Planning of a Multi-Disciplinary Rapid Product Realization Program

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Abstract: This paper describes a multi-disciplinary rapid product realization program being planned at the University of Missouri-Rolla. The goal is to equip our engineering graduates with the necessary knowledge and skills that will make them ready to meet the challenges of rapid product realization when they go to work in industry. The developed program will provide the students with *a solid technical knowledge about critical technologies of virtual reality, solid freeform fabrication, and supply chain networks; an ability to apply this knowledge and integrate the various critical technologies with conventional technologies to develop useful products; and an ability to apply both technical and professional skills in a team environment for distributed rapid development of real-world products.* The plan of program development includes: 1) developing three new courses to introduce modern technologies for rapid product realization: one on virtual reality, one on rapid prototyping and manufacturing, and one on supply chain networks, 2) incorporating the modern technologies of virtual reality, rapid prototyping, and supply chain networks in the teaching of several existing courses related to rapid product realization, and 3) developing laboratories, including a virtual reality instruction laboratory, a rapid prototyping laboratory, and a distributed manufacturing simulation laboratory, to support the curriculum development. Evaluation of the overall impact of this program will be done in a manner analogous to the evaluation process described in the ABET Engineering Criteria 2000. It will make use of multiple (i.e., qualitative and quantitative) methodologies and will differentiate among multiple levels of knowledge (i.e., foundational, functional, and structural).

Keywords: rapid product realization, virtual reality, solid freeform fabrication, supply chain networks

1. Introduction

Due to rapid technological advances, customer demands, and globalization of economy, the time-to-market in introducing a new product continues to shorten rapidly. For instance, the average life of Hewlett-Packard printers is one year and shrinking. The company, which currently sells an estimate of 22,000 products, introduces a new product practically every day. It reported last year that 65-70% of its revenues came from products introduced in the most recent two years. This trend has also been reported by many other manufacturing companies throughout the world. For a manufacturing company to compete successfully in the 21st century, being able to produce high-quality products at low costs is not enough. The company must be able to master the rapid product realization process, starting from product definition, conceptualization, design, prototyping, to manufacturing, in order to bring new products quickly to the market. The science and technologies that can greatly reduce the time-to-market will be critical for any company to win the competition in the 21st century.

The product realization process is a complex activity requiring cross-disciplinary expertise. Stevenson et al.

[1] performed an analysis of the best design practices of U.S. Navy contractors and reported that many companies still appear to be primarily focused on detailed design phase rather than product conceptualization phase. The engineers of the future need to be trained in conceptualizing different stages of product development. Most courses akin to integrated product/process development are limited in scope to just CAD/CAM integration aspects and often fail to capture the perspective of the "bigger" system. Rarely do students gain an experience of the entire product realization process from customer needs identification to prototyping to manufacturing. The product realization process involves the steps of understanding customer needs, product definition and specifications, conceptual design, detailed design and prototyping, process development, and manufacturing planning and production, as shown in Figure 1. This figure also emphasizes the importance of auxiliary professional skills including team work, project management, oral and written communication, etc. to effectively carry out a team-based product realization project.

Since the first introduction of the technology by NASA, virtual reality (VR) is becoming increasingly important in a number of fields including medical training, simulation, visualization, education and entertainment. In the recent years, as a result of the advent of faster desktop computers and wide availability and reducing cost of virtual reality hardware and software, more and more companies are looking at virtual reality solutions for various industry problems. In the manufacturing area companies like Boeing, General Motors, and Caterpillar are looking at diverse applications of virtual reality for their product visualization and conceptualization, training, and collaborative design. The enabling science and technologies in the area of virtual reality have been reported [2]. A survey of software issues in VR-based environments, especially on physics-based modeling, has also been conducted [3]. The use of virtual-reality environments for design and manufacturing applications has been described in many papers, e.g., [4, 5].

