Robot Arm Platform for Rapid Prototyping: Concept

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ABSTRACT

This article discusses the concept of using a robot arm platform for rapid prototyping. The concept being explored is integration of 3D printing technology commonly used in the rapid prototyping process with an industrial robotic arm to create a 3D printer with a higher degree of freedom. The objective is to develop new software tools that will leverage the increased capability of our 3D printer. The software developed will generate nonplanar toolpaths that can be fed into the printer. This will allows for more refined geometry to be printed as well as the ability to control the mechanical properties of the part. In order to accomplish this goal, we need to be able to control the robot movement and the extruder. A Motoman SV3X will be used as the platform for the robot arm. A higher level controller is used to control both the robot and the printer head. To communicate with the robot, MotoCom SDK is used as the interface between the higher level controller and the robot.

Keywords: Rapid prototyping, Industrial robot arm

1. INTRODUCTION

The continuous development of the rapid prototyping process, starting in the mid-1980s and continuing to this day, has caused some to declare it a third industrial revolution [1]. With rapid prototyping, the whole design process can be managed easily by a single operator, starting from conceptual ideas to virtual design and on to part fabrication. Rapid innovation to rapid production is the key element of the rapid prototyping process advantages. Complex geometric structures usually have limitations in fabrication using a conventional manufacturing processes, many of these limitations can be overcome with rapid prototyping technology. Conventional manufacturing processes use a material removal process in order to fabricate a part. However, the rapid prototyping process utilizes an additive material process (3D printing) instead. 3D printing allows for the creation of a three dimensional object from a digital model. The digital model is generated using Computer Aided Design (CAD) software and is preprocessed through a slicer algorithm in order to generate an additive layer from which the design can be built up layer by layer. A conventional plastic 3D printer utilizes 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.

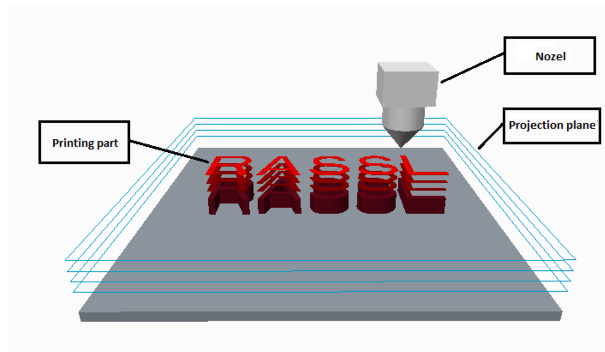

Figure 1. Conventional 3D Printer Surface Layered Up Strategy

Fused deposition modelling (FDM) is a techniques used in 3D printer extruder heads. The FDM process is performed by extruding a material through a nozel to form an object. The FDM method utilizes the movement of the gantry system to control where the material is deposited in a two dimensional plane. Layering of these planes vertically is what generates the 3D printed part (Figure 1). The material being extruded needs to be heated to a certain temperature based on the material properties in order for it to be able to flow through the nozel. FDM is a widely used method for conventional 3D printing due to an inexpensive platform and the open-source movement [4].

Industrial robotic arms are a versatile platform 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, and many more. The industrial robotic arm has a freedom in movement based on the number of serial links that have been connected. The main advantage of industrial robotic arms is their flexible kinematics (high degrees of freedom). Because of this, the end effector of a robotic arm has a greater level of freedom in its interaction with the work environment than that of a gantry machine conventionally used in 3D printers.

In this paper, the concept of rapid prototyping using a robot arm as a platform is explored. The combination of 3D printing element utilizing fused deposition modelling method and robot arm architecture that has a greater degree of freedom in its interaction with the work environment allows for the devolpment of new tool control path strategies that can offer better part quality. Finally, the future work on the robot arm platform in fabrication is discussed.

2. LITERATURE REVIEW

There are many important factors which need to be considered in the development of a robot arm platform for rapid prototyping. The parameters can be categorized in two distinct group: process parameters, and process planning parameters.

A process parameter is a parameter that can affect the dimensional accuracy and building time of the 3D printed part [6]. They are dependent on the 3D printing platform used. The three parameters we are looking at are:

1. *Layer thickness*. Layer thickness is how fine the control over the verticle change between each slice or layer is printed. A smaller layer thickness greatly increases the quality of the final part, however it adversely affects the time needed to print.

