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Procedia Manufacturing 21 (2018) 757–764

Procedia MANUFACTURING

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15th Global Conference on Sustainable Manufacturing

Path planning for the infill of 3D printed parts utilizing Hilbert curves

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Abstract

In an attempt to make Additive Manufacturing more eco-friendly, one comes across the idea of simultaneously minimizing the energy consumption and build time. In line with this concept, this paper suggests a method for generating an infill geometry and a path plan strategy for parts constructed with Additive Manufacturing, in a way that idle times are minimized. Hilbert curves are utilized to this end, and a generalization model is provided for parts of any shape. The idea behind this is to enable the creation of the infill pattern with a single continuous motion of the head, so that rapid feed movements are eliminated (per layer), reducing both time and energy consumption. The proposed method for the design of the infill offers the possibility to adjust the filling percentage and it is capable of providing a structure with isotropic properties. Finally, through simulations, the comparison with traditional linear hatching is shown, and benefits arising discussed.

Peer-review under responsibility of the scientific committee of the 15th Global Conference on Sustainable Manufacturing (GCSM).

Keywords: Additive Manufacturing; Modelling; Product Engineering; Estimation; Kinematics; Fused Deposition Modelling; SLS; SLM

1. Introduction

Additive Manufacturing (AM) is a group of processes that refer to the "process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining" [1]. AM can deliver parts of very intricate and complex geometries with a minimum need for post-processing, built from tailored materials with near-zero material waste, while being applicable to a variety of

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2351-9789 © 2018 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the scientific committee of the 15th Global Conference on Sustainable Manufacturing (GCSM).
10.1016/j.promfg.2018.02.181

materials, including plastics and metals [2]. Therefore, AM is a tool that offers increased design freedom and enables designers and engineers to create unique products that can be manufactured at low volumes in an economical way. Due to its inherent benefits as it regards manufacturing of complex structures as well as production flexibility, Additive Manufacturing technologies and methods are increasing constantly in terms of application and market share, spreading into various manufacturing divisions, such as automotive, medical and aerospace, and are expected that this heavy growth will continue over the next few years.

However, one of the main problems faced by the AM industry is the effective path planning used to build up a part. Path planning refers to defining the scanning strategy that will be used to cover the whole surface of a single layer (slice) of the part. AM software usually have predefined hatching patterns, from which the user can select the desired one [3-5]. This is being done arbitrary, but could affect both build-up times, energy usage due to machine acceleration/deceleration, part dimensional accuracy and thermal-induced stresses.

While covering a layer surface, there are two distinct areas that need to be covered. The first one, called the contour, is the line formed by the intersection of the layer plane with the outer surface of the part (Figure 1). It is obvious that the contour has to be fully dense, without pores and having the best possible quality. The second one, called the infill (Figure 1) consists of the area enclosed by the contour. According to the foreseen use and loads of the part, the infill could be fully dense just like the contour, or have a user-defined infill percentage. The infill percentage is defined as the ratio between the volume of material and the volume of free space/voids. As such a fully dense build will have an infill percentage of 100% whereas an empty space will have an infill percentage of 0%.

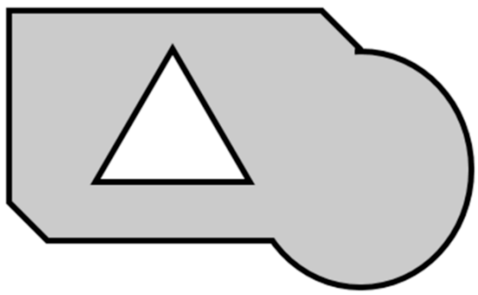

Fig. 1: Slice of part. Black represents the contour while gray represents the infill areas.

An effective path planning strategy would automatically generate the infill geometry as well as create a set of movements in such a way that the total build up time of the layer (and subsequently the part) is minimized.

In the past, there have been works that address the problem theoretically [6] or more elaborated such as Zigzag [7,8], Contour [9-10], Recursive Hilbert's curve [11], Spiral [12] and Fractal curve [13] which is only suitable for some special fractal models. In addition, Hilbert curves have also consisted useful tools in improving the efficiency of Delaunay triangulation in creation of 2D point clouds [14], as well as in generating low-discrepancy point distributions on surfaces [15]. The latter was achieved by distributing points along a space-filling Hilbert curve, reducing the low-discrepancy point distribution generation problem from 2D to 1D.

This work proposes an extended method to generate the curves (path) appropriate for covering the infill of a slice, either with full density or with lower infill percentages (as part of a more generic optimization scheme [16]). The method adopts the idle times minimization methodology [17] to address sustainable manufacturing [18] and more specifically the simultaneous energy consumption and build time minimization.

2. Approach

An effective method to simultaneously minimize energy consumption and total build time in Additive Manufacturing would be the total elimination of rapid head moves. Besides the obvious time delays introduced by these moves, energy consumption during the acceleration/deceleration phases of the processing head is extremely high, due to the high acceleration values. Moreover, rapid feed moves cause the processing head to cool down, requiring additional energy for re-heating. In addition, severe acceleration and deceleration can cause premature wear in motor