Integration of Collaborative Design and Process Planning for Artificial Bone Scaffold 3D Printer Nozzle

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Abstract. The requirement for high-quality product with reduced cost and time-to-market in multidisciplinary project is demanding. Integration of design and process planning with computer aided techniques can provide a solution to this challenge. This paper describes a reference model of integrating computer aided techniques to aid the concurrent development of a multi-nozzle 3D printer for fabricating artificial bone scaffold at the University of Strathclyde and the Northwestern Polytechnical University. This integration reference model, including design tools such as Material Computation (MC), Computational Fluid Dynamics (CFD), and CAD, and planning tool such as CAM techniques, is employed to support this special 3D printer development. The high precision multi-nozzle development was used as a case study to validate this integration of concurrent design and process planning. CAD tools were used to provide several nozzle design concepts and a rigorous CFD analysis of several nozzle designs under the same boundary conditions were undertaken to refine and evaluate them by research staff from both institutions. This cooperative conceptual design case study demonstrated that it drastically reduced development time and cost in devising nozzle conceptual sketch design and optimizing the nozzle design for 3D printer. This makes it an important step in designing a high precision artificial bone rapid manufacturing machine.

1 Introduction

Concurrent Engineering (CE) is a systematic approach to integrate product development processes that aims to improve the responses to customer expectation [1]. It can provide a collaborative, collective and simultaneous engineering approach during product development process, especially for tissue engineering which requires multi-discipline collaborative effort and needs to satisfy various customers' expectations and technological requirements, including important biocompatible issues. The development of an artificial bone scaffold manufacture machine can provide an opportunity to apply collaborative design and process planning. Erens[2] (1996)

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identified four elementary mechanisms that are used in design: decomposition, allocation, composition, and validation. Development team members should figure out various requirements across multi-disciplines. Modern techniques such as simulation, analysis and Rapid Prototyping have been developed and can be used to support product development. But most techniques need to communicate design data and documents among engineers from different disciplines and regions or countries. An effective collaboration among them is vital to the success. The following describes some basic background information about the subject area.

Extensive experiments showed that the porous structure of Hydroxyapatite (HAP) provides a template for fibrovascular in growth when followed by osteoblast differentiation, resulting in the deposition of new lamellar bone[3]. But it lacks sufficient bioactive substance to support continuous biodegradation of itself and new bone's growth. Researchers have found that Bone Morphogenic Protein (BMP) can induce bone cells to adhere to scaffolds and accomplish its biodegradation and new bone growth[4]. In order to satisfy these requirements, at least 70% porosity and the height of deposit of the internal 3D scaffolds are important aspects with respect to the biocompatibility and bioactivity, promoting the formation of new tissues and the blood vessels[5]. However traditional Rapid Prototyping (RP) technology cannot produce the required microstructure and the level of porosity compound BMP and growth factors skeleton. Because these biomaterials can only maintain bioactive at the human body temperature, Stereolithography, Selective Laser sintering and Fused Deposition Modelling are not suitable to make usable bones as the working temperature is far too high. 3D Printing technology can create parts of any complex geometry using several types of material. Furthermore, it can control efficiently the material composition, microstructure, and surface texture at the ambient temperature. Biomedicine, computer aided design and manufacture techniques are "pushed" and "pulled" each other to improve one special RP machine to compensate above defaults and fulfil above requirements.

Collaborative effort is therefore required to conduct this research project. Its aims in long-term to design and prototype an accurate rapid artificial bone manufacturing machine which satisfies the above requirements. It has been undertaken by two teams distributed in UK and China. Pursuing an integration of collaborative design and process planning, different concept types have been developed. It requires collaboration between scientists and engineers from different discipline background. The concept of an information-oriented integration requires the integration and collaboration of MC, CFD, CAD and CAM systems. Here the ultimate aim is to enable designers and process planners to switch between different aspects of the present jobs and to develop concurrent working patterns, in order to optimise the product and process modelling in terms of cost, time and quality.

In the following, a reference model and the methodology, which support the integration of collaborative design and process planning, are described to provide a better understanding of the approach and illustrate which one is most suitable for the 3D printer developed.