

On the Effective Teaching of CAD/CAM at the Undergraduate Level

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ABSTRACT

Due to the growing need for the graduates having solid foundation in computer aided manufacturing, undergraduate programs for manufacturing/mechanical/industrial engineering across the globe offers introductory courses in CAD/CAM. In this paper, a method is presented for integrating various resources available in an engineering college and in the Internet for teaching the fundamentals of CAD/CAM (parametric curve based geometric modeling, machining parameter selection, and cutter location determination). The presented method helps students attain the educational objectives set by the ABET. It is also argued that the presented method is more effective than a teaching method wherein a commercial CAD/CAM package is used.

Keywords: CNC, CAD/CAM, Parametric Curve, ABET, Teaching, Learning.

1. INTRODUCTION

Manufacturing is a wealth generating activity for a nation. To achieve high productivity in manufacturing, there is no alternative of computer aided manufacturing. As a result, graduates having solid foundation in CAD/CAM are needed for the economic growth of a nation. To meet this need, the undergraduate programs for manufacturing/mechanical/industrial engineering across the globe offer introductory courses in CAD/CAM. See the websites to see a typical course in CAD/CAM offered at undergraduate level:

<http://www.nd.edu/~rbs/AME341-sp05/syllabus-sp05.pdf>,

<http://btech.eng.nus.edu.sg/programme/meModuleInfo.aspx>,

<http://catalog.academics.uaeu.ac.ae/trydb.asp?PCode=MECH>.

Most of the times, an instructor depends on commercial CAD/CAM systems to offer the course. See the following websites to know about some of the commercial CAD/CAM package: <http://www.mastercam.com>, <http://www.delcam.com>, <http://www.ptc.com>. Although the user interfaces of the commercial CAD/CAM packages are different, their functionalities are the same, as shown in Fig. 1. As seen from Fig 1, a CAD/CAM system is meant for generating NC codes (G and M codes or other codes specific to a controller) to run a CNC machine. While doing so the system uses the information from: 1) part geometry (machining features with nominal shapes, parametric curves and surfaces), 2) tool path (Zigzag, Contour parallel, Morphing, etc.), 3) cutting tool (ball-nose, flat end mill, etc.), 4) cutting plan (rough for finish), and 5) manufacturing process knowledge (cutting force, surface roughness, material removal rate, cutting power determination). The responsibility of an instructor of a course on CAD/CAM is to teach how the information of part geometry, tool path, cutting tool, cutting plan, manufacturing knowledge should be integrated using the computerized facilities. The students should not only appreciate the existing CAD/CAM systems but they should also come up with alternative solutions for developing more user-friendly CAD/CAM systems.

The above mentioned facet is specific to teaching CAD/CAM as if it is a standalone subject-matter. However, a course is not a standalone course; it is a part of an educational program. In case of an engineering degree program, it (the program) is designed based on a well-defined set of objectives and outcomes in accordance with the recommendations of an accreditation agency. Particularly, an ABET-accredited [1] engineering program must demonstrate that their students attain (a) an ability to apply knowledge of mathematics, science, and engineering, (b) an ability to design and conduct experiments, as well as to analyze and interpret data, (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability, (d) an ability to function on multi-disciplinary teams, (e) an ability to identify, formulate, and solve engineering problems, (f) an understanding of professional and ethical responsibility, (g)

an ability to communicate effectively, (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context, (i) a recognition of the need for, and an ability to engage in life-long learning, (j) a knowledge of contemporary issues, and (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. The authors believe that a course on CAD/CAM at undergraduate level can help students attain such ABET-criteria as (a), (c), (d), (g), (h), (j), and (k). Therefore, the lectures and hands-on should be designed in such a way so that the following objectives can be achieved: Students apply knowledge of mathematics, science, and engineering; Students show an ability to identify, formulate, and solve engineering problems; Students show an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice; Students show an ability (or enhance the ability) to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability; Students show an ability to communicate effectively; Students recognize the need for, and an ability to engage in life-long learning.