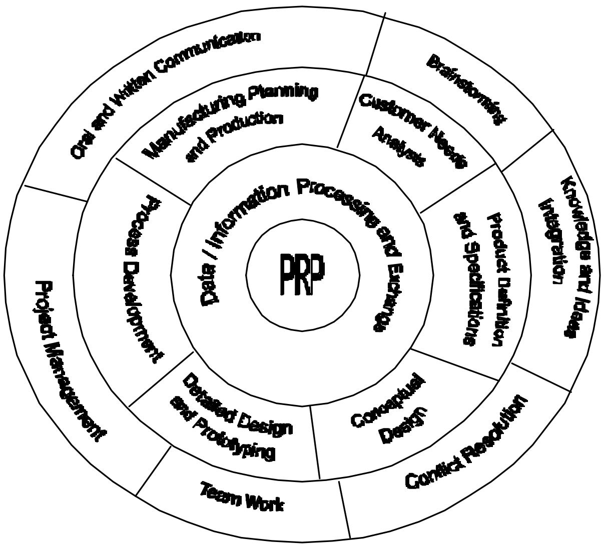

Figure 1 Technical and professional skills of product realization process.

Since late 1980's, quite a few techniques of Solid Freeform Fabrication (SFF), also known as Rapid Prototyping or Layered Manufacturing, have been investigated, and some commercially developed [6-8]. By building three-dimensional parts in a layer-by-layer additive way, these techniques allow freeform fabrication of complex-geometry parts directly from their CAD models automatically, without having to use special fixtures as in material removal processes. These SFF techniques have helped the product developers and manufacturers to develop and market their products more rapidly at lower costs in the ever changing and more competitive global market. It was initially used to make physical prototypes of three-dimensional parts as visualization and communication aids in design as well as for examining the fit of various parts in assembly [9]. Thanks to intensive research and development in the areas of material, process, software, and equipment, applications to rapid tooling have also been developed by directly or indirectly employing SFF technologies in the tool, die and mold fabrication [10].

The traditional concepts of a business model are fast becoming obsolete. Mass customization and quick customer response are two of the critical factors that can provide a significant competitive advantage to a company. To be competitive in the 21st century, companies must focus not only on moving the physical products quickly through retail, distribution, assembly, manufacture, and supply but also the pertinent information in a timely and cost-effective fashion. In today's context, manufacturing and service companies are viewed as "value" creators, not simply "makers" of products. The supply chain network (SCN) focuses on distributed information management technology that seeks to integrate procurement, operations, and logistics from raw materials to final products [11, 12]. Future engineers must be able to add product value, increase product quality, reduce costs, and increase profits by addressing the needs and performance of supplier relations and selection, operation, transportation, inventory and warehousing, benchmarking, electronic commerce using supply chain software, recycling, and customer relations. A supply chain network facilitates the movement of products starting from the customer order through the raw materials procurement and storage, production, packaging, distribution of products to the customer, and collection at the end of the useful life [13].

Virtual reality, solid freeform fabrication, and distributed supply chain networks are key enabling technologies to rapid product realization. They enable immersive 3-D visualization of a design part, rapid physical prototyping, and use of a global supply chain network to rapidly produce the product to meet the market demand. Unfortunately, these enabling technologies of rapid product realization remain largely in research laboratories, and only selective few graduate students have exposure to them. Not many universities introduce these technologies in their engineering curricula, let alone in an integrative manner. Introducing these technologies with integration to effect design and manufacturing of real products constitutes the curriculum innovation that we are planning, with the aim to significantly improve the learning environment and the quality of education toward rapid product realization.

2. Project Goal, Objectives, and Tasks

This project is aimed at developing an "Integrated and Distributed Rapid Product Realization Program" at the University of Missouri-Rolla (UMR). The goal is to equip our engineering graduates with the necessary knowledge and skills that will make them ready to meet the challenges on product realization when they go to work for industry.

