Chapter 1

Introduction

1.1 Introduction

Rapid prototyping (RP) refers to a class of layer based manufacturing processes that produces complex parts directly from CAD models. In contrast to the traditional material removal processes such as milling, turning and drilling, the most common RP processes build a part by gradually adding or solidifying materials layer by layer [Kochan 93]. Sometimes, rapid prototyping is referred to as layered manufacturing (LM) or solid freeform fabrication.

In the late 1970s and early 1980s, there were several attempts to build three-dimensional (3D) objects using lasers with photopolymers. But these attempts never reached a commercial or product phase [Beaman 97]. In 1987, 3D Systems, Inc., USA introduced the first commercially available rapid prototyping system called “Stereolithography Apparatus (SLA)” [Jacobs 96]. Numerous RP processes have been developed since the first RP system was introduced back in 1987.

Most of the RP processes can be classified into five categories based on their material building strategies [Beaman 97]: (1) photolithography, (2) laser fusion, (3) lamination, (4) extrusion, and (5) ink-jet printing. Photolithography systems use light or laser to selectively solidify a photocurable material. Processes in the laser fusion category use laser energy to selectively sinter the powdered materials such as polymer, metal and ceramic powders. Lamination processes use plastic or paper sheets to build RP parts. Each sheet cut by laser is indexed over the previously cut patterns and bonded together using a heated roller. In extrusion, a continuous filament of a thermoplastic polymer or wax is deposited through a heated nozzle layer-by-layer to build the RP parts. Some of the RP processes use the concept of ink-jet printing to create 3D solid parts. All of the processes mentioned here are based on the same idea: build the 3D complex objects with simple layers. Details of each rapid prototyping process are presented in Chapter 2.
There are several advantages in using rapid prototyping processes over traditional material removal processes. First, complex parts can be fabricated just as easily as the simple parts because 3D CAD models are decomposed into simple 2D layers. Second, parts can be fabricated directly from CAD models with little or no human intervention. Third, rapid prototyping does not require any special tooling or fixturing even for complex parts. Fourth, the lead-time required to build a complex part in rapid prototyping is shorter than the time required in traditional material removal processes [Kochan 93].

However, there are some disadvantages in using rapid prototyping. First, most rapid prototyping processes require an intermediate model that is just an approximation of the CAD model of the 3D objects [Bohn 95]. The most widely used approximation model is known as Stereolithography or STL model [Jacobs 96]. The STL model of a part is generated by using triangles to approximate the CAD model. To increase the accuracy of the model, the quantity of facets must be increased, which consequently generates huge STL files for RP processing. STL models with numerous facets make transmission, storage and manipulation of the file difficult and costly [Marsan 97a]. After the STL model of the part is created, it must be sliced to generate 2D layers. Slicing of such large STL files could generate small line segments, which the laser or nozzle has to follow. Moving the laser or nozzle in a small line segment could result in less efficient and poorer surface finish. Therefore, increasing the accuracy of the STL model without increasing the file size is crucial for increasing the accuracy and efficiency of rapid prototyping processes.

Second, a RP part is built by gradually adding or solidifying materials layer by layer, after the slice contours are created. Depositing material or tracing the liquid polymer with a laser over the cross-sectional area of the part is the most time consuming process in rapid prototyping [Sabourin 96a]. For large and complex objects, the build time can take several days. To reduce the product development lead-time, it is essential to build parts in a short time in today’s competitive environment.

Third, the surface finish of the completed parts exhibits a staircase effect along the build direction due to approximating 3D objects with 2D layers. In order to achieve the required accuracy, thin layers can be used. However, using thinner layers increases
the build time [Kulkarni 97]. Also, the accuracy of the vertical or near vertical faces will not improve with thinner layers [Marsan 97a]. Therefore, it is essential to build accurate RP parts without sacrificing from the efficiency of rapid prototyping.

This research attempts to overcome such drawbacks of rapid prototyping by improving the accuracy and efficiency of rapid prototyping processes.

1.2 Dissertation Organization
This report is organized as follows: In Chapter 2, current technologies of different rapid prototyping processes and planning issues involved in rapid prototyping are introduced. In Chapter 3, a biarc curve fitting technique is presented to improve the accuracy of STL models and to reduce the file size for rapid prototyping. In Chapter 4, a new method is presented for uniformly hollowing out thick walls and solid bodies to speed up the rapid prototyping process. In Chapter 5, ruled layer approximation to the tessellated models and path planning for building parts with ruled layers are presented. In Chapter 6, computer implementation and illustrative examples of the proposed methods are presented. In Chapter 7, concluding remarks and future research are provided.