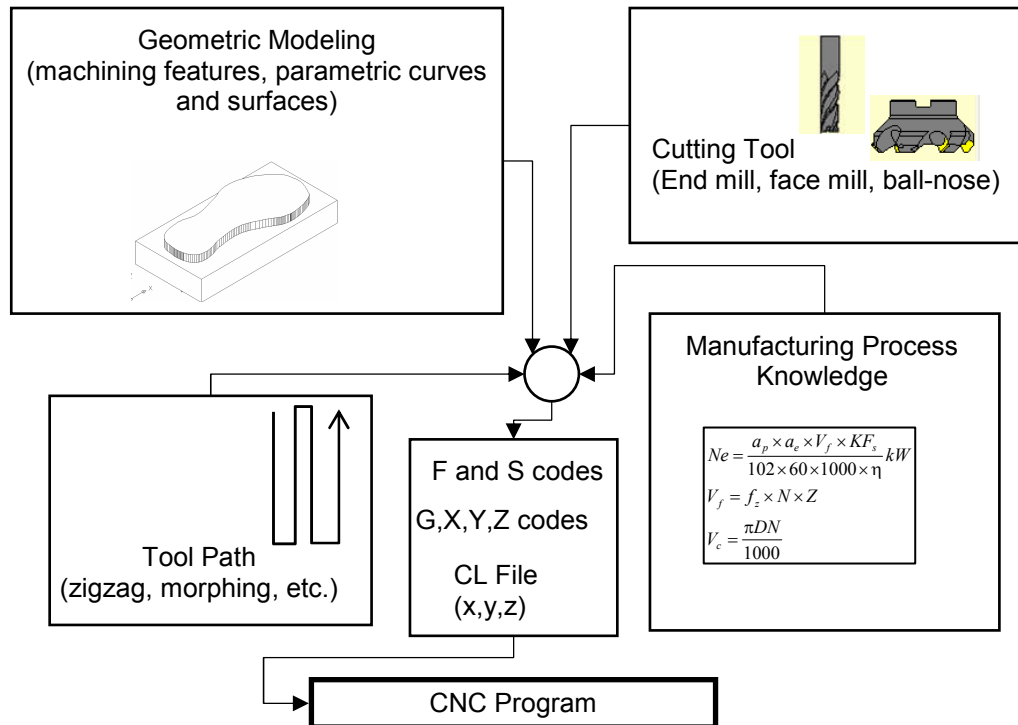


Fig. 1. Block diagram of CAD/CAM systems.

This paper shows a method for offering a course on CAD/CAM at undergraduate level so that the students get enough opportunity to attain the ABET-criteria (a), (c), (d), (g), (h), (j), and (k) in a higher scale of Bloom's Taxonomy [2-3] (Analysis, Synthesis, Evaluation). At the same time the students grasp the fundamentals of CAD/CAM systems so that they not only become better users of such systems but also can become better developers of such systems in the future. The remainder of this article is organized as follows: Sections 2-4 show the methods for teaching geometric modeling, manufacturing process knowledge integration, and cutter location determination process, respectively. This is followed by the section for discussion wherein the proposed teaching method is positioned in terms of other methods recommended before. The last section provides the conclusion of this paper.

2. TEACHING METHOD FOR GEOMETRIC MODELING

There is a growing tendency to model engineering shapes (products (telephone handsets house hold electronics), machine elements, body of automobiles and aircrafts) using parametric curves and surfaces [4-8]. Generally speaking, a parametric curve is given by the following expression:

$$C(t) = \sum_{i=1}^n P_i \times B_i(t) \quad (1)$$

In Eq.(1), P_i is the i -th control point and $B_i(t)$ is the blending function associated with P_i . $B_i(t)$, a function of $t \in [0,1]$ determines how much P_i influences the curve $C(t)$. Students can apply their mathematics and science knowledge to derive the blending functions for a given interpolation (linear (i.e., Bezier curve), hermite, spline, etc.) and apply their programming skill to develop customized equation editor to generate parametric curves of different types. See [4-5] to know the techniques for deriving the blending functions and for developing the equation editors. The instructor can let students model a relatively complex geometric shape using the concept of piecewise parametric curves and let them use the conditions of continuity to make the model smooth and good-looking. This way the students can demonstrate (even can enhance) their abilities related to ABET-criteria (c)-(e).