2. *Deposition speed*. Deposition speed is the speed at which the extruder head moves. It is dependent upon the machines capability to translate in the horizontal (x-y) plane to build a layer of the part. Since the part is built in 2D layers, translation in the z direction is only used after each layer is completed. Because of this the speed in the z direction is not a factor when looking at deposition speed. Having a high deposition speed can reduce the fabrication time of a part, however, it may lead to lower part quality. this is dependent on the repeatibility of the 3D printer used.

3. *Flow rate*. Flow rate is the rate at which material leaves the nozzle of the extruder head. The flow rate must be synchronized with deposition speed and layer thickness to ensure that the current amount of material is deposited to build the part.

Process planning parameters are parameters that can affect the surface quality, mechanical strength (beside material properties), dimensional accuracy, and building time of the 3D printed part [3, 2, 7]. These parameters are co-dependent with the process parameters. The four parameters we are looking at are:

1. *Orientation*. Orientation can affect the quality of the parts outer surface, fabrication time, and the amount of supporting structure needed.

2. *Support structure*. Support structure is used to support the fabrication part. Overhanging and hollow part designs may need to have a support structure. The structure gives the printer a surface on which to build features that would otherwise be unsupported and consequently unprintable.

3. *Slicing*. Slicing is the process of converting a three dimensional part to a stack of two dimensional surface planes, each with a layer thickness. When these layers are placed one on top of another, they aproximate the three dimensional part. High slice resolution will achieve a greater approximation of the part model. Fabrication time be increased as the resolution increases, but it will improve the part's surface quality. Low slice resolution can reduce the fabrication time but the poor approximation of the part's curvature may result in the surface appearing like a staircase, with each layer appearing as a step.

4. *Tool path generation*. Tool path generation is trajectory planning for the extruder nozel. There are several tool path strategies that are being implemented on current 3D printers such as zig-zag, contour, spiral and partition patterns. Examples of the tool path generation are shown in Figure 2. Each tool path strategy can affect the mechanical properties of the fabricated part, as well as the printing time.

For this study, process planning parameters are the main focus area to be considered in the development of the robot arm platform for rapid prototyping. There are several existing research reports outlining research done on the tool path generation strategy to improve the fabrication quality of 3D printed parts.

Jin et al. [3] introduced an adaptive tool path generation strategy for a complex products model. A contour tool path strategy is used by implementing closed, non-uniform, rational B-spline curves in order to improved the surface quality and fabrication time. Jin et al. [2] also introduced a hybrid and adaptive tool path generation strategy for biomedical models. Closed, non-uniform, rational B-spline curves are used to develop boundary contours to improved the surface quality and a zig-zag tool path strategy is used for inner region area to reduce fabrication time. Both methods are implemented for a planar surface tool path.

Keating and Oxman [5] introduced compound fabrication using a robotic arm as a platform. It is a multi-functional robot platform for digital fabrication and manufacturing. The compound fabrication approach is implemented by combining additive, formative and subtractive fabrication in one platform to produce a 3D part. The limitation with the robot arm platform is the need to consider the singularity issue that is going to occur during the operation.

Based on the literature reports, nonplanar tool path generation and singularity avoidance issues need to be taken under consideration in order to develop the proposed platform.

3. METHODOLOGY

In this section, we provide a general description of the proposed concept method to develop a rapid prototyping machine using a robot arm as the platform.

3.1 Hardware

The systems that we are working to integrate are a standard six revolute joint industrial robot arm from Motoman model SV3X and a Reprap J-head type hotend for 1.75mm filament

