Solid Freeform Fabrication 2018: Proceedings of the 29th Annual International
Solid Freeform Fabrication Symposium – An Additive Manufacturing Conference
Reviewed Paper

MULTIPLE COLLABORATIVE PRINTING HEADS IN FDM: THE ISSUES IN PROCESS PLANNING

M. Leite*, N. Frutuoso+, B. Soares†, R. Ventura+
*IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
+ISR, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
†UNIDEMI, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Campus da Caparica, 2829-516 Caparica, Portugal.

Abstract

One of the main drawbacks of large-scale FDM is fabrication time, due to the use of a single deposition head. In this paper we propose a novel approach to tool-path generation for a system with multiple collaborative independent deposition heads. This system allows the size of the parts to increase considerably in comparison to regular FDM systems without the corresponding time increase. However, to enable the tool-path generation, the conventional process planning must be changed.

Once the machine configuration is defined, (e.g. number and size of heads), the regions are attributed to each head as either static or dynamic. Then the layer is divided into domains, assigned to each head. A centralized tool-path planner then generates tool-paths, accounting for collisions and optimizing the fabrication time in the layer. The process repeating for all layers.

Examples of this approach show reduced fabrication time and larger part dimensions than conventional systems.

Keywords: Large parts, FDM, collaborate deposition heads.

Introduction

An Additive Manufacturing (AM) process is any process, method or technology where a virtual 3D model is used to manufacture a three-dimensional object through material addition layer by layer [1]. These processes are divided into any number of groups (depending on author), but in several the material is supplied through a nozzle, such as fused deposition modeling (FDM), concrete printing or direct metal deposition [2]. This nozzle is generally mounted in a moving deposition head which extrudes the material, while moving in a predetermined pattern to obtain the part cross section.

These technologies have many processing variables such as nozzle temperature, bed temperature, material feed rate, print head movement speed, but one of the main ones considered is the layer thickness, since it has the highest influence in final part quality, since a higher layer thickness exacerbates one of the main quality issues in AM, which is the staircase effect, increasing volumetric errors [3]. To counteract this stair effect, and therefore improving surface roughness, layer thickness is reduced, increasing the number of layers and nozzle displacement, with a subsequent increase in fabrication time for the part, especially noticed when increasing part volume.

Which means that, for current FDM systems, with one deposition head, on a single track, a trilemma emerges forcing a choice between two of the following three: fabrication time, part volume and part quality (Figure 1). Given the prevalence of the prosumer market, current systems generally opt for part quality and reduced manufacturing time resulting in small parts.

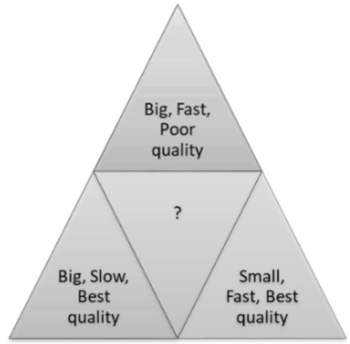

Figure 1 – Trilemma around FDM additive manufacturing process.

Architecture for AM machines with multiple print heads

One answer to the trilemma posed above is the use of multiple print heads. This technology allows material deposition using more than one mechanically independent print head simultaneously. With this technology it becomes possible to increase build area satisfying the need for printing larger objects, without sacrificing quality and with much shorter build times, and increase production volume of smaller parts, maintaining part quality. Considering the latter, a few concepts of multiple print head machines have been created and are described below.

The Stacker company have a patent for a modular system in which the print heads are attached to the same axis in static distances from each other allowing for the replication of (up to) 4 parts simultaneously [4], in what is essentially a 3D printing pantograph, which they commercialize. Jian [5] describes a machine that has rotary print heads than move independently in the radial direction coupled to a rotating shaft perpendicular to the build platform. [6] presents a system where each print head can print its own part simultaneously or print a specific zone of a bigger part. (Zhang and Khoshnevis [7] use what they call the Contour Crafting technique with multiple nozzles, although the deposition is performed at a different scale than FDM. The work proposes two machines, one is composed of one X-Y stage with independent gantries, with the other composed of one overhead platform containing several co-planar gantries, essentially several machines together in one platform.

