Session Number 1526

Integrating RP Technology into Tennessee Tech's Design and Manufacturing Curriculum

Ismail Fidan, Ph.D.

Tennessee Tech University, 920 North Peachtree Avenue
Cookeville, TN 38505-5003, E-mail: ifidan@tntech.edu, Web: http://iweb.tntech.edu/ifidan

Abstract

The rapid advances in computer technology opened new horizons for the faculty who are teaching in CAD/CAM technologies and will continue to do so in the future. Tennessee Tech University (TTU) took the advantage of this opportunity provided by NSF-CCLI-A&I program grant to adapt and implement successful Rapid Prototyping (RP) experiences, and educational practices that have been developed and tested at various engineering schools. RP capabilities affect the pedagogy in the core design and manufacturing curriculum. RP adds excitement and realism to the curriculum by enabling the students to build physical models directly from CAD data. The prototype communicates important information about parts, including engineering data such as fit and limited functional testing, labeling, highlighting, and appearance simulation. Undoubtedly, students who have an understanding of the realities of the relationship between CAD tools and design principles will be much more attune to the realities of the industrial standard in RP. TTU RP objectives have been implemented by integrating new hands-on laboratory experiments into two current junior level required courses; CAD for Technology and CNC Machining Practices. This paper will report the current RP curriculum enhancements accomplished in both courses.

The State of the Art

The mission for all instructors is to educate their students the best way possible. Their teaching techniques should challenge, educate, and promote the students' innovative thinking[1]. The lecture-based format of teaching, which predominates in engineering education, may not be best to achieve these goals[2]. Through the lecture method, an instructor introduces students to course work by producing notes on a chalkboard or overhead. The instructor then hopes that students can regurgitate this collected information on their homework or exams. Some classes, if students are lucky, have accompanying laboratory practices where they can gain hands-on experience. There have been several attempts to revise engineering curriculum to improve understanding and foster creative thinking[3].

The Manufacturing and Industrial Technology (MIT) Department of the College of Engineering at TTU currently has four courses in the CAD/CAM/CNC areas. In order to eliminate the paper-based submissions and automate the delivery of the MIT courses, WebCT distance learning course materials were prepared for some MIT courses and implemented starting Fall 2002[4]. Program changes are being structured to support the advanced technological education and increase the students' marketability. The guiding philosophy behind the creation of this structure is to graduate students who have a firm and realistic knowledge of how the manufacturing world functions and the problems to be faced. Many schools worldwide are committed to providing their students with the innovative tools they need to be successful leaders in their future careers. Now a significant focus of the MIT curriculum has become the incorporation of these new tools into MIT's CAD, CAM, and CNC courses. One of the primary instrumentations to support this purpose is adapting and implementing the RP used by the nation's technological schools into MIT curriculum[5-7].

In July 1999, TTU's Technology Access Fund provided a computer laboratory to support many of the software needs for CAD, CAM and CNC practices. Fifteen DELL OptiPlex GX1, Pentium III computers currently run programs such as: AutoCAD, Mechanical Desktop, Pro/E Wildfire, MasterCAM, and CNCez. In December 2002, this computer lab was upgraded to include 22 Pentium IV computers and multimedia teaching capabilities. Although students gain excellent experience with industrial – level CAD/CAM/CNC software tools, compatible advanced manufacturing hardware is limited for producing parts in a real environment. Since the hands-on labs are very important to concrete the CAD/CAM/CNC concepts, lack of adequate CAM and CAD application hardware is the "weak link" in the current enhancement effort. MIT students' lab practices were limited to conventional CNC turning and milling projects. There was no high technology equipment beyond a couple of CNC machines. Therefore, implementing RP filled the gap between CAD/CAM and provided MIT students with the opportunity to practice high tech prototyping assignments.

A Generic Overview on RP

RP consists of various manufacturing processes by which a solid physical model of a part is made directly from 3D model data, without any special tooling. CAD data may be generated by 3D CAD modelers or model data created by 3D digitizing systems[8]. Charles Hull is given credit with bringing the first commercial RP machine to market in 1987 with SLA-1[5,9]. His machine, like all RP machines, requires 3D CAD data for its operation.

