Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 36 (2015) 217 – 222

www.elsevier.com/locate/procedia

CIRP 25th Design Conference Innovative Product Creation

Functionality-based part orientation for additive manufacturing

Giovanni Moroni, Wahyudin P. Syam*, Stefano Petrò

Department of Mechanical Engineering, Politecnico di Milano, Via La Masa 1, Milan 20156, Italy

* Corresponding author. Tel.: +39-0223998593; fax: +39-0223998585. *E-mail address:* wahyudinpermana.syam@polimi.it

Abstract

Additive manufacturing (AM) is already diffused and well-accepted as a revolutionary method of manufacturing. The main advantage gained by using AM compared to conventional subtractive method is its capability to produce parts which have high shape complexity, different material composition, hierarchical complexity and functionality complexity. Besides, to be able to utilize fully the abilities of AM, specific design tools are needed. For example, the part orientation must be optimally defined before fabrication by AM. Several studies to optimize part orientation have been proposed. Indeed, aspects to optimize in the choice of the orientation include the minimization of the surface roughness, build time, need of supports, and the increase of the part stability in building process, but there are very few work related to the accuracy of the part. Despite all these considerations, they consider the part as a single component. AM instead can directly fabricate assemblies, such as mechanical joints. In this type of part, the most important feature is the assembly feature. As such, orientation consideration should mainly focus on these features and not necessarily the whole part. This paper proposes a method to orient a part considering all components as a functional assembly. A case study of universal U-joint is presented to validate the proposed methodology.

Peer-review under responsibility of the scientific committee of the CIRP 25th Design Conference Innovative Product Creation

Keywords: Additive manufacturing; part orientation; curvature estimation; mesh segmentation; STL

1. Introduction

Additive manufacturing (AM) is well-accepted a revolutionary method in manufacturing. AM technology offers the ability to realize a product having high shape complexity, different material compositions, high hierarchical complexity and functional complexity [1]. It is one of the enabler of mass customization and personal fabrication [2]. AM produces part in a layer-by-layer fashion, realizing very complex shape products non conventionally manufacturable, turning directly a computer aided design (CAD) model into a finished product often without any fixturing design [3]. To be used in AM the CAD model is converted into a triangle-mesh format, called Standard Triangulation Language (STL) format. Before the file is transferred to an AM machine, a file preparation step is carried out to optimize the build process, defining: part placement inside the working volume, support determination for overhang part, and part orientation.

The scheme of additive manufacturing from design to physical product by AM process is depicted in Fig. 1. From this figure, the process is explained as follow. First, a 3D model is designed using a CAD software. The file then is converted into STL format. Subsequently, a file preparation step is carried out to optimize the process, e.g. by determining part orientation, the position of the part inside the working volume, etc. Finally, the file is sent to an AM machine controller to start the fabrication process. The ability of AM to manufacture products with functional complexity means that this technology can directly produce assembled products [1],[5]. Therefore, the number of components required by a functional product can be reduced. Fig. 2 and 3 show an example of a universal-joint design for as manufactured by conventional and AM methods respectively. From these

Peer-review under responsibility of the scientific committee of the CIRP 25th Design Conference Innovative Product Creation
doi:10.1016/j.procir.2015.01.015

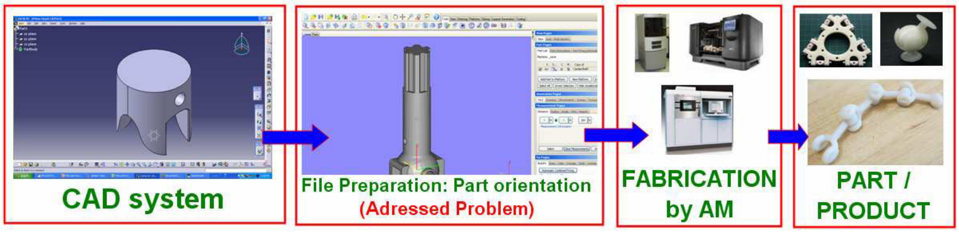

Fig. 1. Steps in AM from design to final part/product.

figures, it is worth noting that the total number of components, moving from conventional to AM method, reduces from seven to three.

