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An ontology-oriented knowledge methodology for process planning in additive layer manufacturing

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ABSTRACT

The goal of this research is the generation of a novel knowledge with process-oriented ontology and the informal model. With regard to the proposed ontology, it establishes an improvement to related ontologies because it involves the demands of fabrication engineering and, specifically, the layer-upon-layer manufacturing planning process with various AM systems. Generally, task of AM planning indicates to make repeated and essential decisions which are always on the basis of the engineers' knowledge and experience in additive manufacturing. Hence, it is a suitable field towards the execution of a knowledge-based engineering system. To represent the knowledge at an upper tier, the IDEF0 diagrams is introduced for identifying the sequence of tasks contained in the AM planning. They are a vital resources for defining the sequence of tasks and the messages flow. Afterward, these messages are analyzed thoroughly by applying schematic graphs, and then they are categorized into knowledge segments. Eventually, each knowledge segment is further divided into knowledge entities. At the same time, the relationships among them are also defined.

Meanwhile, knowledge modeling involved generating an ontology of design feature which is utilized as a general information model in both computer-aided design and process planning, expression of fabrication criteria that depict the basis and properties for picking fabrication parameters. In a first method, the ontology has been examined utilizing an essential activity in AM planning: the task related to the confirmation of parameters over component quality. In this task, decisions have to be made in the orientation, slicing and the other process parameters. In this research, the differences between geometric and dimensional tolerance fabrication is considered in the generated methodology. The knowledge needed to aid all decisions is expressed utilizing the proposed ontology.

1. Introduction

Since 1980s, various additive manufacturing (or Additive layer manufacturing, AM) methods have been generated to support product development [1,2]. It transforms a CAD model into a substantial object using a series of techniques, including facet-based model generation, orientation, slicing, supporting, path creation, layer-upon-layer fabrication, and post processing [3,4]. In spite of experienced fabricators, it is difficult to choose proper parameter values to reach the objectives what customer required in AM [5]. Meanwhile, many researches concerning the modeling and re-utilization of knowledge for process planning in manufacturing are proposed in recent decade, the benefits are more significant than a traditional manufacturing mode [6–8]. Therefore, we intend to generate a knowledge-based approach that can support experienced fabricators to do appropriate and fast decisions in design parameters and their corresponding values in AM.

Generally, the manufacturing process is composed of three major phases: pre-processing, processing and post-processing. In this research, the differences in process planning in subtractive (i.e. CNC machining) and additive manufacturing (i.e. SLA, SLS and FDM) are depicted through these phases. The contents are shown in Table 1. Compared with subtractive processes, task of AM planning indicates to make repeated and essential decisions which are always on the basis of the engineers' knowledge and experience in additive manufacturing. Meanwhile, the consumable materials (e.g. liquid photo polymer, powdered nylon/polyamide, and fused filament) in AM are expensive because of the patent prescription, so the failure in product fabrication must be avoided possibly. For making the same component, the fabricated time in AM is longer than CNC machining. To solve the above problems and apply experts' knowledge and technology effectively, the process planning of additive manufacturing is essential. In addition, additive layer-based fabrication has more restricted parameters and steady planning way, enabling design with knowledge-based methods to handle the situation of process planning.

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Table 1
Differences in process planning in subtractive and additive manufacturing.

Name/Phase	Subtractive manufacturing (i.e. CNC machining)	Additive manufacturing (i.e. SLA, SLS and FDM)
Pre-processing	The workpiece, machine-tools (such as cutters and fixtures), as well as other consumable (e.g. cutting fluid) have to be prepared.	The consumable material (e.g. liquid photo polymer, powdered nylon/ polyamide, or fused filament) and machine-tools (such as laser unit or extrusion nozzle) are prepared according to the type of AM machine. Meanwhile, the CAD model has to be converted into specific file format, e.g. STL, SLC, etc., before part fabrication.
	The planning is designed using the above mentioned information. Besides, cutting path planning is vital in this phase. According to the available information of CAD model, the machining parameters have to be assigned, especially, the planning of interference-free tool path and tool exchange	Furthermore, three primary tasks have to be accomplished: determination of build direction, slicing mode and optimization of fabricated parameter.
Processing	Machining of component	Fabrication of component
Post-processing	The inspection operation is implemented to ensure all requirements of the component are achieved. Besides, the surface treatment is also considered for some cases which are required to reach expected quality.	The surface treatment is main task, including support removal, polishing, and painting, etc.