To begin the RP process, the 3D CAD data is sliced into its thin (~.005 in.) cross-sectional planes by a computer. The cross-sections are sent from the computer to the RP machine, which builds the part layer-by-layer. The first layer's geometry is defined by the shape of the first cross-sectional plane generated by the computer. It is bonded to a platform or starting base and additional layers are bonded on top of the first, shaped according to their respective cross-sectional planes. This process is repeated until the prototype part is complete.

The advantages of RP are obvious: development of physical models can be accomplished in significantly less time as compared to the traditional machining process. Some other applications of these technologies include development of molds, patterns for casting, and tooling. The prototype built by RP machines can be put to a number of uses as given in Table 1.

Table 1: The Advantages of Rapid Prototyping Systems

Check the feasibility of new design concepts	Visualization
Function/fit test and verification	Conduct market tests/evaluation
Promote concurrent product development	Make Rapid tooling
Make many exact copies simultaneously	Use as a master for metal mold conversion
Manufacturing producibility and supplier quoting	Reverse Engineering using RP

Three-dimensional prototypes put students and designers on equal footing in evaluating designs. All the interested parties can see, touch, and handle the design, just as the ultimate customers will.

Most students can't see the design changes or final designs in product form until tooling is produced. New concept-stage RP technologies can provide dozens of snapshot views of the final product at a fraction of the time and cost of RP systems. This lets students watch as the product evolves and lets them take more chances and be more creative as less time, effort, and ego are invested in each model.

The various existing RP methods can be categorized by the material they use: photopolymer, thermoplastic, and adhesives. Photopolymer systems start with a liquid resin, which is then solidified by discriminating exposure to a specific wavelength of light. Thermoplastic systems begin with a solid material, which is then melted and fuses upon cooling. The adhesive systems use a binder to connect the primary construction material. The typical processes are SLA, LOM, SLS, FDM, and 3D Printing[8].

Rapid Prototyping Technology at TTU

Although neither the current TTU curriculum nor any other school in the state of Tennessee had an educational RP laboratory to practice[10], Middle Tennessee State University, Murfreesboro, TN has recently purchased some rapid prototyping machines for their machine tool technology lab. These machines were planned to be used in industrial projects and senior level capstone courses[11].

At TTU, all the CAD design labs are currently done with AutoCAD2002 in the computer lab, and the CNC production labs cover only Milling and Turning Processes practicing CNCez and MasterCAM. Establishing the RP laboratory and enhancing the current courses with RP help the course instructor to convey the cutting edge technology to current students in these courses.

Since the initial introduction of the RP process in 1987, several machines have entered the market, which are now affordable by universities. Project team has searched many sources in order to decide which RP machine will be selected. A low cost per prototyped part is important because of the need to prototype a large number of concepts, and to have many student teams use the machine. Speed is important as well. With a class size ranging from 15-20 students and plans to increase the class size to 40 students, a machine that takes 1-2 days to produce a part would limit student access. The use of benign printing materials also would make it safer to let students work with the system.

Because of the short time allowed in the course schedules for the projects, and large number of student teams, cost and speed are the two main determinants in the decision to purchase the Z406 machine[12]. The speed of the system allows an entire class of students to color print parts out for their projects within a week. Additionally, it is easier to modify parts after they have been printed, just as traditional foam models are reshaped.

Safety concerns are negligible with the Z406 machine. After a communal build is completed, students receive the final parts they designed and built. There is also no need to add additional support structure on the CAD part design. This extra work is totally eliminated with the Z406 system.

Course Improvements

With the installation of the RP equipment, more challenging student laboratory assignments and industrial projects were developed in the areas of CAD, CAM, and CNC programming and practices.