In this project we will develop an integrated curriculum that introduces the modern technologies of virtual reality, solid freeform fabrication, and supply chain networks in new courses, as well as implements these technologies in existing courses. As part of the proposed project efforts, laboratories will be developed for support of these instructional activities.

The developed curriculum on rapid product realization will provide the students with:

- *A solid technical knowledge about critical technologies of virtual reality, solid freeform fabrication, and supply chain networks.*
- *An ability to apply this knowledge and integrate the various critical technologies with conventional technologies to develop useful products.*
- *An ability to apply both technical and professional skills in a team environment for distributed rapid development of real-world products*

The Integrated and Distributed Rapid Product Realization Program being planned emphasizes the importance of "Rapid" realization in new product development, which requires technology integration and distributed manufacturing. The main innovation of the proposed Program is to introduce the modern enabling technologies of virtual reality, solid freeform fabrication, and supply chain networks. The students will be able to gain knowledge on the fundamentals of these technologies and learn the skills of applying these technologies to rapid product realization. The resulting technical competencies from learning these critical technologies are depicted in Table 1.

The proposed program development will include developing new courses, modifying and further developing existing courses, and developing laboratories to support the teaching of these courses. Specific tasks of the project will include:

- Developing three new courses to introduce modern technologies for rapid product realization: one on virtual reality, one on rapid prototyping and manufacturing, and one on supply chain networks.
- Incorporating the modern technologies of virtual reality, rapid prototyping, and supply chain networks in the teaching of five existing courses related to rapid product realization.
- Developing laboratories, including a virtual reality laboratory, a rapid prototyping laboratory, and a distributed manufacturing simulation laboratory, to support the curriculum development.

Table 1 Relationships between the introduced enabling technologies and technical competencies

	VR	SFF	Distributed SCN
Advanced Product Visualization	✓		
Product Conceptualization	✓	✓	
Rapid Product Design and Prototyping	✓	✓	
Distributed Manufacturing Planning			✓
Virtual Business Alliances			✓
Rapid Product Realization	✓	✓	✓

3. Project Development Plan for New Courses and Laboratories

Course #1: Virtual Reality Concepts and Applications

This course will introduce students to the state of the art in the field of virtual reality. Hardware, software and human perception aspects of the virtual reality will be discussed. In-depth understanding of the capability and limitations of the virtual reality environment will be stressed. The aim of the course will be to enable the students to understand the technology, to integrate a virtual reality system with commercially available hardware and software, and to develop virtual reality applications. This course will cover the basic introductory concepts in computer vision, computer graphics, human-perception issues relevant to virtual reality, and human interface design issues. The relevant hardware technology for 3-D stereoscopic display, immersive head mounted display, electromagnetic tracking, haptic device and 6-D mouse and software technology for 3-D visual modeling, stereoscopic image creation, photorealistic rendering, and realistic virtual dynamic modeling of collision and motion will be introduced. The course will provide hands-on experience with the available virtual reality hardware and software.

Course #2: Rapid Prototyping and Manufacturing

This course will provide a comprehensive, in-depth coverage of solid freeform fabrication and its applications. The students will gain fundamental knowledge on solid freeform fabrication and will learn the tradeoffs including part accuracy, build speed, and material coverage among different solid freeform fabrication processes. They will also learn the practical skills of STL file preparation, part slicing, support generation, etc. They will be provided with hands-on experience using commercial rapid prototyping machines. They will also have opportunities to compare solid freeform fabrication with CNC machining for making physical parts. The content of the course will consist primarily of three parts. The first part will consist of in-depth description of various solid freeform fabrication processes, the second part will address the fundamentals of solid freeform fabrication, and the third part will describe the applications of SFF to prototyping, tooling, casting, and medical applications.