Autodesk has Project Escher where the concept of multiple independent gantries was also proposed, all working in the same X direction rail. Not much information is available and at the time of writing the authors did not receive a reply for more information on the project. Either way, Project Escher claims to be a technological demonstrator which will not be developed into a commercial product with Autodesk focusing on developing a parallel processing system [8]. Massivit has a patent called Additive Manufacturing Device [9], with multiple print heads in one or multiple tracks parallel to one axis (X axis) of the build platform. Multiple carriages, along these tracks and parallel to the other axis (Y axis), allow for multiple print heads to move independently from each other.

This change in the architecture from one print head, with however many extruders, to a multi print head configuration poses new challenges which means that both machine and process planning must be changed, in order to address the coordination among print heads. What follows is the authors work in a different proposal for a multiple print head machine, where the new challenges are discussed and how the process planning for such a machine might work

A NEW PROPOSAL FOR MULTIPLE PRINTING HEADS

The manufacturing system proposed in this paper in that it allows the different print areas of each print head to overlap. Furthermore, the system proposed allows for a modular design, with multiple printheads in both the X and Y axis, with individual print beds to allow for different sized parts to be printed simultaneously, independent of shape.

The printheads, or deposition modules are divided into upper and lower deposition modules mounted onto rails, with the grouping of deposition modules dependent on the number of rails: if two or more pairs of rails are used, each pair is assembled with only one type of deposition module, but if only one pair of rails is used, then upper and lower deposition modules can work along the same rail pair.

This allows for the different printheads to occupy multiple positions in the print area, and the use of multiple heads to print one part (Figure 2), restrained only by the outer shell of the system and the possibility of contact between deposition heads, although this contact between print heads is prevented by the main module responsible for the process planning.

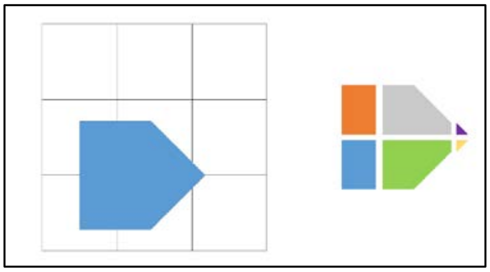

Figure 2 – Diagram showing how multiple heads can print the same part. In the left the part is positioned in a grid. In the right the part is shown with each area corresponding to each deposition head.

This configuration allows for virtually infinite expansion in both axis of both deposition modules and rail pairs, with the deposition modules being removable and interchangeable to suit any specific build. This system modularity presents non-trivial challenges in process planning, since each new configuration represents what is essentially a new architecture, which means that the process planning must adapt to every configuration possible to make use of the collaborative capabilities of a multiple deposition head system, (Figure 3).

Figure 3 – manufacturing system modularity

Since multiple deposition head systems can be considered a new system, there is no standard process planning- at least, not yet. Although it shares all of the steps of a single deposition head AM system, the inherent complexity of using multiple deposition heads collaboratively, avoiding collisions, optimizing the placement of part for least deposition head downtime, among others, presents a significant challenge. The major steps required are presented next and explained in detail below:

- Choice of the most favorable orientation, assessment of the support structure needed and slicing of both part and support.
- Part positioning and partitioning for a calculated number of print heads
- Tool-path generation for multiple print heads, avoiding collisions among them.

Determining orientation, support structure and slicing are straightforward issues, closely related with one deposition head machines. Nonetheless part positioning and partitioning are new challenges, since unlike single deposition head systems, the part should be positioned in a way that allows for the highest amount of printheads to diminish print time (Figure 4).

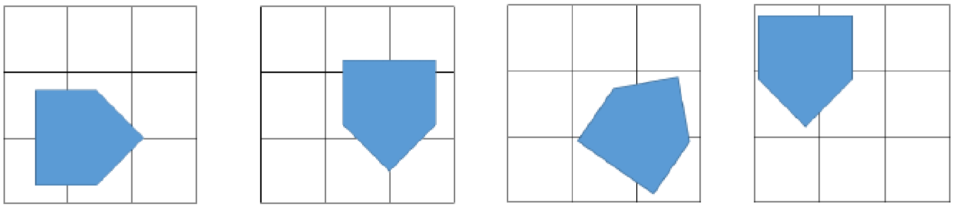

Figure 4 – Possible part positionings in the system

This positioning has to take into account several factors. One factor is that the more heads are used, more collision possibilities exist, which means, if two heads share a printing area, the process planning will have to idle one head to allows the other to deposit material which, at the limit might increase printing time (Figure 5).