For example, consider the case shown Fig. 2. Fig 2 shows an example of such a teaching method, wherein the students develop an equation editor for Bezier curve. (Instead of using this tool, the students can use spreadsheet like Microsoft Excel as an equation editor.) The students use this tool to model a shape (shoe) [5, page, 397] using a few piecewise Bezier curves and collect the points representing the curve in a text file. Then the students transfer the points to computer-aided visualization tool (e.g., AutoCAD™) using a Script function applicable to the tool. In case of AutoCAD™, a set of points saved in a text file can be transferred using a Script function. Afterward the students construct a solid model using the available solid modeling functions to display the shape they will produce by using a CNC machine. The set of points saved in the text file is of high importance because these points will be used to automatically generate the CNC program. The authors observed that accuracy of the model shown in Fig 2 depends on the intellectual ability of the students and as well as how much cooperative the students are to share their ideas with the students in a group. However, if a commercial package is used to do the geometric modeling, it would be difficult to demonstrate or enhance the students' ability defined by the ABET-criteria. Moreover, the working principles of the CAD/CAM package remain a black-box to the students.

3. TEACHING METHOD FOR INTEGRATING MANUFACTURING PROCESS KNOWLEDGE

Teaching the integration of manufacturing process knowledge in the CNC program generation is important due to two reasons. The first reason is that it helps students appreciate what they learned in a course for manufacturing process (usually offered before offering CAD/CAM-like course). The other reason is that it demonstrates the automation procedure for determining spindle speed (S code) and table or tool feed (F code) ensuring the desired machining performance (material removal rate for rough cuts and surface finish for finish cuts) without causing any damage to the cutting tool or to the machine tool. Therefore the students should be able to use the manufacturing process knowledge to determine the values of the process parameters ensuring a safe and efficient machining operation. This in turns provides an instructor to show how and at what extent the ABET-criteria [1] are fulfilled with respect to Bloom's Taxonomy [2-3] because the students will be able to apply the knowledge they acquired in other courses and synthesize the solutions and will be able to evaluate the solution using real-life constraints.

For example, consider the case of rough milling. For rough milling the following three equations [9] can be used to ensure safe and efficient operations.

$$Ne = \frac{a_e \times a_p \times V_f \times KF_s}{102 \times 60 \times 1000 \times \eta} \text{ kW} \quad (2)$$

$$V_f = f_z \times N \times Z \quad (3)$$

$$V_c = \frac{\pi DN}{1000} \quad (4)$$

In Eqs. (2)-(4), a_e is the width of cut, a_p is the depth of cut, V_f is the table feed, KF_s is the specific cutting pressure or energy, η is the efficiency, Ne is the power consumption during milling, f_z is feed per tooth, N is the spindle rpm, Z is the number of teeth, D is the diameter of the tool, V_c is the cutting velocity. KF_s depends on the workpiece material and f_z , a_p and a_e depend on the cutting plan (how many passes for roughing operation and how many passes for the finishing operation), limit of V_c depends on the tool material.

