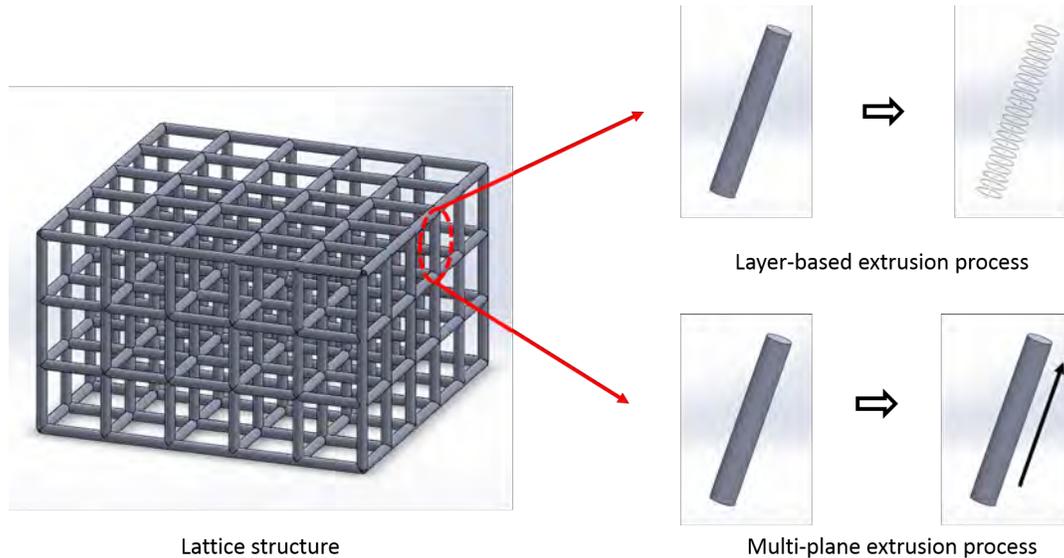
3D lattice structures enhance the strength to weight ratio of the material [2, 3, 4]. The strength to weight ratio of the material can be improved by increasing the material strength or reducing

the material density [3]. For the application of the same material, reducing the part density is more desirable. With many different AM processes available, the fused deposition modeling process is one of the techniques that can be used to produce 3D lattice structures.

Fused deposition modeling (FDM) is a technique used in 3D printer extruder heads. The FDM process is performed by extruding a material through a nozzle to form an object. A conventional 3D printer using the FDM technique utilizes a horizontal planar layering to deposit the material. The horizontal planar layering process is repeated on different layer heights which enables the 3D printed part to be produced. Some of the typical platforms used in 3D printing utilize a gantry style computer numerical controlled (CNC) machine to move the printer head. One of the constraints with the current process is that the gantry machine limits the motion of the extruder head to only translate in the x, y, and z directions. Because the extruder head cannot rotate, conventional 3D printers are limited to only printing in flat layers. The conventional AM process uses a layer upon layer deposition, the FDM process produces struts to build 3D lattice structures. These lattice structures are limited to a minimum of 2 mm in diameter in order for the part to be usable [5]. To enable a part to be printed in a multi-plane manner, a higher degree of freedom platform is needed to produce the multi-plane motion.

Industrial robotic arms are versatile platforms used in most manufacturing industries. Flexibility in their functions is what allows them to be utilized in so many different applications including welding, painting, assembly, pick and place, product inspection, testing, etc. The industrial robot arm has a freedom of movement based on the number and types of joints that have been connected. The main advantage of industrial robot arms is the relatively high degree of freedom (DoF). Because of this, a serial arm with 6 DoF is capable of performing multi-plane motions in their work environment [6, 7]. A gantry machine style conventional 3D printers that have 3 DoF are only capable of performing planar layering.

In this research, an additive manufacturing process using a robot arm as a motion generating platform is explored. The combination of a 3D printing element utilizing the fused deposition modeling method and a robot arm architecture that has 6 degrees of freedom in its interaction with the work environment allows for the development of multi-plane toolpath strategies. The multi-plane toolpath strategies in 3D printing can be used to produce 3D lattice structures. With the 6 DoF robot arm and the FDM printing



**Figure 1.** Comparison of additive manufacturing processes based on different approaches

process, a strut to be utilized in fabricating a 3D lattice structure can be fabricated directly based on its geometric shapes without the need to be sliced (see Figure 1). Finally, the future work on the robot arm platform in development is discussed.

## 2. LITERATURE REVIEW

A lattice structure is a structure with the combination of a connected network of struts [8]. A lattice structure has advantages through the use of minimum structural material while achieving higher strength capabilities. Regarding 3D printing applications, 3D lattice structure geometries can be achieved with the benefits of 3D printing technologies that allow the production of complex structure geometries.