Currently, the CAD courses are designed to teach engineering design principles using CAD techniques. These courses help prepare students for subsequent process engineering and tool design classes. The two courses are restructured to comprise four modules; each module is accompanied by many CAD projects. The first module embraces lecture material on AutoCAD 2002 commands and system parameter configuration; materials designation and machine processes; English and metric systems of dimensioning; threads and fasteners; title block elements. In the second module, students receive instruction on three-dimensional pictorial representation and tolerancing for assembly. Specifically, instruction is provided on the methods of calculating types of fit through use of ANSI B4.1 (English) and ANSI B4.2 (Metric) standards. The projects for this module challenge the student to develop a working drawing along with an exploded isometric assembly drawing of a multiple part pictorial that displays dimensions in basic size and types of fit values. The third module focuses on solid modeling and the different types of graphical computer modeling available. Aspects investigated include differences and applications of wireframe modeling, surface modeling, and solid modeling.

The fourth and final module of the course includes introducing the student to both layer additive and layer subtractive process; hands-on team exercises including set-up of Z406 machine operations, construction of models, and use of a prototype to critique the current design from design, manufacture, and assembly standpoints.

The current CNC courses are built around the concepts and programming CNC mill and turning using G&M codes. The CNC courses are restructured to have four major modules. In the first one, the fundamentals of the CNC are highlighted. Coordinate systems, absolute and incremental programming, units, feed rates, spindle speeds, cutting tools, material properties, coolants, and machine classifications are covered in detail. The second module is focused on Milling

Processes. After the introduction of preparatory and miscellaneous functions, CAD draftings are converted to G&M programming via CNCez or MasterCAM. A number of labs is done in the CNC/CAM Lab. The third module covers turning programs generated via CNCez or MasterCAM for the given parts' CAD data and their labs are performed in the CNC/CAM Lab. In the fourth module, the solid CAM knowledge is introduced into MIT curriculum. This portion covers the advanced RP manufacturing technologies that offer significant reductions in the time and cost of product design and manufacturing. This module is presented as a combination of course lectures and hands-on team exercises.

An integral part of this new module is to become involved in a RP manufacturing project dealing with RP, rapid tooling, workpiece fixturing, and/or part assembly. Consequently, each student becomes a part of a 4- to 5-members team that work on one particular RP project.

To sum up, the MIT CAD/CNC syllabuses were restructured. There were assignments to specifically introduce RP, allowing students to create a solid model of their design and use the Z406 to create a physical model as part of the concept and sketch model refinement process. Figure 1 shows some of the projects accomplished in CAD for Technology and CNC Machining Practices courses.

Figure 1: Sample RP Projects from Fall2003 Student Teams

As can be seen from the Table 2, more than fifty students practiced the RP Technology in the CAD and CNC courses in Fall2003.

Table 2: Students practicing the RP in Fall 2003

Course ID	Session/Dates	Status	Activity	Days	Time	Building/Room	Enrolled
MIT -3060-001 Comp Num Cont Mchng Prct	Normal Academic Term 08-18-03 12-05-03	Open	LEC	R	03:00-03:50PM	LH 101	20
MIT -3060-100 Laboratory	Normal Academic Term 08-18-03 12-05-03	Open	LAB	R	04:00-07:50PM	LH 106	19
MIT -3300-001 Cad for Technology	Normal Academic Term 08-18-03 12-05-03	Closed	LEC	W	01:00-02:50PM	LH 101	21
MIT -3300-100 Laboratory	Normal Academic Term 08-18-03 12-05-03	Closed	LAB	W	03:00-04:50PM	LH 101	21
MIT -4060-001 CNC Concepts, Adv Techniq & App	Normal Academic Term 08-18-03 12-05-03	Open	LEC	M	11:00-11:50AM	LH 101	14
MIT -4060-100 Laboratory	Normal Academic Term 08-18-03 12-05-03	Open	LAB	WF	10:00-11:50AM	LH 101	14

Evaluation Plan

In order to evaluate the impact of these courses' enhancements through RP, the following tools were developed:

TTU Assessment Office conducts course assessment every semester through the official faculty evaluation process. Through the feedback of this evaluation, results are used to further improve the RP courses.

