Miniature pellet extruder concept for robotic 3D printing application

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ABSTRACT

Additive manufacturing more commonly known as 3D printing has been in the limelight of manufacturing research for a long. Many advances have been made in the past in elementary printing techniques, materials, and post-processing schemes. In this paper, a concept of a miniature pellet extruder is added at the end of the articulated robotic arm. The idea is to create a system that capable to print larger and more complex shapes of any parts with the help of a low payload capacity robotic arm and provide output as a single-piece structure. It also helps to print and handle objects with larger and more complex geometry with an optimized cycle time. Knowledge from this research work will also help to choose not only the right low payload capacity robotic arm, but also provides a logical approach for selecting a pellet extruder over a filament extruder.

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1. INTRODUCTION

During the last decades, manufacturing involves removing material from a large block with the help of machining, whereas 3D printing helps to grow organically with the advent of technologies, the rise of additive manufacturing is reinforcing the manufacturing process across industries [1], [2]. This technology helps to design complex shapes with optimized features with the help of more design freedom. Additive manufacturing is generally an additive process in which layer-by-layer deposition of materials is done. Additive manufacturing can be broadly classified in by types: i) selective laser melting (SLM), ii) fused deposition modeling (FDM), and iii) binder jetting.

In all mainstream observers, 3D printing almost exclusively refers to printing using FDM technology. This process has become the most popular mode of 3D printing as it is cheap, uses simple technology, and is easy to learn. In FDM printing, the starting material is typically plastic filament or pellets, which are fed into an extruder and a hot end nozzle. The melted filament/pellet is then laid down on a build platform, the printing head moves according to the design loaded to the printer [3]–[7].

The conventional 3D printers using FDM technology mostly utilize a gantry for the motion control of the nozzle on a horizontal plane is having limited scope due to several limitations, insufficient mechanical properties, poor surface quality, and very limited bed size [8]. On the other hand, moving towards a robotic arm for 3D printing operation offers a larger degree of freedom. In most of the robotic 3D printing solutions, high payload robotics arms were used because of the high weight and size of the filament-based extruder. Although the provided solutions were good for those who can bear the high cost of investment but not well for the masses. This research article deals with the design and development of an innovative miniature extruder mechanism for 3D printer working along with a low payload capacity industrial robotic (KUKA) arm for building a very cost-effective large part with complex geometry and it also reduces post-production work. This mechanism will help in printing and manufacturing components of different shapes, sizes, and structures by layer deposition of meltable material by digital design data as a proof-of-concept.

2. RESEARCH METHOD

In this work, we used fuse deposition technology for printing 3D models with the help of a low payload capacity robotic arm. The advantage of the FDM process is that it reduces cycle time for product development without the need for expensive tools. We have used a pellet extruder mechanism instead of filament because it offers some major advantages i.e. can be mixed easily with different types of pellets to achieve a composite structure and multiple colors of the pellet can be used for providing a good appearance of an object and also make it very cost-effective [9]. Table 1 shows the comparison of important properties between filament extruder and pellet extruder.

Table 1. Comparing important properties for extruders [10]

Specifications	Pellet extruders	Filament extruders
Cost of extruders	Moderate	Moderate
Cost of raw materials	Low	High
Flow rate	High	Low
Surface finish	Low	High
A variety of materials can use	More	Less
Extruders temperatures	High	Low
Printing of complex designs	Inflexible	Flexible
Reinforcement with fibbers	Very good	Bad
Cost of the final product	Low	High

In the present experimental work, we used polylactic acid (PLA) pellets. This material has the benefit i.e. high tensile strength, low ductility, and is biodegradable as compared to acrylonitrile butadiene styrene (ABS). It can also print at a lower temperature than ABS, between 190 to 230 ºC, and also required a low bed temperature of 20 to 60 ºC. [11].

2.1. Design of extruder mechanism

In this project, we are using the FDM methodology for robotic additive manufacturing [1], [12]–[16]. The design mechanism of the pellet extrusion image is shown in Figure 1. This mechanism is typically designed for PLA material. In this kind of mechanism, PLA granules/ pellets of 3-4 mm in length instead of a wire spool. The major components for the pellet extrusion mechanism are as follows; i) KUKA servo motor, ii) gearbox, iii) nozzle and heater, iv) temperature sensor and controller, v) hopper, vi) cooling fan, and vii) printing bed.