Gorguluarslan et al. [4] introduced a design and fabrication framework for periodic lattice-based cellular structures in additive manufacturing. The design framework uses a size optimization algorithm to produced an optimum lattice structure design based on the load on the structure. The optimized lattice structure is built with the 3D printer using SLS and FDM processes. However, the 3D lattice structure built by the 3D printer used for the research still uses parallel planar layering techniques to produce the struts of the lattice structure.

A research group from ETH Singapore, ETH Zurich and SIKA Technologies AG received a patent [9] for a method to fabricate a 3D structure. One of the methods used for building a 3D structure uses a movable robot arm. A mesh formwork element is used to build the 3D structure. The robot can produce different mesh formworks with various designs made of filament extruded through the end effector of the robot arm. One of the applications of the project is to implement the robotic platform for fabrication in architecture, art, and design.

## 3. METHODOLOGY

In this section, we provide a general description of the robot arm as a platform for additive manufacturing. To investigate the idea of printing 3D lattice structures, an industrial robot arm was utilized as the platform to perform multi-plane motion and was integrated

with an extruder head typically used in a gantry-style 3D printing process.

### 3.1 Hardware

The robot system used includes a Motoman model SV3X arm driven by a Yasnac XRC SV3X controller. The SV3X has a maximum speed of 7.33 rad/s for the wrist angle, with a maximum reach of 677 mm. The system is setup for filament made of PLA plastic. The robot arm platform for the system is shown in Figure 2. The 3D printer components utilized are a 0.4 mm extended nozzle with an air forced cooling system (see Figure 3).

### 3.2 Software

A personal computer (PC) was implemented as the higher level controller. The PC runs custom software that interfaces with the XRC robot controller as well as the controller board for the extruder. Communication with the robot is accomplished by using the MotoCom SDK libraries. Communication between the PC and the extruder controller is facilitated by an Arduino board flashed with the Repetier Firmware [10]. Having a single program on the PC controlling the whole system allows for the movement and material deposition speeds to be controlled synchronously. The higher level control software was developed using Microsoft Foundation Class (MFC) Library created using Microsoft Visual Studio.

### 3.3 Interfacing Hardware & Software

Communication between hardware and software is crucial in order to successfully 3D print a part. The process involved coordination between the extruder system and the robot arm. The printing process starts by reading toolpaths from a text file. The toolpaths contains information for the printing workspace and extruder parameters. The printing workspace parameters are X, Y, and Z axis coordinates, RX, RY, and RZ axis wrist angles and the motion speed. For the extruder system, it has four parameters: extruder flowrate, amount of extrusion, extruder temperature and cooling fan speed. The printing workspace and the extruder system parameters