An unofficial TTU evaluation team was formed to monitor the course enhancement with RP. A special assessment instrument was designed with a mix of multiple choices and written detail questions on the efficiency and effectiveness of the RP portion of the courses and labs in relation to course objectives. Figure 2 shows the RP Evaluation developed by the team. Survey results were collected and evaluated for the Fall 2003 courses given in Table 2.

Dissemination of Results

Since this equipment created the first NSF funded RP Lab in the state of Tennessee for educational use, it is important to give access to other universities and community colleges to give them exposure. The lab and course development was made available for others through Tennessee Tech University's Instructional Web Server, *http://iweb.tntech.edu/ifidan/RP_Lab.htm* (See Figure 3). The RP lab development, its capabilities, and versatilities will also be presented to other statewide colleges, high schools, industries via workshops and trainings in the near future.

Tennessee Tech University

Evaluation Form of the TTU RP Lab Project funded by NSF

Today's Date: ______________________

Course Name: ______________________

Current Semester: ______________________

Sex: ______________________

Age: ______________________

Major: ______________________

Expected Graduation Time: ______________________

Have you ever practiced RP Technology before?

Yes No

Have you ever seen or read anything on RP before?

Yes No

What are the conventional manufacturing processes you practiced so far?

____

____

____

What are the most important points in your RP projects?

a) Short production time of the part
b) Seeing the physical model in a short period of time
c) Integration of CAD and RP

Where can you use RP in the future?

____

Rate your satisfaction on your RP projects

Low **Moderate** **Medium** **High** **Very High**

Do you recommend having RP integrated projects in the other courses?

Yes **No** **Does not care**

Your Comments on RP Projects/Instructions:

....

....

Figure 2: A Sample Survey developed by the unofficial TTU evaluation team

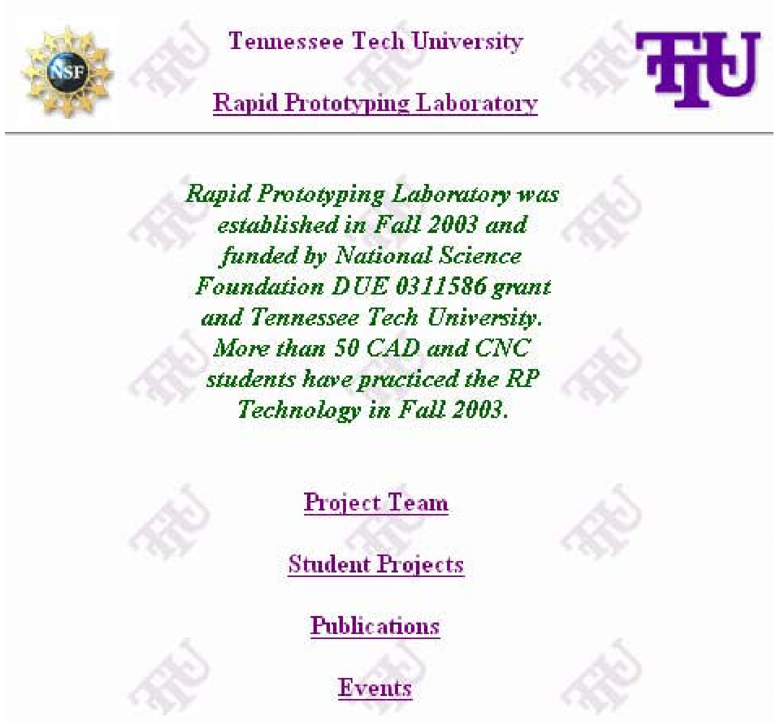

Figure 3: Project Web Link, http://iweb.tntech.edu/ifidan/RP_Lab.htm

Conclusion

TTU Rapid Prototyping Lab has been established in Fall 2003. This lab was the first NSF funded educational RP Lab in Tennessee. The lab consists of Z406 3D colored printer and its accessories. RP Lab has been extensively used in CAD for Technology and CNC Machining Practices courses. Over 50 students have practiced this technology and compared it to conventional manufacturing processes. The project evaluation results showed that almost all students have never practiced RP before and their satisfaction with the RP practices was very high. Students also indicated that they wanted to see more RP integrated projects in the other courses.