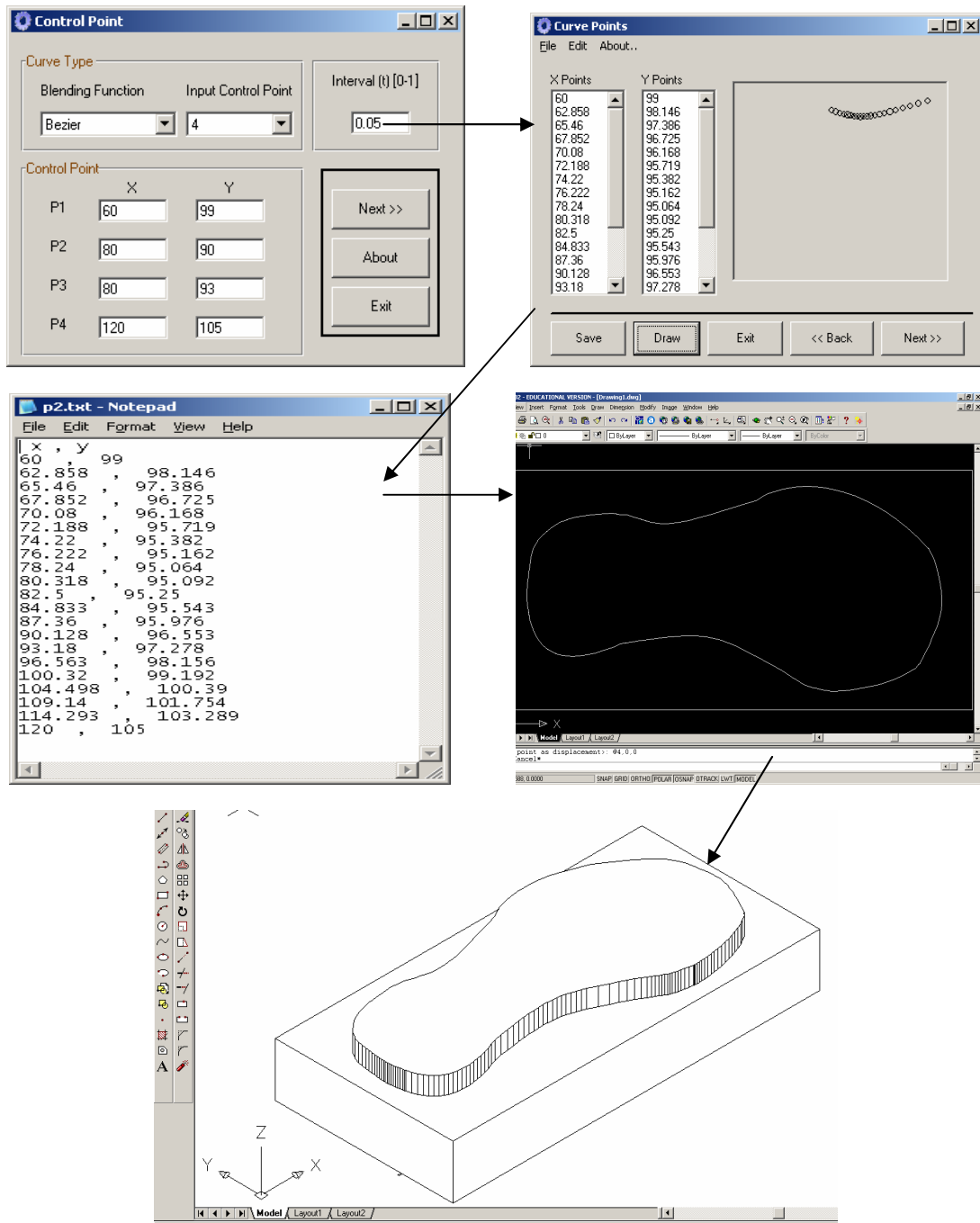


Fig. 2. Geometric modeling for teaching CAD/CAM.

A knowledge-based iterative process is needed to determine optimal N and V_f , which are values of S code and F codes of a CNC program [10-13]. For the undergraduate students equation based iterative process is more appropriate. For example, the following process can be used to let the students determine F and S code ensuring safe and efficient milling.

Step 1:

Input workpiece material (e.g., hard steel). Assume a value for feed per tooth (e.g., 0.1).

Step 2:

Consult a database and determine the value of KF_s (e.g., for hard steel and feed per tooth 0.1, $KF_s = 252$ kg/mm²). See [9] for the table.

Step 3:

Input depth of cut (5 mm) and width of cut (3 mm), maximum power output of the machine tool and the efficiency of the power transmission unit (e.g, 0.9)

Step 4:

Use Eq. (2) to calculate V_f . Round up V_f and reduce the value of V_f to determine F code.

Step 5:

Calculate N using Eq. (3) and see whether it exceeds the limit of the machine tool to be used. If it exceeds the limit then go to Step 1 and increase feed per tooth.

Step 6:

Calculate V_c using Eq. (4) and see whether it is less than the recommended cutting velocity for the tool material because cutting velocity is mostly responsible for tool life and the maximum cutting velocity depends on the tool materials. If V_c is greater than the stipulated value then go to Step 1 or 2. Otherwise, accept N as the S code after round up.

A simple program can be developed to exercise the above mentioned procedure of determining F and S code values. Fig 3 shows the screen-prints of such a program implemented by using Microsoft™ Excel™.

