Computer-Aided Design 37 (2005) 387–397

COMPUTER-AIDED DESIGN

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Direct slicing of STEP based NURBS models for layered manufacturing

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Received 19 November 2003; received in revised form 4 June 2004; accepted 26 June 2004

Abstract

Direct slicing of CAD models to generate process planning instructions for solid freeform fabrication may overcome inherent disadvantages of using stereolithography format in terms of the process accuracy, ease of file management, and incorporation of multiple materials. This paper will present the results of our development of a direct slicing algorithm for layered freeform fabrication. The direct slicing algorithm was based on a neutral, international standard (ISO 10303) STEP-formatted non-uniform rational B-spline (NURBS) geometric representation and is intended to be independent of any commercial CAD software. The following aspects of the development effort will be presented: (1) determination of optimal build direction based upon STEP-based NURBS models; (2) adaptive subdivision of NURBS data for geometric refinement; and (3) ray-casting slice generation into sets of raster patterns. The development also provides for multi-material slicing and will provide an effective tool in heterogeneous slicing processes.

Keywords: Direct slicing; Solid freeform fabrication; Layered manufacturing; Biomodeling; Medical rapid prototyping

1. Introduction

The growth of solid freeform fabrication (SFF) or layered manufacturing (LM) in biomedical applications has created the need for better technology in terms of model representation, accuracy and functionality [1]. SFF models in medicine have been used mainly for assisting diagnosis, surgical planning, and manufacture of orthopedic implants. However, the technology has recently seen applications in the field of tissue engineering specifically in the fabrication of tissue scaffold structures. Traditionally, LM process involves the conversion of the 3D models into STereo-Lithography (.STL) format, a tessellation procedure where the model is approximated by triangles, sliced and then fabricated by the machine. The procedure worked well in the manufacturing industry which used RP to evaluate product designs and aesthetics by producing actual prototypes of the proposed design. However, the geometric description used to represent solid CAD objects significantly affects the accuracy and quality of the final parts produced especially in the case of freeform shapes. This is particularly relevant in the field of computer aided tissue engineering [2] which involves the use of these freeform shapes to model the external shape of the scaffold that intends to replace actual body sections. The complexity of the internal and external shape of these scaffolds [3,4] requires a more direct method in conversion of CAD data to process planning instructions. The process of tessellation and representation in STL format is inadequate for designing biomimetic scaffolds with complex internal architecture. This is due to the large number of triangles required to represent small features in the scaffold which results in failure during the conversion process. Direct slicing of CAD models without the intermediate .STL format is preferred because it helps keep the geometric and topological robustness that the original data have and no intermediate conversion process is required. This approach has advantages over the indirect slicing method which include greater model accuracy, pre-processing time reduction, checking and elimination of repair routines, file size reduction and more importantly support for multi material slicing.

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doi:10.1016/j.cad.2004.06.014

The field of direct slicing for LM has been researched on for some time. Some of the earliest works were applied to traditional industrial applications and did not really focus on medical prototyping applications. Jamieson and Hacker [5] developed an adaptive direct slicing algorithm based on the unigraphics based slice modules which directly sliced models using a constant layer thickness. Consecutive contours were compared and if the difference was small, they were accepted. If not, a middle slice is created and the process of comparison performed again. The procedure is repeated until the difference between any two consecutive slice contours is either small or the minimum layer thickness has been reached. Rajagopalan et al. [6], have directly sliced non-uniform rational B-spline (NURBS) based models in an I-DEAS based CAD system. The process relied on I-DEAS system functions to perform the slicing which made it package-specific. In a more recent study, Ma and Peiren [7] developed an adaptive direct slicing algorithm that operates directly on NURBS based models to generate skin contours and then uses a selective hatching strategy to reduce the build time of the model. All of the papers published above depend on external modeling packages to perform the slicing process which in turn limits the capability on the level of control and variety that can be achieved. Zhao and Laperriere [8] in their work worked on an adaptive direct slicing approach independent of CAD vendors in which they make use of AUTOCAD API functions to perform the slicing operation. Using API functions does provide more control but they have showed inappropriate slicing when applied to scaffolds with complex external shapes. Fig. 1 shows failure at a particular z-level during slicing of a sinus implant using the slice functions available from a major CAD vendor.

Therefore, the objective of this paper is to present a direct slicing approach that is independent of any CAD modeling package and that which makes use of STEP as the starting input file of the model to be prototyped. The approach described here is feasible for both traditional manufacturing designs as well as for biomedical applications. We have currently focused on NURBS based freeform shapes to demonstrate the capability of the algorithm and the proposed methodology with regards to raster line pattern layout suited for the 3DP™ machines. However, the work can be extended to include contour slice patterns along with a hatching strategy depending on the intended RP machine. A point that we would like to stress is that the proposed method in no way replaces the STL based method of indirect slicing which is more suited to traditional manufacturing components. The following method however works well for freeform shapes that have complex outer geometry which in its STL representation carries drawbacks as mentioned in the first paragraph. Since the design of scaffolds for tissue engineering applications involve complex outer geometrical shapes, the direct method of slicing would be more advantageous than the indirect method of slicing.

Fig. 1. API slice errors from a major CAD vendor.

The paper is organized as follows. The following section will briefly detail the generalized process of RP manufacturing in the clinical medicine and tissue engineering scenario. A brief description of the NURBS equation that we need to solve for is also described. The third section details the process of ray-casting and the steps taken to obtain the ray-raster patterns during slicing. The key steps of optimal orientation, adaptive refinement, root finding and evaluation of points are detailed. Section 4 gives several case study characteristic models that have been sliced to showcase the efficacy of the proposed method. The paper concludes with a summary and future research initiatives.

2. Overview of direct slicing using STEP based NURBS models

2.1. General biomodeling application process path

The first step involves the acquisition of CT/MRI images of the bone under replacement. These CT images are loaded in commercially available image processing software to reconstruct them to CAD models through reverse engineering techniques. The CAD model is now sliced to generate process plan instructions for the relevant RP machine. The machine prototypes the required scaffold for the desired application. Although tissue engineering applications processes would involve more stages until final fabrication, the steps remain the same and a similar process path needs to be followed. For further details regarding reverse engineering techniques and CAD based model reconstruction, the authors refer them to [9]. Our focus in this paper will be the conversion of CAD models to process planning instructions for the RP machine. Although the conventional method is to convert the CAD model to an STL based model, our effort is to directly slice the CAD model and transfer information to the machine eliminating the need for the intermediate file format. The overall process path for a general medical rapid prototype production in building the external shape of a scaffold is as shown in Fig. 2.

The process data flow is shown in Fig. 3 that is implemented within a Fabrication Planning software framework. Initially, the CAD STEP file is input into the software framework wherein a STEP reader is implemented to extract out the model features. The B-rep features of the model are viewed using graphic kernels for easier manipulation and display. The model features in its NURBS representation is then transferred to the slicing module. Each cross sectional layer is then extracted from the model based on the slicing parameters and then converted to machine job instructions. A print job database is also maintained for database records and future retrievals.