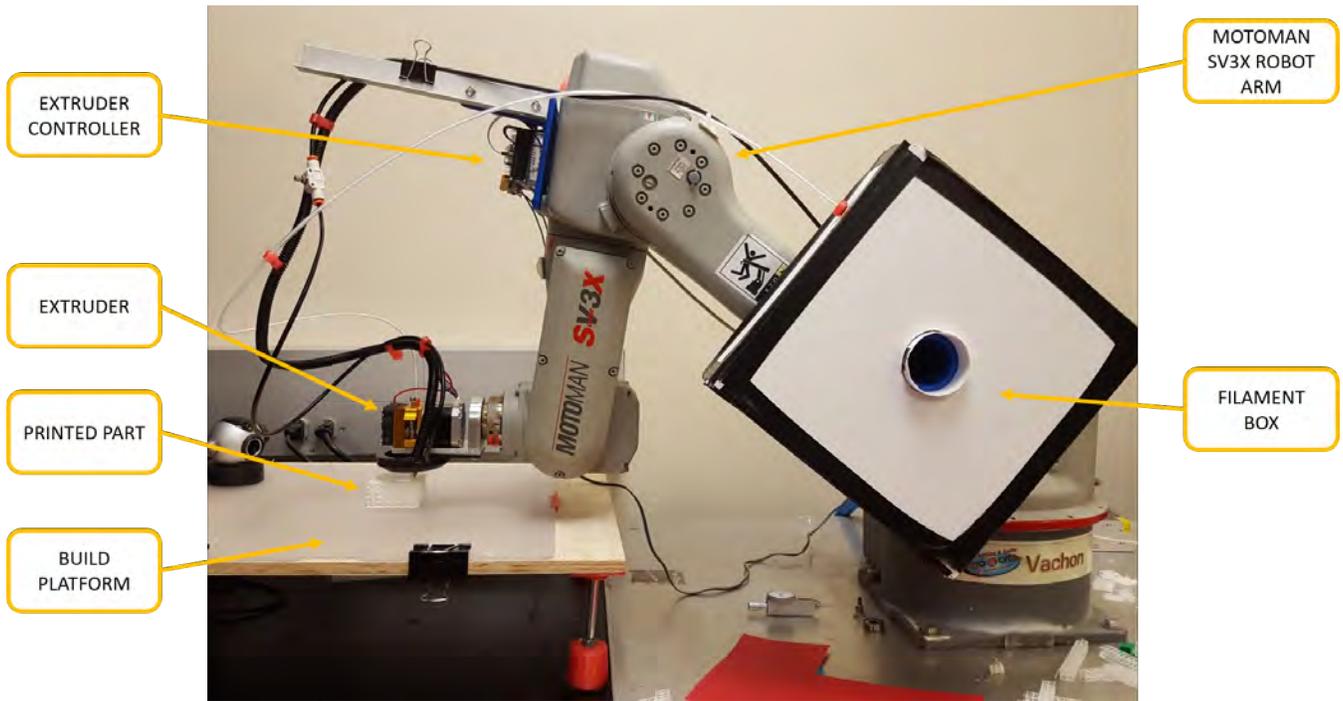


Figure 2. Robot arm platform

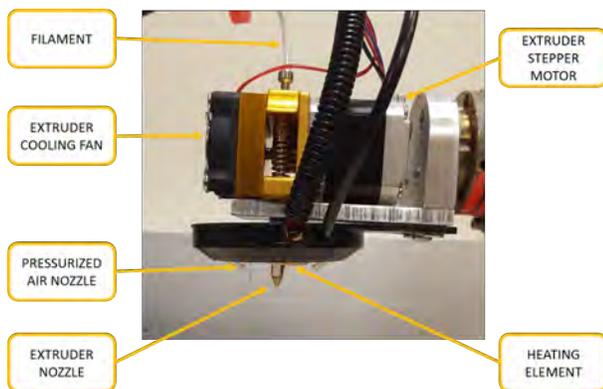


Figure 3. Extruder nozzle with forced air cooling

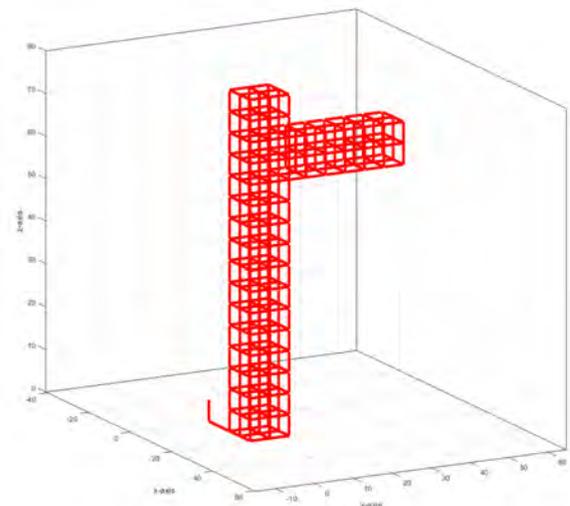


Figure 4. Toolpath simulation

data are sent to the robot controller through the interface program. The communication with the robot arm uses Ethernet protocols and the extruder system uses USB UART protocols.

#### 4. 3D LATTICE STRUCTURES

In order to demonstrate the capability of multi-plane printing to create 3D lattice structures, a 3D lattice structure test block with an overhang structure was printed using the platform. The test block dimensions are 10 mm width  $\times$  10 mm length  $\times$  80 mm height and the overhang structure dimensions are 10 mm width  $\times$  30 mm length  $\times$  10 mm height. The printing toolpath strategy used is based on the geometric features of the 3D lattice structure. A simulation for the toolpath is shown in Figure 4. The horizontal and vertical planes are chosen for the toolpaths layering because they

demonstrate the capability of the robot arm platform to perform multi-plane motions.