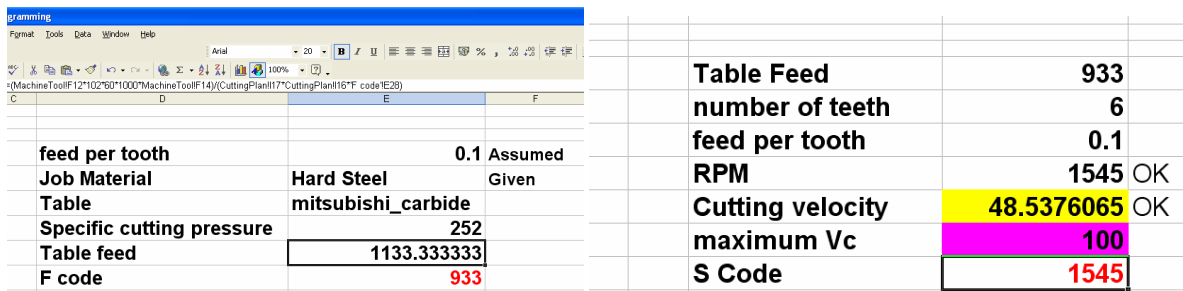


Fig. 3. Determining F and S codes.

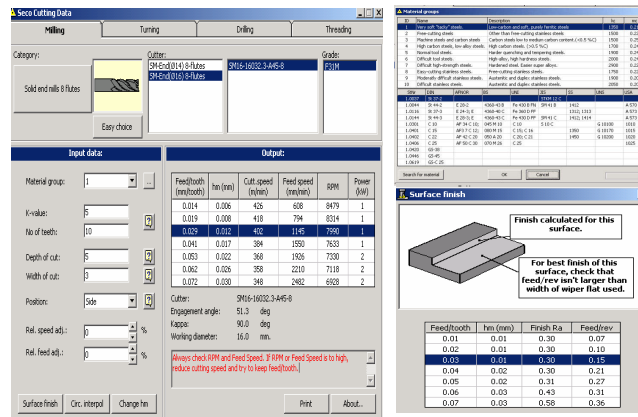


Fig. 4. Determining F and S codes using free software tools from a tool maker.

There are free software tools developed by the cutting tool makers to assist the process of determining S and F codes. For example, SECO™ Tools provides a free software called SecoCut™ [14] that can be downloaded from the company's Website. Fig 4 shows a typical user interface of the SecoCut™. As seen from Fig 4, one can change cutting tool, workpiece material, depth of cut, width of cut and can see how rpm, feed per tool, cutting velocity and cutting power are related with each other. Instead of using the method shown in Fig 3, an instructor can alternatively use the method shown in Fig. 4. However, as far as the ABET-like educational objectives are concerned [1], the method underlying Fig 3 is preferable over the method underlying Fig. 4. It is worth mentioning that the textbooks [6-8] for teaching CAD/CAM do not provide any chapter from where the students can learn how to integration of the manufacturing process knowledge with the geometric model module (i.e., CAD module).

4. TEACHING METHOD FOR CUTTER LOCATION DETERMINATION

The procedure shown in the previous section is useful for determining the S and F codes for a CNC program. What about the X, Y, Z, and G codes? To achieve this, a definite tool path is needed. In addition, an algorithm is needed to automate the tool path. The automated tool path works on the elementary geometry of the workpiece (workpiece modeled by using a set of points) and draw in the points representing the workpiece geometry sequentially to determine the cutter location (CL) (center tip of a tool) so that the desired materials are removed from the workpiece. For example, consider the case shown in Fig. 5. In this case, the task is to machine a part as shown in the left-hand-side in Fig. 5. To achieve this, one can plan that first the material will be removed contouring along the curve. In this case, the tool center will follow the dotted line in the right-hand-side in Fig. 5. Later the material will be removed by applying cutting action in the X-direction. While cutting, the tool will not travel beyond the points on the curve (dotted line in the left-hand side in Fig 5). To achieve this cutting, a zigzag tool path should be used, as follows:

Zigzag = Draw Tool Depth Width Cut Up Back Depth Width Cut Up Back Depth Width This tool path can be programmed by using the following If...Then... rules:

If tool_path[previous] = (Draw Tool or Back) Then tool_path[present] = (Depth)
 If tool_path[previous] = (Depth) Then tool_path[present] = (Width)
 If tool_path[previous] = (Width) Then tool_path[present] = (Cut)
 If tool_path[previous] = (Cut) Then tool_path[present] = (Up)
 If tool_path[previous] = (Up) Then tool_path[present] = (Back)