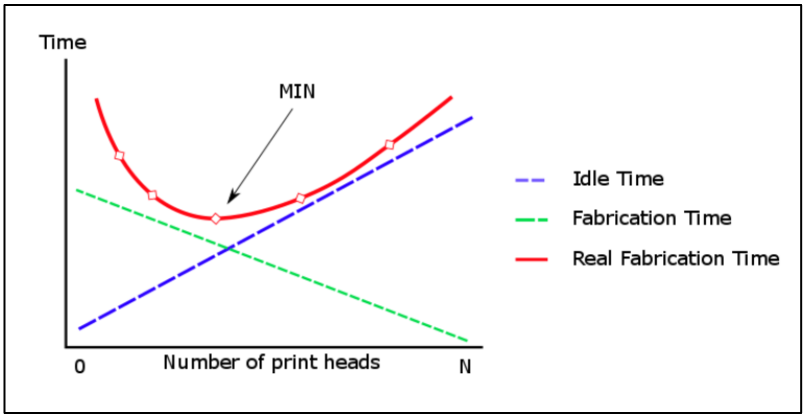

Figure 5 – Relationship between number of print heads, idle time, theoretical fabrication time and real fabrication time

Another factor is the material properties. When using multiple heads there will be two contour lines at each border among the several domains, which might have an implication in material properties under load [6]. To minimize collisions, the tool path generation plays an important role in optimizing toolpaths so that idle times are minimized due to collision avoidance. Figure 6 presents the major steps concerning multiple printing heads.

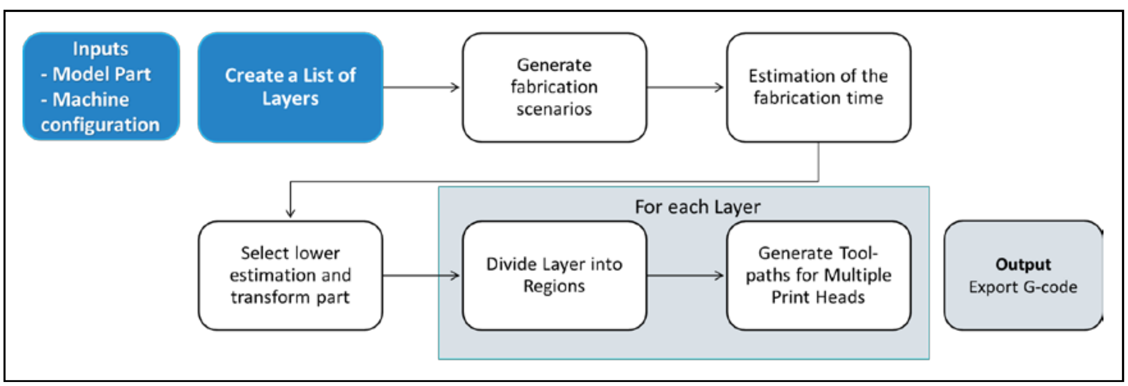

Figure 6 – Process planning for multiple printing heads.

These steps are important for the proposed machine to function properly, and after successful implementation, new avenues of research are open. With the contour lines mentioned above, and the possible loss of mechanical properties, the way the joining of the different deposition heads is performed, called stitching, is of importance.

Another avenue of research is the monitoring and control of the machine. If in the prosumer market, the machines are in open loop, which require constant tuning, or else the part might be scrapped, a small misalignment of the deposition heads in multi head system can cause significant problems, both in terms of possible collisions, but, most importantly, an untuned deposition head in a large part may render the entire part scrap. This problem is compounded by the fact that the build platforms are also movable, which means that, if maintained in an open loop system a 3 by 3 multi deposition head system will have 18 possibilities of failure (9 deposition heads and 9 printing platforms). This means that the system must be in closed loop control, which must be studied.

Each machine described in the beginning exhibit strong valued proposals to users of additive manufacturing technologies for large parts fabrication. The Stacker system allows fabrication of multiple equal parts at the same time. The rotary system suggests that the center might not be printable but is a solution for cylindrical parts that are hollow taking advantage of polar coordinates. Parallel systems push the X dimension for bigger parts. Our proposed concept architecture pushes the dimensions of fabrication area on both, X and Y axis, being at the same time the most complex machine to build and control.