The 3D lattice structure test block printing process is shown in Figure 5. The printing process is started by extruding filament in the horizontal x-y plane. The x-y plane printing process is used to produce the 10 mm  $\times$  10 mm  $\times$  80 mm structure. The toolpath of the printing process is based on the strut profile. To create the overhang structure, the extruder head was rotated  $-90^\circ$  about the

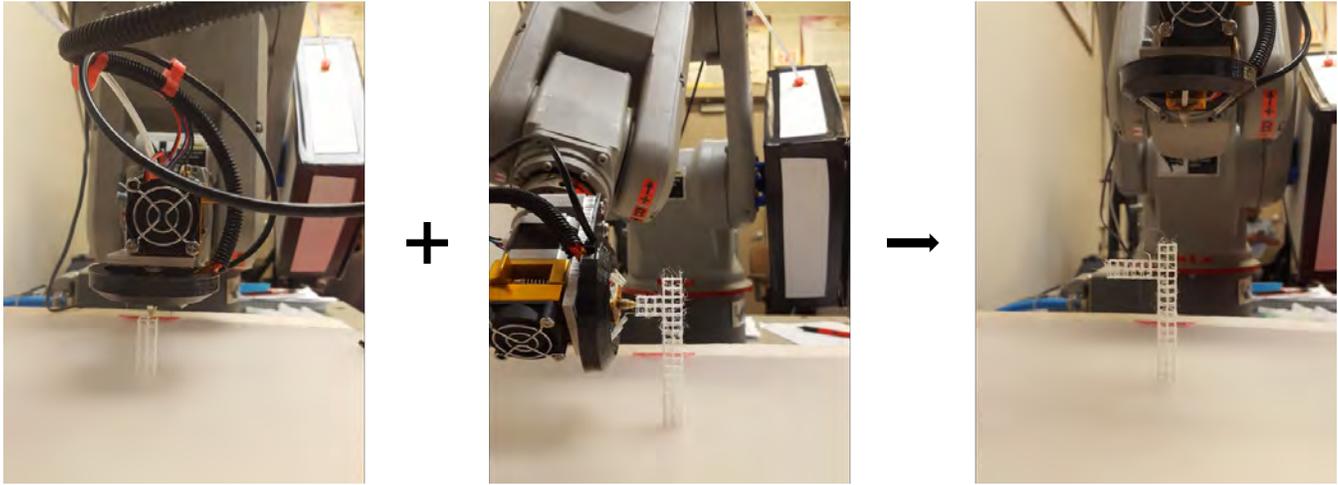


Figure 5. 3D lattice structure printing process

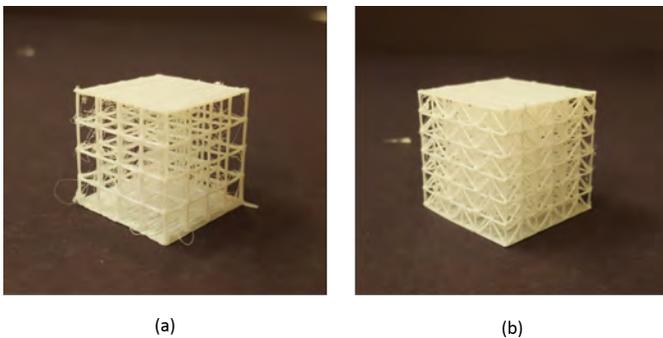


Figure 6. Different 3D lattice structure designs

X axis. The printing process continued on the side of the block in vertical x-z plane. The x-z plane printing process was used to produce the 10 mm × 30 mm × 10 mm structure. The printing speed is set to 1 mm/s in order for the extruded material to solidify with the assistance of forced air cooling from compressed air at the nozzle outlet. The diameter of each strut is  $0.48 \pm 0.02$  mm. The length of the strut is 5 mm.

Different lattice structures could be implemented by utilizing unique 3D lattice structure printing toolpaths. Moreover, 3D lattice structures could be designed based on the number of the struts connected to the nodes. Examples of different 3D lattice structures are shown in Figure 6. The 3D lattice structures with a dimensions of 20 mm width × 20 mm length × 20 mm height are printed using the robotic arm platform.

## 5. FUTURE WORK

The use of the robotic arm platform for additive manufacturing enables a new approach for 3D printing. From horizontal planar layering using a conventional 3D printer to multi-plane layering strategies using a robotic arm platform can be implement in 3D printing. With these new possibilities, new 3D lattice structure designs may be explored. A 3D lattice structure could be designed to provide improved strength to weight ratio. The continued development should focus on testing the 3D lattice structures using standard ASTM methods to determine their mechanical properties.

## 6. CONCLUSIONS

In this article, we presented the integration of a 6 DoF robot arm with an extruder head used in conventional 3D printing systems. 3D lattice structures with overhang structures are able to be printed with the use of multi-plane motion of the printing platform. New material toolpath strategies to design 3D lattice structures can be explored that may lead to improvement in mechanical strength, lowered fabrication time, and reduced filament usage to produce the 3D printed part.

## 7. ACKNOWLEDGMENTS

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