Chapter 2
The Principle and Process of Digital Fabrication of Biomedical Objects

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ABSTRACT

Biomedical objects are used as prostheses to repair damaged bone structures and missing body parts, as well as to study complex human organs and plan surgical procedures. They are, however, not economical to make by traditional manufacturing processes. Researchers have therefore explored the multi-material layered manufacturing (MMLM) technology to fabricate biomedical objects from CAD models. Yet, current MMLM systems remain experimental with limited practicality; they are slow, expensive, and can only handle small, simple objects. To address these limitations, this chapter presents the multi-material virtual prototyping (MMVP) technology for digital fabrication of complex biomedical objects cost-effectively. MMVP integrates MMLM with virtual reality to fabricate biomedical objects for stereoscopic visualization and analyses to serve biomedical engineering purposes. This chapter describes the principle of MMVP and the processes of digital fabrication of biomedical objects. Case studies are presented to demonstrate these processes and their applications in biomedical engineering.

INTRODUCTION

Mounting pressure of market globalization and intensifying competition has ferociously been driving the manufacturing industry to survive on incessant reductions in cost and lead-time. However, conventional manufacturing methods can no longer satisfy increasingly diverse customer demands, tight cost control, and complex new products.

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Against this background, much research efforts have been devoted to developing various technologies to help the manufacturing industry, and layered manufacturing (LM, or now often called 3D printing) and virtual reality (VR) simulation have been among the most significant technologies developed over the past couple of decades.

Despite recent proliferation of LM (3D printing) for free-form fabrication, most of the current systems can only fabricate objects of a single material (Wohlers Report, 2013). There are imminent demands for multi-material layered manufacturing (MMLM) processes to fabricate advanced products and biomedical objects comprising of multiple materials. A few experimental MMLM machines have been developed based on the conventional single material LM systems for relatively simple objects (Bellini, 2002; Wang & Shaw, 2006; Wachsmuth, 2008; Li et al, 2009; Åklint et al, 2013). However, their fabrication speed is unsatisfactory for most complex, large products or medical objects for emergency cases.

More recently, many researchers have worked on virtual prototyping and virtual manufacturing (VPM) (Bracht and Masurat, 2006; Wang and Li, 2006), which is regarded as one of the most important technological advancements for product design and development. VPM has been successfully used in shipbuilding and car industries (Kim et al, 2002; Wöhlke and Schiller, 2005). It uses simulation techniques to analyze and improve a product design and validate the fabrication processes and production schedules.

Through simulations in a VR environment, key factors such as the product shape, manufacturability, and durability that may affect the profitability of manufactured products are optimized. VPM enhances profitability by reducing production cost and material usage, etc. Moreover, it reduces time and tooling cost by eliminating the need for multiple physical prototypes. This allows the users to review and validate a product design to "get it right the first time" for delivery of quality products to market on time and within budget.

This chapter describes the principle of virtual prototyping and virtual manufacturing, with a focus on the processes of modeling and subsequent digital fabrication of multi-material biomedical objects. Case studies of modeling and digital fabrication of biomedical objects using a multi-material virtual prototyping and manufacturing (MMVPM) system will be presented to demonstrate its principle and possible applications in biomedical engineering.

BACKGROUND

There has been a huge surge in demand for biomedical objects in recent years for various medical and dental purposes (Khan & Dickens, 2014; Lee et al., 2001; Maji et al., 2014; Pinnock et al., 2016; Ripley et al., 2016; Sanghera et al., 2001; Winder et al., 1999).

Biomedical objects have been traditionally used as prostheses to repair damaged bone structures or to replace missing body parts (D'Urso et al., 2000; Eufinger et al., 1995; Sannomiya et al., 2008). They are now commonly used by medical students, surgeons, and dentists to help study the intricate anatomical details of human organs and bone structures, as well as to facilitate planning of implantations and surgical procedures (Singare et al., 2009). For example, artificial hip joints, and bone and jaw structures are often used in hospitals to assist complex medical operations. In addition, they are used as specimens for experiments in pharmaceutical manufacturing enterprises.

Depending on the required properties and applications, biomedical objects can be made of either homogeneous (single) material, or heterogeneous (discrete multiple) materials, or functionally graded materials (FGM) (Pompe et al., 2003; Sun et al., 2005). Watari et al. (2004) described the fabrication

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