A pellet extruder combines a pellet melting device and a pushing mechanism device. The extrusion mechanism contains a servo motor, gearbox, coupling, and feeder screw used to feed the pallets for extrusion purposes. The servo motor is to push the filament to overcome the pressure drop in the nozzle. It mainly consists of a driving role supported by a gearbox. This servo motor is added as an external axis with a KUKA KR C4 controller for synchronized motion control. The maximum torque of the motor is 0.4 Nm and the maximum extrusion force is 136 N. For the synchronized operation of extruder material with robot speed, 10:1 speed reduction is done with the help of servo gearboxes. Extrusion mechanism mounted on robot flange as shown in Figure 2.

Hooper is used to feed granules/pellets in an extrusion mechanism. The photosensor is connected to the hopper assembly for sensing if pellets running out during operation. To convert the material into softened plastics, a 24 V high watt density cartridge heater is attached to an extrusion head which is extruded via a 0.8 mm nozzle and deposited on a heated bed to form the 3D model. For PLA, nozzle temperature is set at 215 ºC. Two small fans are also conceded with nozzles from the front and left direction for cooling purposes. An aluminum alloy sheet (thickness = 10 mm, length*width = 400 mm*400 mm) is placed on the rotary axis along with a heater for material deposition. During the operation, the bed temperature is set at 60 ºC. RTD sensor is also connected to the Nozzle and Bed for temperature control during the operation.

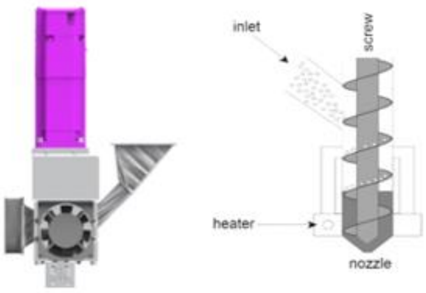

Figure 1. Pellet extrusion mechanism for 3D printing

Figure 2. Extrusion mechanism mounted on robot flange

2.2. Hardware description

The experimental robotic cell was created with the KUKA KR 120 robot to achieve robotic motion control of the nozzle in 3D space. It is a six-axis industrial robot with a payload capacity of 120 kg, a maximum operating speed of 2 m/sec, and offers a maximum reach of 2,496 mm and repeatability at ±0.06 mm. The pellet extruder mechanism, weight less than 14 kg mounted on a KUKA robot flange plate as an end effector for 3D printing operation. In front of the robot cell, a 360° rotary Table positioner is placed as the 7th axis of robotic operation. Figure 3 shows an arrangement for a robotic 3D printing application. The main advantage of using the 7th axis rotary positioner in front of the robot is to provide a large working envelope and extend reachable for the tool center point (TCP).

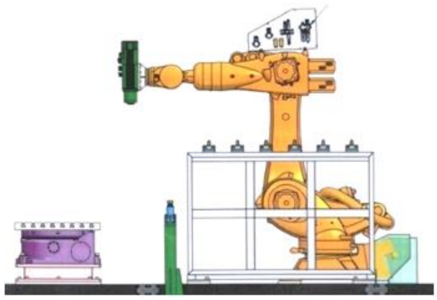

Figure 3. KUKA KR 120 robot with rotary axis positioner

3. PROGRAMMING APPROACH AND EXECUTION METHOD

We required an appropriate program code that stores the information for the tool center point (nozzle trajectory's coordinates) to program the robot with the 3D print head for printing application. For printing the part with a designed extrusion mechanism along with the 6-axis industrial robot it needs to take care of some important process parameters i.e. path trajectory coordinates, nozzle tip diameter, robot velocity, feed rate, layer height, extrusion multiplier [16]–[18]. The key steps of the robotic 3D printing programming approach are shown in Figure 3.

