

A Hands-on Approach To Teaching CAD/CAM for Manufacturing and Rapid Prototyping Applications

Abstract

This paper describes an integrated laboratory-oriented course IT445 in computer-aided design/manufacturing and computer numerical control. Teaching this subject in an 11-week of academic quarter is a challenging task requiring a combination of instructional delivery methods. We used a hands-on learning approach involving in-class computer-based exercises and team-based laboratory projects. The course content is designed around four major subjects: software familiarization, hardware familiarization, design and manufacturing integration, and industrial applications. The author will share his observations and experience with educators in the field.

Introduction

Many industrial and engineering technology programs offer laboratory-oriented manufacturing courses with the mission of providing students with a practical experience in product design and manufacturing. Common courses in these programs may include manufacturing automation, computer-integrated manufacturing and/or numerical control systems^{1,2,3}. These courses typically cover a wide range of topics such as control theory, robotics, and programmable logic controllers, and limited coverage of computer numerical control (CNC) and computer-aided design/computer-aided manufacturing (CAD/CAM).

This paper describes a new laboratory-oriented course at the industrial technology (IT) program of California Polytechnic State University exclusively dedicated to CAD/CAM-CNC. The course provides students with an in-depth hands-on experience in integrated product design and manufacturing and exposure to available options for rapid prototyping. The course benefits other areas of the IT program such as plastics processing and packaging laboratories by enabling students to fabricate molding tools for plastic processing equipment through the capstone use of senior projects or special projects.

The learning outcome of the new CAD/CAM-CNC course includes:

- Understanding the role of CAD/CAM in product development
- Relating CAD/CAM to various industrial applications
- Relating CAD/CAM to traditional rapid prototyping methods
- Creating 3-dimensional CAD models
- Creating/simulating cutter toolpath
- Set-up/operation of industrial grade CNC machines
- Comparing final products (prototypes) with corresponding CAD model for validation
- Demonstrating successful execution of a complex CAD/CAM-CNC project
- Managing team-based projects

The remainder of this paper is dedicated to describing the teaching approach, course content, computer-based exercises and laboratory projects that have been developed for the spring 2006 offering of this course.

Teaching Approach

We used two design/manufacturing software and hardware teaching tools for achieving the learning objectives. These include a CAD/CAM software (MasterCAM) and two industrial grade CNC machines. The choice of this particular software is mainly due to its wide applications in industry and academia, ease of use, low pricing and prompt technical support. The lecture sessions are designed to support individual students and teams working at computer stations, each connected to the instructor-controlled computer. The laboratory sessions are designed to allow students to continue in-progress computer exercises, followed by demos and hands-on projects on CNC machines. The new course design allows minimal lecture while providing the students with the opportunity to learn the subject matter through hands-on in-class computer-based exercises, and team-based laboratory projects. This teaching approach results in a more positive educational experience in technology-oriented courses by providing the students exposure to professional practices early in the educational process⁴. The class meets twice a week in 3-hour sessions. Typical class time is used as follows:

- Lecture: 30-40 minutes
- Demonstration: software and hardware
- In-class exercises (individuals and teams)
- Laboratory projects (teams)

Typical student activities include:

- Creating 2D and 3D wireframe and surface models (CAD)
- Creating cutting toolpaths using CAM
- Post-processing toolpath to generate NC code
- Downloading part programs into CNC machine tools
- Machine setup (CNC)
- Prototyping and production (CNC)

Course Content

The course content of IT445 is designed around four major subjects: software familiarization, hardware familiarization, design and manufacturing integration, and industrial applications.

Software Familiarization (CAD and CAM Programming): The first third of the course is dedicated to familiarization with 2D and 3D wireframe and surface modeling using CAD, followed by cutting toolpath generation using CAM.

Hardware Familiarization (CNC Machines): The hardware familiarization is organized around two computer-controlled machine tools-- a vertical machining center (Milltronics RW14), and a turning center (Milltronics ML14), both are industrial grade CNC machines capable of machining various materials and producing relatively complex shapes. Most students enter the

course with basic exposure to manual machining. Hardware familiarization takes place during weeks 4-10 of the classes.

Integration (CAD/CAM and CNC): The integration of software and hardware is introduced during weeks 6-10 and in parallel to hardware familiarization. During this period, students downloading the programs into the CNC machine controller, verifying the cutting toolpath on the machine's monitor, modifying the programs on site or at their computer stations, and setting up the machine for cutting operations (Fig.1).