Acknowledgements

This project has currently been funded by ‘NSF Award Number 0311586’ *Integrating Rapid Prototyping Technology into Tennessee Technological University's Manufacturing and Industrial Technology Curriculum*[13]. Author of this paper greatly appreciates this current NSF-CCLI-A&I grant. Further developments and pilot testings are in progress. Special thanks are also conveyed to project evaluation team chair, Mr. Eugene Mitchell for his time and support.

Bibliographical Information

1. K. A. Higley and C. M. Marianno, "Making Engineering Education Fun," Journal of Engineering Education, v. 90, n.1, pp. 105-107, January 2001.
2. B. G. Davis, Tools for Teaching, Jossey-Bass Publishers, p.100, 1993.
3. M. O. Haggler and W. M. Marcy, "Strategies for Designing Engineering Courses," Journal of Engineering Education, v. 88, n. 1, pp. 11-13, 1999.
4. http://webct.tntech.edu/webct/public/show_courses.pl?994954339
5. J. E. De Leon and G. Winek, "Incorporating Rapid Prototyping Into the Engineering Design Curriculum," Engineering Design Graphics Journal, v. 64, n. 1, pp. 18-23, 2000.
6. S. Chiappone, "Applying RP Process to Educational Laboratories: Educating Future Engineers on Rapid Prototyping& Tooling Capabilities," Proceedings of the 1999 SME Rapid Prototyping and Manufacturing Conference and Exposition, Rosemont, IL, pp. 167-172, April 20-22, 1999 or http://www.rpi.edu/dept/aml/public_html/RPproject/SMEpaper.htm
7. K. Stier and R. Brown, "Integrating Rapid Prototyping Technology into the Curriculum," Journal of Industrial Technology, v. 17, n. 1, November 2000 to January 2001.
8. http://ecoleing.uqtr.uquebec.ca/geniedoc/gmm/productique/rp_gener.htm
9. Stereolithography: Applications for Rapid Prototyping, R. Schweikhart, SME Technical Paper, MS90-261, 1990.
10. T. Wohlers, Wohlers Report-Executive Summary, 2002. http://www.wohlersassociates.com/Universities%20with%20RP%20Activity.html
11. http://www.mtsu.edu/~isdept/mtt.htm
12. http://www.zcorp.com/products/printersdetail.asp?ID=2

13. https://www.fastlane.nsf.gov/servlet/showaward?award=0311586

Biographical Information

ISMAIL FIDAN

Dr. Ismail Fidan is an Associate Professor in the MIT department, College of Engineering, Tennessee Tech University, Cookeville, TN. He has been at Tennessee Tech University since August 2000. Dr. Fidan received his PhD in Mechanical Engineering from Rensselaer Polytechnic Institute in 1996. He is a senior member of IEEE and SME, life member of TAS, and member of ASEE, NAIT, and ASME. Dr. Fidan also serves as an associate editor for the IEEE Transactions on Electronics Packaging Manufacturing and International Journal of Computer Applications in Technology. He has been ABET and NAIT manufacturing program evaluator since 2003. Dr. Fidan is the recipient of 2004 TTU Leighton E. Sissom Innovation and Creativity Award, 2003 SME Jiri Tlusty Outstanding Young Manufacturing Engineer Award, 2003 TTU Exemplary Course Project Award, 2002 Provost 'Utilization of Technology in Instruction' Award, 2002 Technology Award by The Institute for Technological Scholarship, and 2001 NAIT Outstanding Professor Award. His teaching and research interests are computer-integrated design and manufacturing, electronics manufacturing, rapid prototyping, and manufacturing processes.