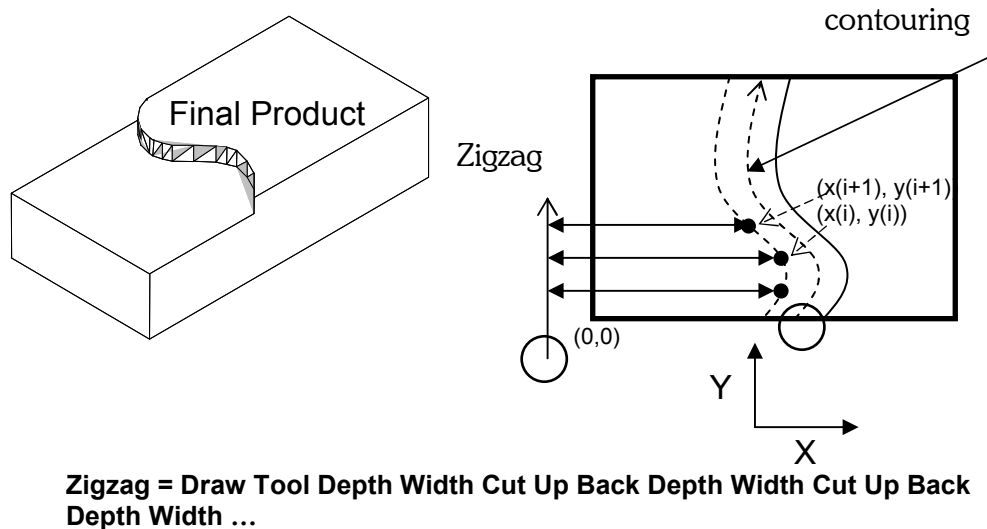


Fig. 5. Tool path planning for achieving a parametric curve.

To determine the cutter locations the following rules can be used:

For X code:

If tool_path[present] = (Cut) Then $X[\text{present}] = x(i+1)$

If tool_path[present] = (Up) Then $X[\text{present}] = X[\text{previous}]$

If tool_path[present] = (Depth or Width or Back or Draw Tool) Then $X[\text{present}] = -20$ (say)

For Y code:

If tool_path[present] = (Width) Then $Y[\text{present}] = y(i+1)$

If tool_path[present] = (Up or Cut or Depth or Back or Draw Tool) Then $Y[\text{present}] = y(i)$

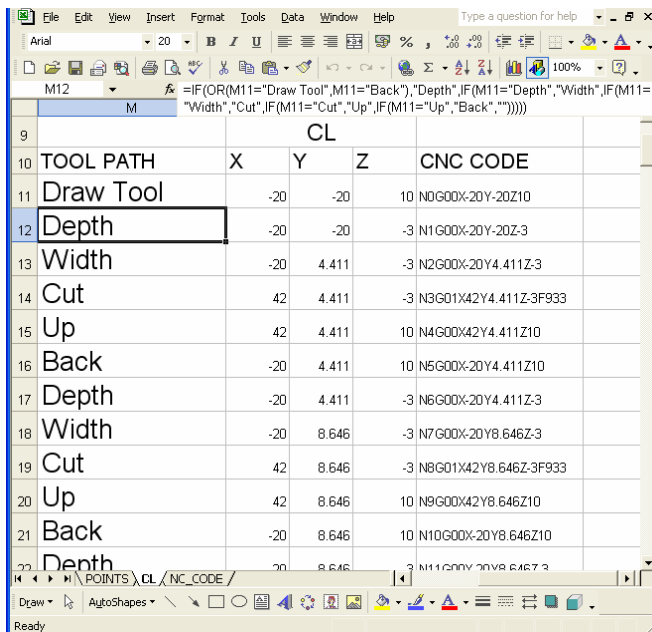
For Z code:

If tool_path[present] = (Up or Back or Draw Tool) Then $Z[\text{present}] = 10$ (say)

If tool_path[present] = (Depth or Width or Cut) Then $Z[\text{present}] = -a_p$

Here, $(x(i), y(i))$ and $(x(i+1), y(i+1))$ are two consecutive points on the curve.