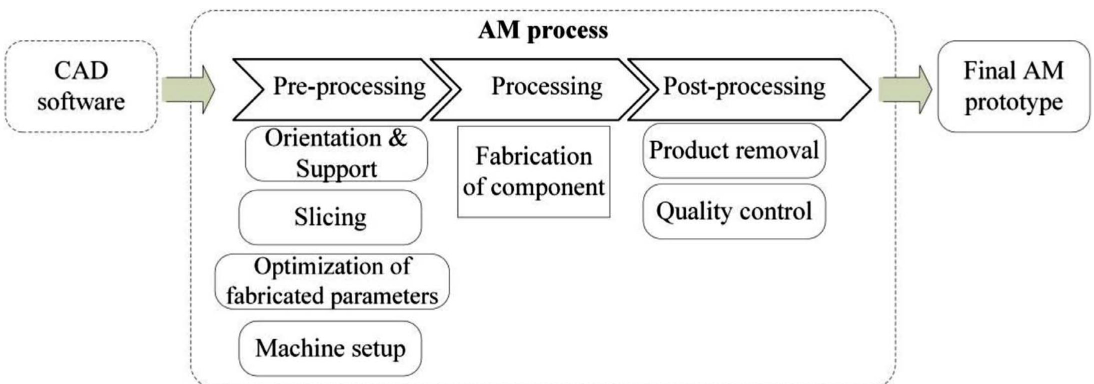

Fig. 1. Diagram of the overall process flow in AM.

The tasks related to process planning in AM are illustrated in Fig. 1. The present AM machines usually can accept facet-based models (e.g. STL file) from CAD software. This enables the availability of implementing orientation, support generation, slicing, and other fabricated parameters on different pre-processing modules installed in different AM machines. Concerning the aspect of part orientation, it is one of the vital tasks to assure the fabrication quality of components. For one given component, in principle, several possible infinite fabricated orientations can be selected. To assure component's quality, it should be constructed in its optimal or near optimal position. Masood et al. [9] presented an algorithm that analyzes staircase area and volume error of slice thickness to decide the optimum orientation. Pandey et al. [10] developed a multi-objective methodology is applied for deciding optimal component orientation in FDM through considering proper component surface quality and build time. To determine the optimal orientation from the alternative orientations selected in the convex hull of a model, a decision-making approach of multi-property was proposed [11]. In the aspect of support generation, it is an important task in AM process for promoting the efficiency of fabrication. There are two support structures built: external and internal support structures. The former is used to support the overhanging regions; the latter is applied to fill internal region with support structures, therefore material and time for fabricating model could be reduced obviously. Bo et al. [16] mentioned a discrete-marking support algorithm for processing a triangular facet-based part model on the support plane. Strano et al. [17] applied a novel optimization algorithm to use mathematical three-dimensional connotative functions towards the creation of the unit support structures. Habib and Khoda [18] developed the approach of *k*th nearest point to create the boundary support contour for building the support structure. For free-form model, the support structure is constructed by applying both approaches of continuity and connectivity.

As for the aspect of slicing mode, the model followed by slicing of it into many horizontal slices after support generation. Each layer becomes important element to approaches for generating the paths of material deposition /solidification. Afterward, they are re-built physically in fabricating the prototype. Chen et al. [12] generated a module that split a CAD model into slices directly, each of which are recorded in the graph file. Chakraborty and Choudhury [13] exported a sliced file using an intersection plane approach. Zhou et al. [14] presented an adaptive slicing approach to get a more efficient result applying a variable cusp height as a basis. Huang and Singammeni [15] developed an alternate slicing and deposition strategies in FDM. Regarding the aspect of process optimization, Ponche et al. [19] addressed a novel numerical chain on the basis of a global DFAM approach. Through the process features and conditions from the specifications of a component, an optimized process planning is decided. Kroa et al. [20] applied a finite element method to determine the prioritization of process variables for achieving the purpose of an efficient optimization in AM. Due to a large number of researches in the corresponding issues of AM process, it is great potentiality to establish a knowledge-based methodology to help process planning.

To satisfy the design for manufacturing, process planning serves as a crucial coordinator in both phases. Thus, creation of a product information model is essential. Furthermore, feature is often defined and applied for product development [21,22]. It is also treated as an element of product recognition in process planning [23,24]. On the other hand, ontology is a conceptualization with explicit specification in unanimity filed knowledge, it has been used popularly in modeling and retrieval of knowledge engineering for product lifecycle management. For example, Garcia et al. [25] proposed the design and implementation of an ontology-based system in the domain of sheet-metal engineering. Dartigues et al. [26] presented a methodology for integrating CAD and CAPP by means of feature ontology. Gruninger and Delaval [27] generated an ontology for the machining process of sheet metal components, this method was presented as a theoretical step for supporting process planning.