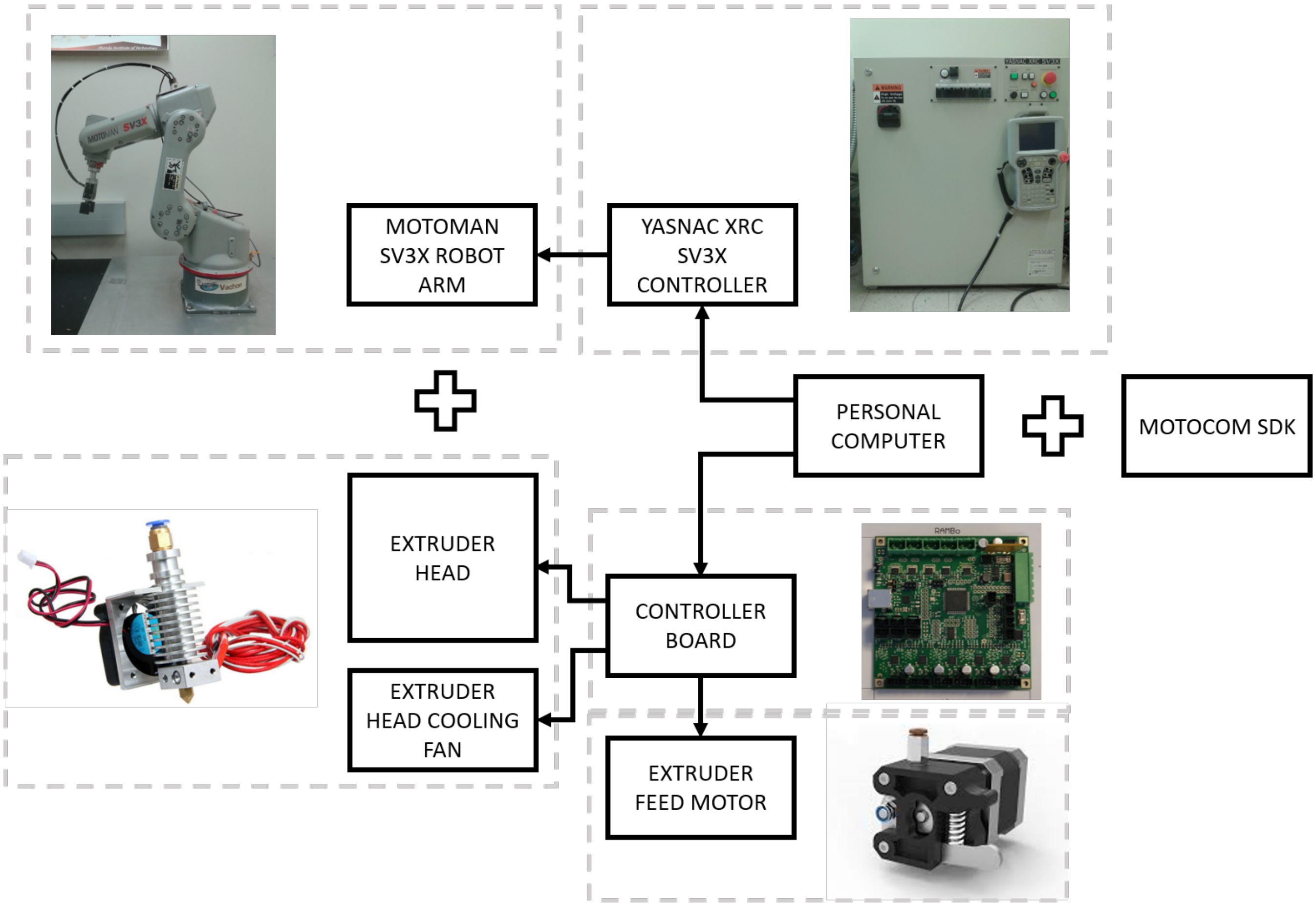

Figure 3. System Block Diagram

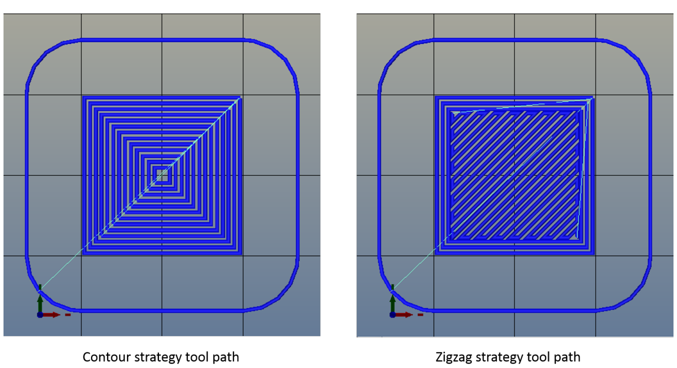

Figure 2. Tool Path Strategy created using SLIC3R[8]

with a 0.4mm nozzle. It will also utilize a remote Bowden style extruder motor setup. The printer uses polylactic acid (PLA), which is a thermoplastic polymer, as the filament for the extruder. The Motoman SV3X has a maximum speed of 7.33 rad/s for the wrist angle, with maximum reach of 677 mm, repeatibility of $\pm$ 0.03 mm, and the controller used is the Yasnac XRC SV3X. A block diagram of the system model is shown in Figure 3.