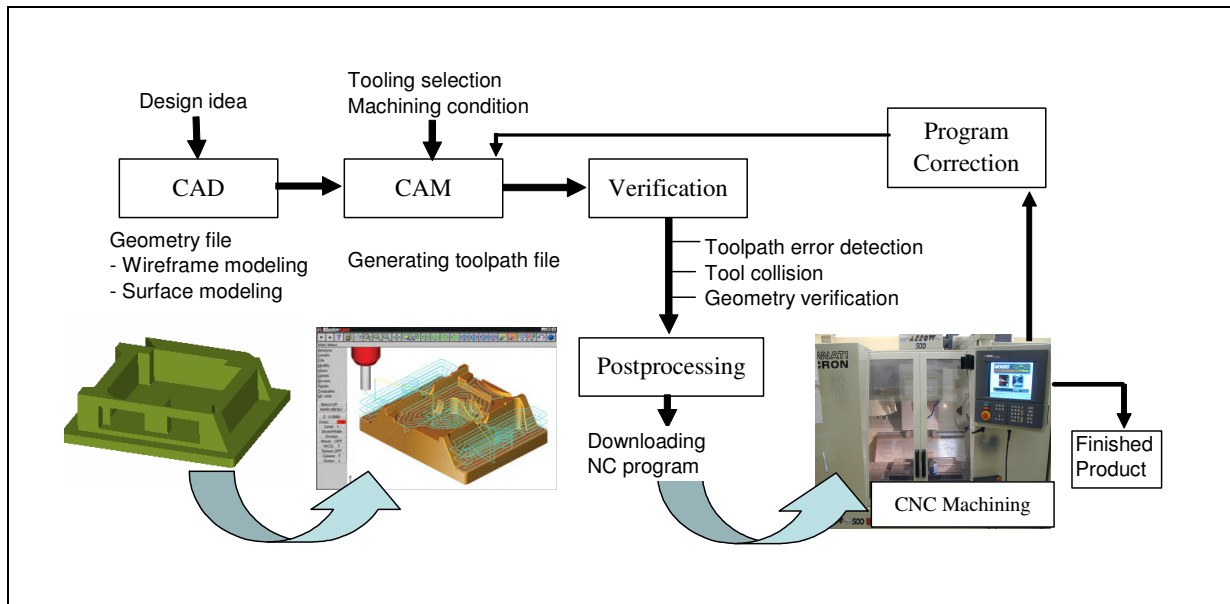


Figure 1. Integrated software (CAD/CAM) and hardware (CNC)

Industrial Application: All exercises and projects in IT445 are designed around material removal processes (i.e., milling, turning, and drilling) which constitute a major application area of CAD/CAM in manufacturing. However, to help students to gain a broader appreciation of applications of CAD/CAM in industry the following projects are also included in the course:

- CAD/CAM in Metal Fabrication (demo)

A plasma cutter is an electric arc cutting tool which can cut through thick steel, aluminum, and other metals. A CNC plasma cutter provides students with the capability to cut out sheet metal parts with considerable accuracy and speed. Using CAD/CAM-CNC, a part drawing is translated into a CNC code file and transferred from a student's computer to the plasma machine controller for cutting operation. This demo shows several advantages of integration of CAD, CAM and CNC including time saving and error prevention (Fig. 2).

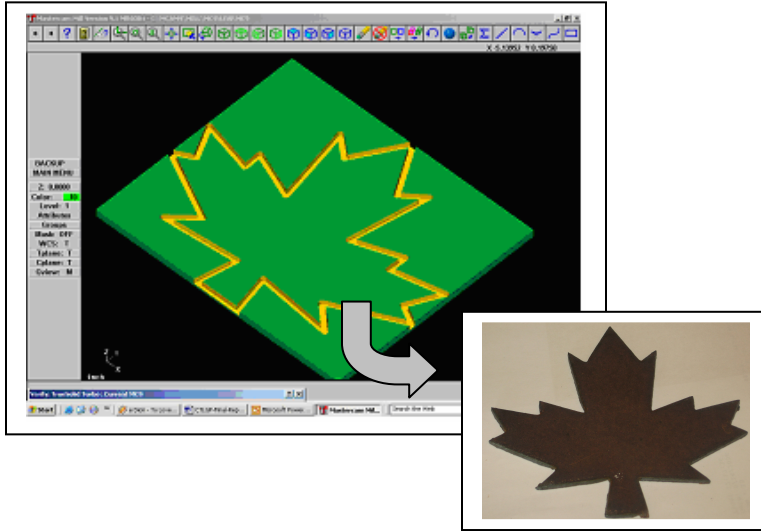


Figure 2. A sheet metal part fabricated by CNC plasma cutter.