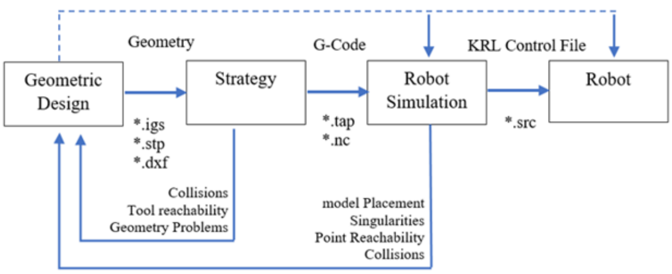

Figure 3. The key steps of the robotic 3D printing programming approach

3.1. Path planning

Path planning is the most important element in additive manufacturing, for generating extruder motion control that should be jerk-free and continuous, within the reach of the robot, also avoiding any kind of singularities limitation. To generate a robust toolpath for extruder motion control, offline robot programming (OLRP) is the best platform to cross-check all the possible solutions. OLRP also supports synchronizing the robot speed along with an additional servo motor mounted on an extrusion mechanism and controlling its possible motion pattern, [19], [20]

In our setup, we have to use Robo DK software for path planning and generate G code for the extrusion mechanism. Robo DK developed a path for the robot along with the 7th axis positioner that can rotate with constant speed over the entire process and validate the program graphically with an associative motion path [21]. Figure 4 shows path planning on Robo DK software.

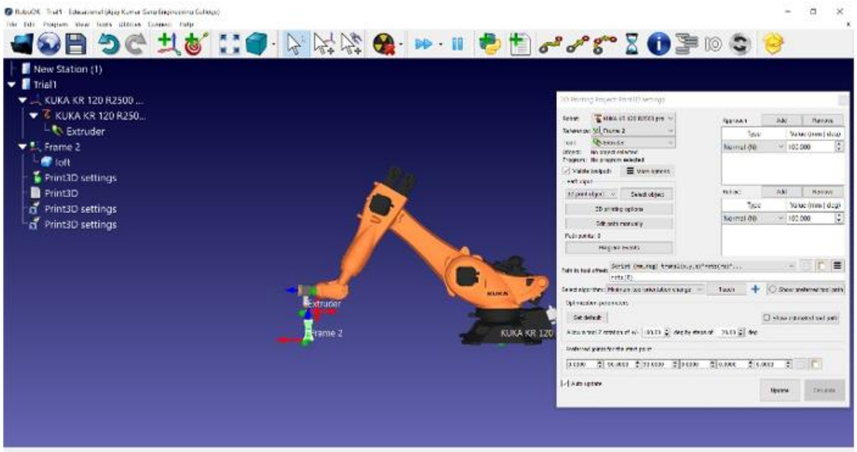

Figure 4. Path planning on Robo DK software

3.2. Process parameter optimization

Software is required for part visualization and analysis of the image in 3D view and after that, it will cut the model into thin layers and generate coordinate paths as per set parameter. This software also generates G code which stores information about the nozzle coordinates as per trajectory along with layer and parameter settings [22]. In our project Slic3r software is used for 3D models part processing. Figure 5 shows the parameter optimization window for Slic3r software, where we can set parameters as per job work and nozzle size. The optimize parameter can be only set after the extensive testing i.e. layer height 0.75 mm, first layer height 0.5 mm, extrusion multiplier 27.8, and as per current nozzle size 0.8 mm retraction height is 2 mm.