Course #3: Supply Chain Networks

This course will cover various supply chain functions such as demand forecasting, sourcing and procurement, inventory and warehouse management, and distribution logistics. The course emphasis will be on streamlining the business processes of a manufacturing and distribution enterprise by linking the multiple manufacturing sites and distribution facilities into the planning and execution equation. The students will learn how to coordinate the various links of the supply chain network under a variety of performance goals such as maximizing the customer satisfaction, reduced inventories, and minimizing the operation costs. They will learn various strategic decisions and operating decisions that are associated with supply chain management. The strategic decisions will deal with corporate policies and its impact on the design of the supply chain network. The operational decisions will deal with the day-to-day activities. The course will take into account the interplay of various considerations such as market demands, customer service, transportation, distance consideration (with distributed vendors), and pricing pressures to structure the supply chain network effectively. We plan to use the SAP R/3 system's supply chain cockpit to provide an intuitive and configurable graphical user interface to manage and optimize the supply chain. The students will have the opportunity to build a graphical model of the supply networks – suppliers, plants, distribution centers, and customers.

Laboratories for Support of the Curriculum Development

The laboratories to be developed for support of the rapid product realization curriculum development will include a virtual reality laboratory, a rapid prototyping laboratory, and a distributed manufacturing simulation laboratory. These laboratories will be used to develop lab modules that complement the lectures and provide hands-on experience for students. The Virtual Reality Lab will have equipment providing 3-D visualization and simulation capabilities such that about 10 groups of 2-3 students can work on different aspects of virtual reality at any time. The Rapid Prototyping Lab will consist of a Sander's Model Maker, a JP System 5 prototyping machine, and an FDM 3000 rapid prototyping machine integrated to form a rapid prototyping center that can be used to make decisions on material and machine selection for given parts to be prototyped. The Distributed Manufacturing Simulation Lab will provide capabilities for simulation of manufacturing planning, production systems, and distributed supply chain networks with software including SAP R/3, ProModel and other commercial packages.

4. Project Evaluation Plan

Evaluation of the various courses and the overall project impact will be a crucial component of this project. Our assessment design will be driven by the specific project curriculum objectives, and thus will serve to indicate the extent to which these objectives are met. In addition, the assessment will be ongoing and action oriented [14, 15]. That is, in a manner analogous to the "2-Loop Process" described in the ABET Engineering Criteria 2000 [16], the assessment will not only serve to evaluate objectives, but will also lead to ongoing modifications in the courses. Further, the evaluation will make use of multiple (i.e., qualitative and quantitative) methodologies [17] and will differentiate among multiple levels of knowledge (i.e., foundational, functional, and structural). The first objective (*a solid technical knowledge about critical technologies of virtual reality, solid freeform fabrication, and supply chain networks)* will be addressed through a battery of objective and subjective foundational measurement tools aimed at assessing students' knowledge of basic information related to the courses. The second objective (*an ability to apply this knowledge and integrate the various critical technologies with conventional technologies to develop useful products*) will be addressed through measures of functional and structural knowledge. Functional knowledge refers to the ability to apply basic foundational knowledge to real-world problems, while structural knowledge can be viewed as "big-picture" knowledge of the interconnectivity among concepts within a given domain. For the third objective (*an ability to apply both technical and professional skills in a team environment for distributed rapid development of real-world products*), students will be asked to respond to quantitative-subjective and open-ended qualitative questions on team skills and attitudes.

5. Conclusion

With the participation of four academic departments, this project is expected to have significant impact on education and infrastructure development, as well as support of research. The faculty and students involved in the project will be able to broaden their technical knowledge in different fields and gain teaming and other professional skills. The planned curriculum development is targeted at the students in the degree programs of BS Mechanical Engineering with Manufacturing Option and BS Engineering Management with Manufacturing Option. The courses will also be of interest to the students in the master degree programs in manufacturing engineering and to other undergraduate and graduate engineering students, especially those majoring in mechanical engineering or engineering management. It is also expected that the introduction of modern technologies and use of them for rapid product realization in new and existing courses will help us recruit and motivate students to study engineering, and the students who have exposure to these new technologies are more likely to be attracted to graduate studies in related research areas.

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