3.2 Software

New software tools must be developed to interface between the Motoman controller and extruder controller board. Communication between these two systems is critical to developing a robust 3D printer as the robot and extruder need to be synchronized to deposite material appropriately. In order to be able control the robot arm, the MotoCom SDK is used to communicate between a personal computer (PC) and the robot controller utilizing Motoman Robot Job Files (.jbi). The software also needs to control the extruder temperature and speed through the extruder controller board using an Arduino as an interfacing platform. The software will be built to use a PC for preprocessing operations and to control of the robotic arm as well as the extruder head through communication with their respective controllers. A flow chart of the software setup is shown in Figure 4. The proposed software will be developed in the MATLAB enviroment.

4. FUTURE WORK

The increased DoF of an industrial robotic arm platform will enhance the capibilty of rapid prototyping machines over the current generation of machines. To prove the viabily of robotic arms in rapid prototyping, the system described in

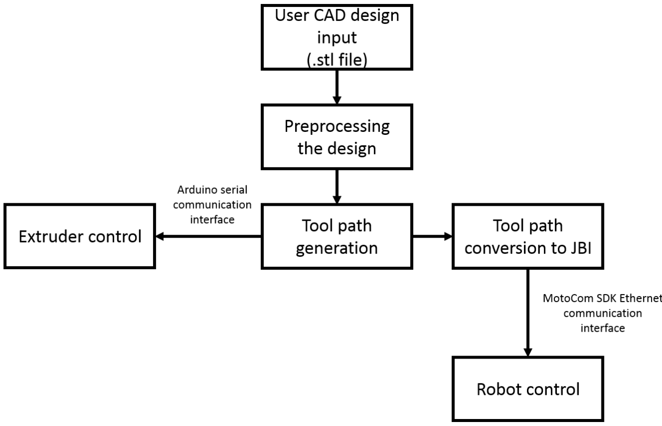

Figure 4. Software Flow Chart

this paper will be built, and the communication software will be developed. To expand the capabilty of the system beyond simple forms, new tool path generation algorithms need to be developed to produce non-planar tool paths for the robot arm that will allow the platform to produce complex 3D parts from CAD models.

5. CONCLUSION

Exploration of the capabilites of the new integrated system leveraging the advantage of the robot arm's kinematics may lead to improvements in the current rapid prototyping process. New material layout strategies can be developed that may lead to improvements in the mechanical strength of printed parts and reduced fabrication time.

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References

[1] T. Economist. Manufacturing: The third industrial revolution. `http://www.economist.com/printedition/2012-04-21`, 2012. [Online; accessed 31-March-2015].

[2] G. Jin, W. Li, L. Gao, and K. Popplewell. A hybrid and adaptive tool-path generation approach of rapid prototyping and manufacturing for biomedical models. *Computers in Industry*, 64(3):336 – 349, 2013.

[3] G. Jin, W. Li, C. Tsai, and L. Wang. Adaptive tool-path generation of rapid prototyping for complex product models. *Journal of Manufacturing Systems*, 30(3):154 – 164, 2011.

[4] R. Jones, P. Haufe, E. Sells, P. Iravani, V. Olliver, C. Palmer, and A. Bowyer. Reprap – the replicating rapid prototyper. *Robotica*, 29:177–191, 1 2011.

[5] S. Keating and N. Oxman. Compound fabrication: A multi-functional robotic platform for digital design and fabrication. *Robotics and Computer-Integrated Manufacturing*, 29(6):439 – 448, 2013.

[6] A. Lanzotti, M. Martorelli, and G. Staiano. Understanding process parameter effects of reprap open-source three-dimensional printers through a design of experiments approach. *Journal of Manufacturing Science and Engineering*, 137(1):011017, 2015.

[7] A. M. Phatak and S. Pande. Optimum part orientation in rapid prototyping using genetic algorithm. *Journal of Manufacturing Systems*, 31(4):395 – 402, 2012. Selected Papers of 40th North American Manufacturing Research Conference.

[8] Slic3r. G-code generator for 3D printers. http://slic3r.org/, 2011. [Online; accessed 30-March-2015].