- CAD/CAM in mold/die making

A major beneficiary of CAD/CAM-CNC is the mold and die making industry which produces tools for various plastic molding, metal casting, and metal stamping processes. To help students to relate CAD/CAM to these applications, they are encouraged to build aluminum molds as their major project. One such project is shown in Figure 3 which is an aluminum mold made for a compression molding machine in our plastic processing lab.

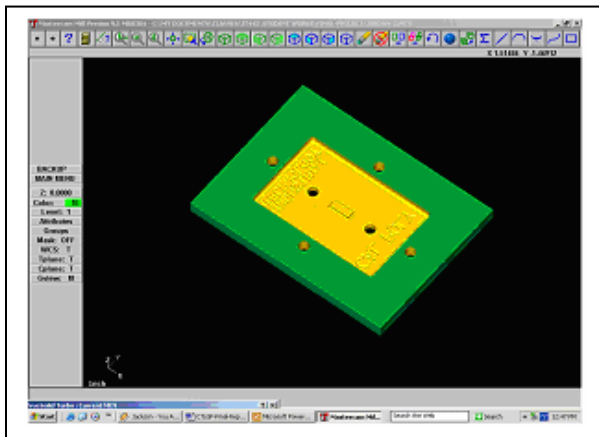


Figure 3. A mold designed for plastic compression molding.

- Rapid prototyping (RP)

There are two major approaches for rapid prototyping of a component: traditional RP systems such as stereo-lithography or selective laser sintering; and CAD/CAM-CNC approach. To provide the students with an understanding about the differences between the two approaches a demo of RP on Dimensions 3D Printer is presented. In this demo, a CAD file of a component is generated in STL format using MasterCAM then downloaded to the 3D Printer to generate a plastic model of the component (Fig.4). While this demo enhances the student's learning about

this new product development technology it also provides a basis for comparing the available RP options including subtractive RP (material removal) and additive RP (layered manufacturing).

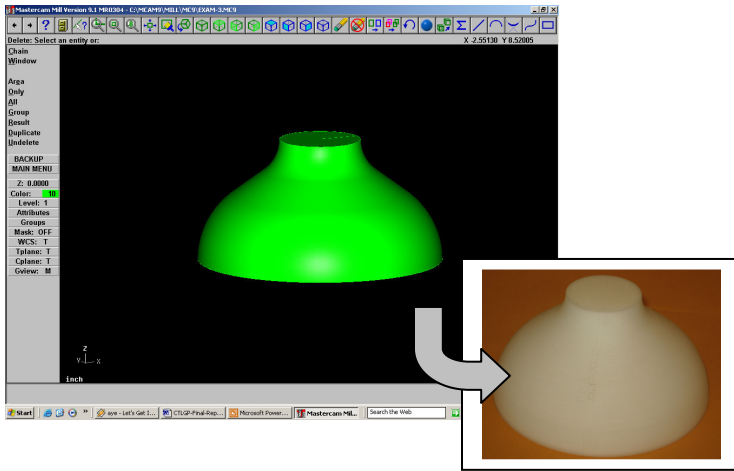


Figure 4. A component produced by Dimension 3D Printer

Projects/Exercises

A total of two laboratory mini-projects, one major project and two demo projects are included in the course as described in Table 1. Ten computer exercises are also designed for in-class active learning purpose (Table 2).