Sample Results

To demonstrate the fabrication time savings of the multiple deposition head system, a computer simulation was developed to determine fabrication time of a sample part with a layer area of 76861 mm^2, as shown in Figure 7.

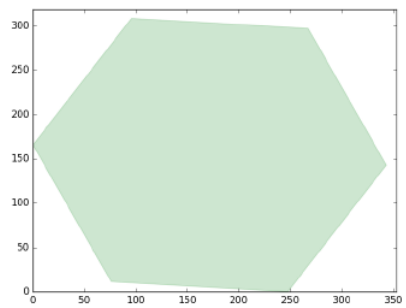

Figure 7 – Example of a part fabricated with multiple printing heads. Units in mm.

The build area was set at 600x600 mm with 9 printing heads available. The printing velocity was 1mm/s with a 35% infill. Collision distance between heads was set at 60 mm. Part positioning was done using a combination of fixed vs variable printing areas, the former meaning that each deposition head would only work in a fixed 200x200 mm space and the latter allowed for a freedom of 600x200mm of each head. Positioning and rotation were performed either with Monte Carlo simulations or with heuristics with Figure 8 showing the position of the part in the build tables and build areas for each deposition head of the 4 cases. It is clear that the first 3 strategies encompass only 4 out of 9 available printing head and the last using 6 deposition heads.

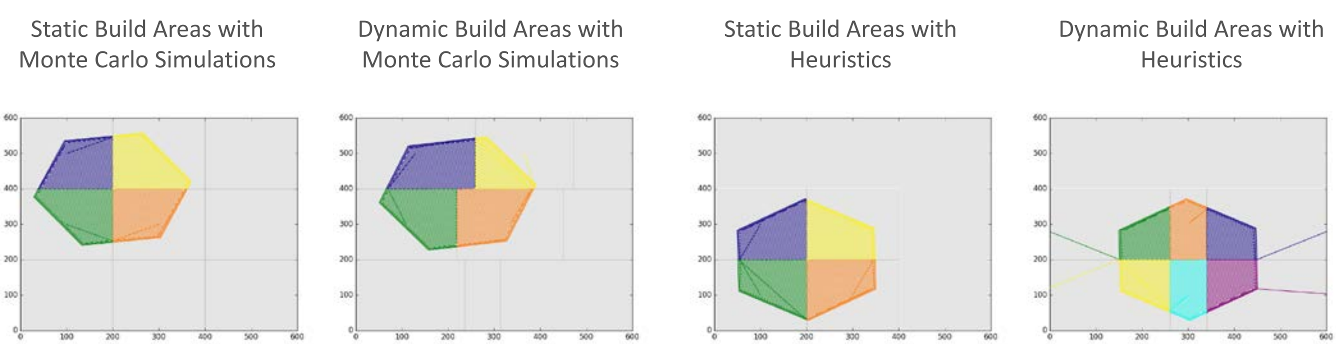

Figure 8 – Part positioning according to several strategies for one layer.

Figure 9 shows the results for part 1.