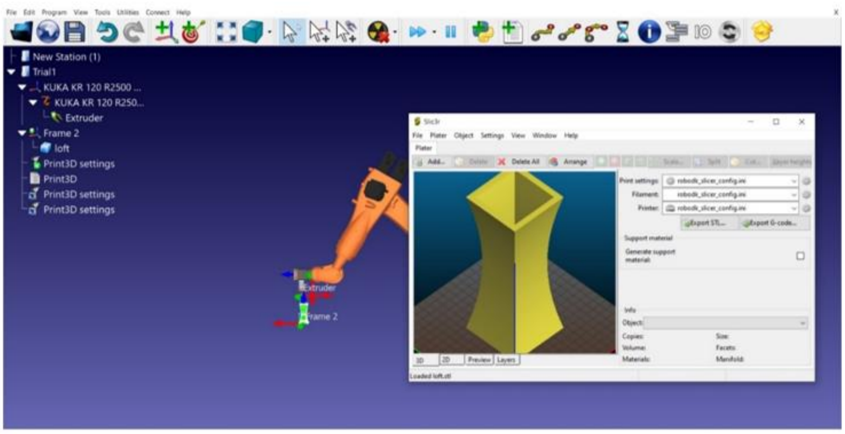

Figure 5. Slicing software window

3.3. Post Processing

Post processing is the backbone unit for any robotic cell for the off-line development of robot codes. In this project, Robo DK software is used to execute post-processing tasks for 3D printing applications. Figure 6 shows the generated program for hardware setup. It provides extruder motion coordinates based on available posting modules and it does not require any kind of manual modification or setting [23]. The generated program will be deployed on hardware setup for actual printing.

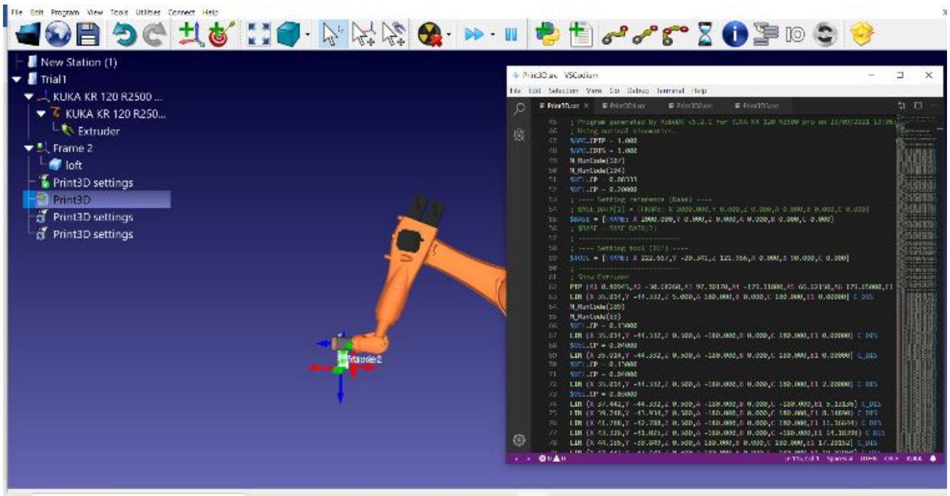

Figure 6. Post-processed program for hardware setup

4. RESULTS AND DISCUSSION

The methodology discussed in the above section for an additive manufacturing extrusion system for Robotic 3D printing applications can validate in Figures 7 and 8. We can also see that the additive manufacturing process is simulated and developed on the discussed hardware setup. To check the feasibility of this integrated system several 3D model object programs were generated on simulation software on a virtual platform and later on same actual part was developed with the help of design and developed hardware robotic cell.

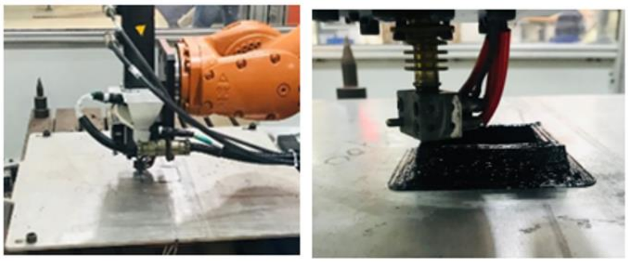

Figure 7. The actual printing of cash on setup

Figure 8. Printed models of different sizes of vash

5. CONCLUSION

The purpose of this work is to design and develop a miniature pellet extruder and its integration with the robotics arm for printing the components with the built-up rate of the larger and more complex geometry with an optimized cycle time and excellent repeatability. This research work provides information about the latest methodology of robotic 3D printing applications using miniature pellet extruders and detailed information about the robot programming process using simulation software for robotic 3D printing applications. Pellet extrusion technology can also print wide ranges of materials with higher printing speed and recyclability compared to filament extruders. The total cost of the setup/system gets automatically optimized because the proposed miniature pellets-based extruder has a very low weight and size that lower its cost and it can be very easily integrated with low payload capacity robotic arms i.e., KR 3, KR 6, or KR 10 that also helps in lowering the cost of the robotic arm.

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