Mini Project #	Product	Learning Objectives
1	Coaster	CAD and CAM programming, setup and operation of an industrial grade CNC milling machine.
2	Chess Figure	CAD and CAM programming, setup and operation of an industrial grade CNC lathe machine.
Major Project		
Teams of 2-3 students	Determined by the teams	Integrating and applying skills gained in IT445 to a complex product development project. Managing a team project (Gantt chart). Writing a formal report.
Demo Project #		
1	Plasma Cutter	Recognizing the broader application of CAD/CAM
2	RP Machine	Recognizing the linkage between CAD/CAM and RP

Table 1. Laboratory projects

Ex. #	Topic	Learning Objective
1	GETTING STARTED	Overview of CAD and CAM processes
2	2D CAD-1	Basic 2D CAD functions
3	2D CAD-2	Advanced 2D CAD functions
4	3D CAD -1	Basic 3D wireframe and construction planes
5	3D CAD -2	Basic 3D surface modeling : Draft, Revolved Free-form Surfaces: Ruled, Loft, Swept
6	3D CAD-3	Construction of a 3D surface using Coons surface modeling technique.
7	CAM-1	Generating toolpath for machining a 3D surface using CNC mill (Coons surface)
8	CAD/CAM-1	Creating CAD models of complex molds and dies Generating toolpaths
9	CAM/CAM-2	Construction of CAD models for cylindrical shape parts. Generating toolpath for machining on CNC lathe

Table 2. In-class computer-based exercises

Assessment

Assessment was conducted by evaluating four types of student activities:

- In-class computer exercises
- Team projects in CNC machining and prototyping
- Closed book and notes written exams
- Open book and notes computer-based exams

Two computer-based exams were given to the students for the purpose of verifying their understanding of :

- The concept of numerical control (CNC)
- The concept of 3D modeling and construction plans (CAD)
- Toolpath generation (CAM)
- Cutting tool selection (CAM)
- Cutting parameters (CAM)

Entry/Exit Assessment

In addition to aforementioned evaluations two survey-based assessments were conducted during first and last weeks of the classes. The survey questionnaire along with the numerical student responses for the spring of 2006 class are shown in Figure 5.

ENTRY-EXIT ASSESSMENT OF IT__

		None	Basic	Moderate	Advanced
		1	2	3	4
1	My skill in 2D CAD after taking IT445 is:			50%	30%
	<i>before:taking IT445 is:</i>	25%	10%	60%	15%
2	My skill in 3D wireframe modeling using CAD after taking IT445 is:		10%	50%	30%
	<i>before:taking IT445 is:</i>	60%	35%	15%	
3	My skill in 3D surface modeling using CAD after taking IT445 is:		5%	60%	10%
	<i>before:taking IT445 is:</i>	60%	30%	10%	
4	My skill in CNC programming after taking IT445 is:		10%	60%	5%
	<i>before:taking IT445 is:</i>	70%	15%	15%	
5	My skill in CAD/CAM programming after taking is:		5%	75%	5%
	<i>before:taking IT445 is:</i>	75%	15%	10%	
6	My knowledge in rapid prototyping after taking IT445 is: (considering last week demo)	5%	60%	35%	5%
	<i>before:taking IT445 is:</i>	60%	40%		
7	My knowledge about CNC machines and tooling after taking IT445 is:		25%	50%	25%
	<i>before:taking IT445 is:</i>	15%	15%	55%	15%
8	My skill in developing a product using CAD/CAM-CNC after taking IT445 is:		15%	60%	25%
	<i>before:taking IT445 is:</i>	65%	15%	20%	
9	Please rate your learning experience with in-class exercises: 1. Not Valuable 2. Somewhat Valuable 3. Valuable 4. Extremely Valuable			15%	45%
				40%	
10	Please rate your learning experience with collaboration on lab projects: 1. Not Valuable 2. Somewhat Valuable 3. Valuable 4. Extremely Valuable			15%	35%
				50%	

Figure 5. Students learning assessment

Observations

Our experience with this course has been positive and students have reacted favorably to using in-class exercises and team-based projects. Class discussion indicated that students believe they learn more by hands-on class exercises. Most students rated the in-class exercises and collaboration on lab projects all as either valuable, or extremely valuable, in enhancing their learning experience. Students also indicated that, through collaboration and use of computer technology in classroom, the product development experience became a true learning experience. Judging by the group projects outcome, including the actual physical products and two computer-based exams in general, students as whole did well, though there were a few students who were relatively slow in executing some of the sequences of CAD/CAM programming.

Not every class fits this approach. However, a CAD/CAM-CNC class, which is heavily hands-on and practice-oriented is a good fit. This approach helped the instructor to overcome a challenging task of teaching sophisticated design and manufacturing software and hardware in a short 11-week time frame.

It is noteworthy to mention that teaching a laboratory-oriented course may demand a great deal of physical and mental effort by students as well as the instructor. However, most students enjoy the opportunity to make things and appreciate the value of education they get as attested by their positive feedback.

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