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Automatic multi-direction slicing algorithms for wire based additive manufacturing

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ABSTRACT

One of the key challenges in Additive Manufacturing is to develop a robust algorithm to slice CAD models into a set of layers which requires minimal support structures. This paper reports the concept and implementation of a new strategy for multi-direction slicing of CAD models represented in STL format. Differing from the existing multi-direction slicing approaches that are mainly focused on finding an optimal volume decomposition strategy, this study presents a decomposition-regrouping method. The CAD model is firstly decomposed into sub-volumes using a simple curvature-based volume decomposition method. Then a depth-tree structure based on topology information is introduced to merge them into ordered groups for slicing. In addition, a model simplification step is introduced before CAD model decomposition to significantly enhance the capability of the proposed multi-direction strategy. The proposed strategy is shown to be simple and efficient on various tests parts especially for geometries with large number of holes.

1. Introduction

Additive manufacturing (AM) builds up a component through the deposition of materials layer-by-layer instead of starting with an over dimensioned raw block and removing unwanted material as in conventional subtractive manufacturing [1,2]. It becomes a promising alternative for fabricating components made of expensive materials, such as titanium and nickel, in aerospace industry, which suffers an extremely high buy-to-fly ratio [3,4]. Recently, wire based AM technologies have gained research interest for manufacturing metal components with medium to large size due to its combined advantages of high deposition rate, environmental friendliness, and cost competitiveness [5–7].

Most of the current powder bed fusion AM processes involve slicing a 3D CAD model into a set of 2.5D layers with a constant or adaptive thickness perpendicular to the build-up direction (usually designated as the $Z+$ direction) [8,9]. However, to fabricate parts with complex shapes in wire based AM technologies, processes based on a uni-directional slicing strategy are generally limited by the need for support structures to deposit overhangs. Fig. 1a shows a component and its usual build direction B. It is clear that to fabricate the component in direction B, support structures (refer Fig. 1b) are required due to overhangs. For metal components, the supports are normally deposited using the same material [10]. The deposition of supports results in the wastage of materials and the removal of these supports requires costly post-processing.

Robotic AM, which mounts a deposition nozzle on a multi-axis robot arm, is able to deposit materials along multiple directions [11]. The application of robotic AM could eliminate or significantly decrease the usage of supports for complex components. As shown in Fig. 1c, the component can be fabricated in multiple directions, e.g., B_1, B_2, B_3, without support structures. Such a multi-direction deposition system furthers the capability of layered manufacturing by reducing the need for supports. A key challenge in multi-direction AM is to develop robust algorithms capable of automatically slicing any 3D model into a set of layers which satisfy support-less and collision-free layered deposition.

This paper proposes an innovative strategy to slice CAD models in multiple directions for wire based AM system, such as wire arc additive manufacturing. The remainder of the paper is organized as follows: Section 2 presents the related works on multi-direction slicing for AM. Section 3 provides an overview of the proposed strategy. Detailed algorithms are introduces in Section 4 followed by implementation and results in Section 5. The paper ends with conclusions and future works in Section 6.

2. Related works

In AM, slicing is an important process that yields a set of layers for subsequent tool-path generation. These 2.5D layers are

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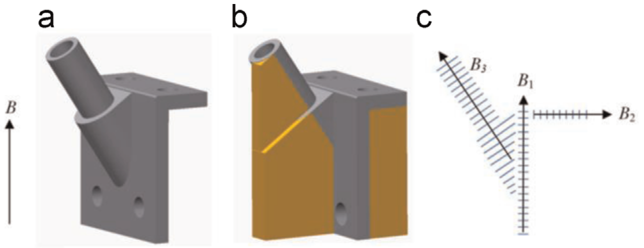

Fig. 1. (a) The component and its usual build direction *B*; (b) support required (parts coloured in orange); (c) multi-direction slicing and various build directions B_1, B_2, B_3. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

generally parallel to each other and perpendicular to the build-up direction. Slicing algorithms producing 2.5D layers with both a constant and adaptive thickness have been widely studied. Recently, research focus has shifted to multi-direction slicing which varies not only in layer thickness but also in slicing direction. This technique significantly improves the ability of AM for producing complex components. Some existing multi-direction slicing strategies are reviewed here.