The above If...Then... rules can easily be implemented in Microsoft™ Excel™ and the CL can automatically be determined. See Fig 6, wherein the above rules are used to determine the CL automatically. Fig 6 also shows the result after machining using the generated CNC program. As seen in Fig 6, two cases are shown one for machining wherein only zigzag tool path is used to generate the CNC program and for the other case both contouring along the curve (Bezier curve) and the zigzag tool paths are used to generate the CNC code. From this exercise, the students realize that the geometric modeling (here how much accurately the curve has been modeled, i.e., how many points are used to represent the curve) and tool path are collectively responsible for getting a better result after machining. The issue of surface finish is however is not appropriate to bring here because the students may not have enough analytical knowledge of how surface finish is affected by process parameters and cutting tool geometry. This issue may be addressed in more details in an advanced course on manufacturing, however.



	CL			
TOOL PATH	X	Y	Z	CNC CODE
Draw Tool	-20	-20	10	N0G00X-20Y-20Z10
Depth	-20	-20	-3	N1G00X-20Y-20Z-3
Width	-20	4.411	-3	N2G00X-20Y4.411Z-3
Cut	42	4.411	-3	N3G01X42Y4.411Z-3F933
Up	42	4.411	10	N4G00X42Y4.411Z10
Back	-20	4.411	10	N5G00X-20Y4.411Z10
Depth	-20	4.411	-3	N6G00X-20Y4.411Z-3
Width	-20	8.646	-3	N7G00X-20Y8.646Z-3
Cut	42	8.646	-3	N8G01X42Y8.646Z-3F933
Up	42	8.646	10	N9G00X42Y8.646Z10
Back	-20	8.646	10	N10G00X-20Y8.646Z10
Depth	-20	8.646	-3	N11G00X-20Y8.646Z-3



(only zigzagging)



(both contouring and zigzagging)

Fig. 6. Automatic CL and CNC code determination and the machining results.

The method explained above for cutter location determination provides students an opportunity to use their ability to identify, formulate, and solve engineering problems formulate a problem. Meaning that the students can imagine various tool paths as they feel appropriate or reasonable and later they can see the consequences of their judgment. More specifically, the students can also show the ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (particularly, programming skill). This way, the method helps fulfill some of the ABET-criteria.

5. DISCUSSIONS

The teaching aspects of CAD have been studied elaborately by different authors [15-18] from the recent context of information technology whereas the teaching aspects of CAD/CAM have not been studied elaborately from the recent context of information technology. There were some studies on teaching CAD/CAM done two decades back [19-20]. Therefore, the present study helps fill this gap. The teaching method shown in the above three sections can be implemented without using a commercial CAD/CAM package. As a result, even though the commercial CAD/CAM software companies are not interested in offering the academic licenses to an academic program, the program will be able to the conduct the course without hampering the integrity and quality teaching CAD/CAM. Less dependence on commercial packages at least for geometric modeling part of CAD/CAM is somewhat desirable as reported in [17]. The older studies also recommend the same that a commercial package should be viewed as a productivity tool but not as a replacement of engineering fundamentals [19].

Although a computer-generated geometric shape looks perfect but perfect production of the shape depends on many other engineering considerations. Compare the pictures shown in Fig. 6. Therefore, as future engineers the students should realize what kind of engineering practice and skills fill the gap between the “virtual reality” (i.e., computer generated geometric shape) and “reality” (the machined part). The teaching methods shown in Sections 2-4 actually unveil (to the students) the steps and engineering skill necessary to materialize a “reality” from a “virtual reality”. In this process the students explicitly apply the knowledge of mathematics, science, and engineering. Students show an ability to identify, formulate, and solve engineering problems. Students show an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (i.e., they use available drafting, computing, and programming tools). Students show an ability (or enhance the ability) to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability. All these can not be achieved by student along. This means the students show an ability to communicate effectively. Students recognize the need for life-long learning, i.e., they recognize the need for using and developing more sophisticated engineering tools to produce more complex engineering parts.

6. CONCLUSIONS

The main responsibility of an instructor of a course on CAD/CAM at undergraduate level is to teach how the information of part geometry, tool path, cutting tool, cutting plan, manufacturing knowledge should be integrated using computerized facilities to generate the CNC program. While doing this, the instructor should help students attain some of the ABET-criteria such as: an ability to apply knowledge of mathematics, science, and engineering, an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability, an ability to function on multi-disciplinary teams, an ability to identify, formulate, and solve engineering problems, an ability to communicate effectively, an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. To achieve this, the methods for teaching geometric modeling, manufacturing process knowledge integration, and cutter location determination process are presented. The teaching method is design in such a way so that there is no need for using commercial CAD/CAM package while offering the course.

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