1.1. Part orientation problem

In this study, how to optimally orient a part for AM is addressed. The problem is a part of the file preparation stage in the AM process chain (Fig. 1). It is a relevant problem since the determination of part orientation is complex and time consuming due to many contradictive trade off which have to be considered, including surface quality and build time [4]. Different approaches yield different solutions, e.g. High volume of support materials will be needed if large area of surface is horizontally placed, instead in this condition the build time will be reduced since the number of layers will be less compared to that if the part is in vertical orientation. Usually, the proposed orientation optimizes some objective function related to the part functionality. Common objective functions to optimize the part orientation selection are to improve surface finish (reduce roughness), increase part strength in a specific direction, reduce support material, minimize build time and maximizing part geometric accuracy [6]. In the case AM manufactures an assembled product, part orientation should consider all the components constituting the product. This paper proposes a method to orient a part (representing an assembled product) considering all components as a functional assembly.

2. Existing part orientation methodology: state of the art

Many methods have been reported to optimize part orientation for fabrication by means of AM. Starting from 20 years ago, Cheng et al [7] optimized part orientation by optimizing two contradictive objective functions, maximizing surface accuracy and minimizing build time. The part analysis process was carried out from the CAD environment by means of a CAD interface library. The optimized orientation of the CAD file was then converted to an STL file and sliced. Pham et al [8] reported a method to orient a STL part by addressing the objective one-by-one. By this, the problem becomes a single objective optimization that is easier to solve compared to a multi-objective one. Their objective function included maximizing surface finish, minimizing support volume, minimizing build time. Masood et al [9] studied part orientation by minimizing the difference between CAD

volume and built volume of prismatic part. The problem is a single objective optimization. They also studied part orientation optimization based on similar criteria for sculptured parts which is more general [10, 11]. The files used in their studies were both CAD and STL.

Heuristic search by genetic algorithm (GA) method to solve optimization problem of part orientation were used, especially the one with multiple objective function [12-20]. The common objectives were maximizing surface finish and minimizing build time. Additional objective beside these two were minimizing support needed for overhang feature [15], maximizing part stability in building process [16], minimizing post-processing time [18] and minimizing quantity of material used to fabricate a part [20]. Particle swarm optimization was utilized by Ghorpade et al [21] for objective function of optimal surface finish and build time. An iterative-based trust region method to solve the multi-objective function problem was used by Singhal et al [22]. All the optimization procedures for the multi-objective based part orientation were carried out on STL files.

Ahn et al [23] used GA to solve single objective optimization to orient a STL part fabricated by laminated object manufacturing. Their main goal was to minimize post machining time. A trust-region method was used by Singhal et al [24] to optimize surface finish as the single objective. They used STL file to carry out the analysis. Paul and Anand [25] used graphical technique to orient the part to increase the part accuracy. They used both CAD and STL file in their method.

The mentioned part orientation studies mostly concentrated on a single part and considered its whole part body to build. The question is if one builds a functional assembled product by AM, then the part analysis should be carried out for specific features of the whole assembly. In an assembly product, the most important features to guarantee the components can be assembled and functioning are its assembly features. Therefore, care should be taken mainly in the choice of the orientation of these features during AM. In this paper, we propose a method to determine assembly orientation by focusing on its assembly features to fabricate a functional assembled product. The feature considered is a cylindrical feature presenting a shaft-hole relationship. In a rotational join of shaft and hole, it is important that the surface quality of these features should have low roughness. Based on this consideration, the part orientation problem is addressed.

3. Functionality-based part orientation methodology

This section presents the methodology to optimize functionally the STL part orientation. The basic idea is to focus part orientation on the assembly features of components