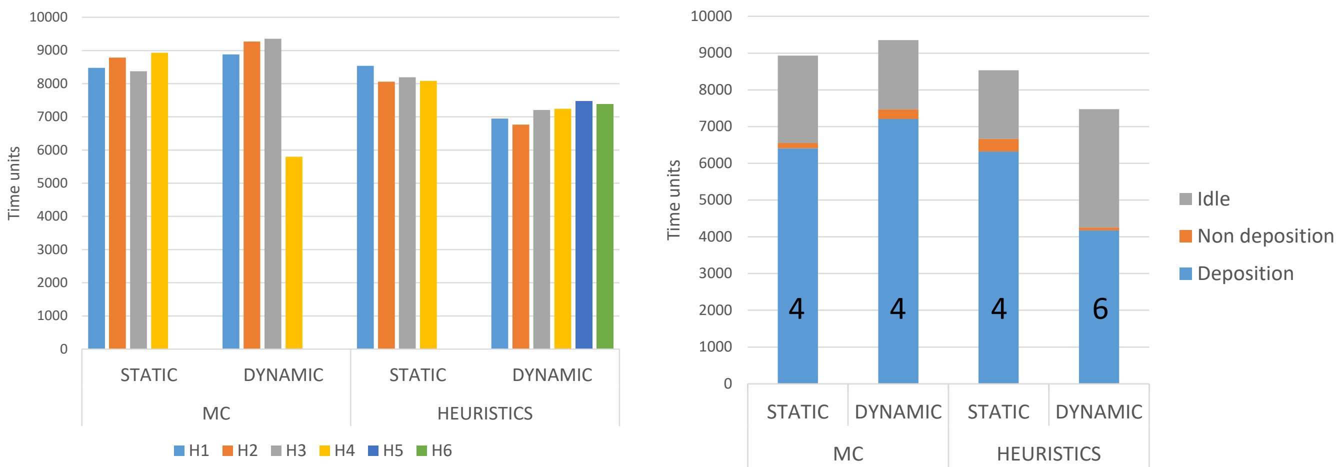

Figure 9 – Left: fabrication time of Part 1 for each print head. Right: Distribution of the fabrication time of Part 1 between idle, deposition and non-deposition times. Time units in seconds.

Regarding positioning, using the heuristics method results in the shortest fabrication time, for both the static and dynamic print areas. The addition of the two extra print heads reduces the print time to about 2 hours from the worst case (dynamic print area with Monte Carlo simulations) of 2 hours and 30 minutes.

It should be noted that although this case is the fastest it has the highest idle time, since with 6 heads the possible number of collisions increases, which results in more deposition head idling.

A run was also performed with only one deposition head, with a fabrication time of about 7 hours, which means that the multiple print head system fabricates the same part 70% faster.

It must be said however, that these fabrication times will tend to vary if subsequent layers are smaller than the one studied, since it may reduce the number of possible deposition heads. And extreme case would be a pyramid shape, where the number of simultaneous deposition heads gets smaller and smaller.

On the other hand during the simulations the deposition head speed was set at 1mm/s, when the even the simpler systems have a head speed of at least 60mm/s, which means that, at those speeds the time per layer would be significantly reduced.

CONCLUSIONS

In this paper the need for printing larger parts using additive manufacturing is addressed, namely in FDM. It is a problem to be overcome if there is to be any penetration of FDM in big part/medium production volume markets, and there are several attempts to solve this issue. The trilemma of time, space and quality is addressed and from the literature review, we can only have two out of three for a single printing head. One possible solution is to multiply the number of heads, while making the fully independent. If the printing heads are independent that means that time to build is reduced, quality can be maintained and dimensions of parts can increase significantly. Several concepts from the literature were reviewed and a new concept for multiple printing heads was presented. With this innovative concept the size of a part can increase without the expense of quality or time. Also new possibilities for research and development are identified and discussed, especially on part positioning and partitioning.

ACKNOWLEDGMENTS

This work was supported by FCT, through IDMEC, under LAETA, project UID/EMS/50022/2013. “Authors gratefully acknowledge the funding of Project POCI-01-0145-FEDER-016414, cofinanced by Programa Operacional Competitividade e Internacionalização and Programa Operacional Regional de Lisboa, through Fundo Europeu de Desenvolvimento Regional (FEDER) and by National Funds through FCT - – Fundação para a Ciência e Tecnologia.”

REFERENCES

1. Gibson, I., D. Rosen, and B. Stucker, *Introduction and Basic Principles*, in *Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing*, I. Gibson, D. Rosen, and B. Stucker, Editors. 2015, Springer New York: New York, NY. p. 1-18.
2. Gibson, I., D.W. Rosen, and B. Stucker, *Additive manufacturing technologies*. Vol. 238. 2010: Springer.
3. Panda, B.N., et al., *A CAD-based approach for measuring volumetric error in layered manufacturing*. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 2016: p. 0954406216634746.
4. Fontaine, N., *Modular user-configurable multi-part 3d layering system and hot end assembly*. 2016, Google Patents.
5. Jian, Z., *3D printer with multiple rotary disc type independent spray heads*. 2015, Google Patents.
6. Wachsmuth, J.P., *Multiple Independent Extrusion Heads for Fused Deposition Modeling*, in *Mechanical Engineering*. 2008, Virginia Polytechnic Institute and State University. p. 95.
7. Zhang, J. and B. Khoshnevis, *Optimal machine operation planning for construction by Contour Crafting*. Automation in Construction, 2013. **29**: p. 50-67.
8. Autodesk. *Project Echer, available at http://projectescher.com/*. 2016, accessed 2 January 2017].
9. Uzan, M. and I. Yakubov, *Additive manufacturing device*. 2015, Google Patents.