Silhouette edges projection [11]: this strategy firstly identifies the unbuildable surface features of a model by projecting silhouette edges along the user defined original build direction. Then the part is decomposed into buildable and unbuildable sub-volumes using the silhouette-edge based method. For the unbuildable sub-volume, a new suitable build direction is determined using the Gauss and Visibility maps. With the new build direction, the unbuildable sub-volume is further decomposed through repeating the same projection procedures. This projection method is recursively used to decompose the sub-volume until the generated sub-volume is buildable along one direction. The framework for the multi-direction slicing and some essential problems have been addressed and discussed by the authors. However, the implementation of the strategy could be complicated and computationally expensive for complex components with inner cavities.

Transition wall [12]: the key idea of this strategy is to identify the overhang layers by computing the difference between the current layer and the previous layer. Then, to build an overhang structure, the machine is turned 90° to start depositing a transition, namely thin wall. After the deposition of the first few layers, the wall is finished and the subsequent overhang structures can be deposited in the vertical direction again. Although this strategy is simple, it is only suitable for a subset of part geometries. In some cases, the deposition of the transition wall is difficult or impossible to implement due to deposition nozzle collision, such as the part shown in Fig. 1a.

Centroid axis extraction [13]: the first step in this strategy is to extract the centroid axis of the model which provides a global perspective on the geometry, allowing the slicing procedure to be conducted on an optimal sequence. Through analysing the topological information from the centroid axis, the splitting surface is identified and the subsequent decomposition operation is conducted. For each sub-component obtained from decomposition, multi-axis slicing is performed and the collision free slicing sequence is finally generated. The centroid axis extraction method decomposes the component by detecting the change of centroid of pre-sliced layers, making the geometry analysis process easier. However, in some cases it will be difficult to decompose components efficiently as required since the centroid axis does not always indicate the change of the geometry.

Other multi-direction slicing methods have been proposed that are either adaptions or combinations of a few techniques from the above strategies, such as normal marching algorithm [10], offset slicing [14], skeleton method [15], and modular boundary decomposition [16]. However, each method is only suitable for a subset of part geometries. In addition, these methods are not efficient for processing parts with holes and depression features. As shown in Fig. 2a, the part is decomposed into buildable volume and unbuildable volume due to the direction of hole, *H*, is vertical to the build direction, *B*, of its associated volume. Fig. 2b shows the part with holes as well. The part is firstly decomposed into buildable and unbuildable sub-volume [11]. The unbuildable sub-volume could be further build by offset slicing strategy [14] with the direction as shown in Fig. 2b. Even though, unbuildable volume also exists due to the holes. It is clear that holes would be obstacle for implementing multi-direction slicing algorithm.

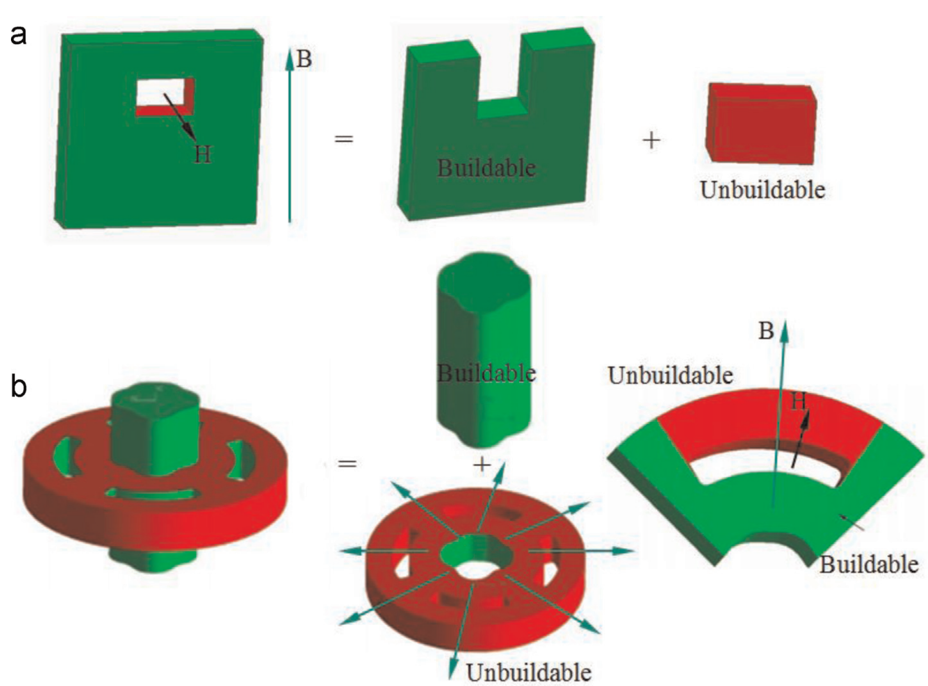

Fig. 2. Illustration of the impact of holes on multi-direction slicing strategy.