A Project-Based Learning Approach to Teaching Computer Vision At the Undergraduate Level

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Abstract

This paper documents an attempt to use the project-based learning approach to develop and teach a computer vision class in the undergraduate electrical and computer engineering program. The project-based learning approach is one of the innovative methods promoted in the Advanced National Effective Teaching Institute (NETI-2). It combines the traditional lecture-based deductive learning with the inductive learning described by Prince & Felder in a 2006 JEE paper.

The paper describes the class objectives as well as the projects that were developed to achieve those objectives. The paper also discusses the challenges encountered during both the development and the delivery phases of the class. These challenges include, identifying suitable class projects, achieving adequate student assessment, and most importantly, students’ resistance to the new learning paradigm. The paper also includes assessment results including the faculty assessment reports and the student evaluations of the course.

Introduction

Image processing and computer vision (also known as machine vision) are gaining a growing popularity in various fields of engineering including instrumentation, robotics, and security systems. In today’s quickly changing world, staying up-to-date is a recipe for success. This is particularly true in the very dynamic fields of Electrical and Computer Engineering (ECE). Although the main concepts and fundamental courses like electric circuits and logic design remain unchanged, some of the tools that were very popular few decades ago are totally obsolete today, and some of the essential tools in the industry today didn’t exist back then. As a result, ECE programs and faculty members continuously strive to update their curricula to ensure that their graduates are well prepared to excel in both the industrial and the research worlds.

Surveying the curricula of various ECE programs around the country, one can notice that some coursework in signal processing is required in virtually all undergraduate ECE programs. Dedicated classes in Digital Signal Processing (DSP) may be either required or offered as technical elective classes for ECE students. These DSP classes may or may not include an image processing module, depending on the course designer. With its increasing popularity and applications, the relatively newer field of computer vision, is quickly making its way to the curricula of ECE programs. We strongly believe that, topics in image processing, pattern recognition, and computer programming can be put together to create a very rigorous course in computer vision to be offered as a technical elective for higher level undergraduate ECE students. The class can also be made available as an elective to higher level computer science students assuming they have, at least, a working familiarity with matrices and matrix operations.
In a quick survey, it was found that an undergraduate course in computer vision has been previously addressed in several works. An overall review about the subject was published in 2003. After that, one of the efforts addressed teaching the course to complement a robotics curriculum. In another paper, the authors describe a course that is particularly targeting manufacturing engineering applications. Both of these works are application specific and appear to be teaching the course in a traditional deductive approach.

In our work, this paper describes a general purpose course that is offered as a senior level technical elective to teach image processing and computer vision. Due to the extremely applied nature of the class topics, and considering the numerous studies showing the effectiveness of inductive learning, the class was developed and taught using the project-based learning methodology. The paper describes in details the course objectives as well as the various class activities that are used to achieve them. These activities can be categorized into traditional lectures, where students acquire basic knowledge, and assigned projects that require students to both use their previously acquired knowledge and develop brand new skills to complete. The paper also discusses the challenges encountered while developing and teaching the class. The challenges include identifying projects that cover the course topics, creating effective assessment rubrics, and dealing with student resistance to the new learning paradigm. The paper also discusses the approaches used to deal with all these challenges.

The paper is concluded with a discussion of the assessment results collected from the last two offerings of the course. These assessment results include both the faculty assessment reports as well as the student evaluations of the course.

**Course Format and Objectives**

The course is offered as a 3-credit hour technical elective. The pre-requisite for the course is a course in signals and systems. Students are also expected to have some prior exposure in computer programming. While all of the course projects are carried out in Matlab, a programming background in any high level language is accepted. Multiple textbooks were suggested as a reference but no textbook was required as the students could rely on the instructor’s note for the course work.

The class is scheduled to meet, for 50 minute meetings, 3 times per week. The class meetings can be categorized into three broad types: lectures, project discussions, and project labs. In the lecture class meetings, the instructor presents new concepts and fundamental material in a traditional lecture format. The project discussion class meetings are where the instructor introduces the projects and explains the submission requirements. Students also use these meetings to ask high-level questions about the projects and, in some cases, suggest or negotiate modifications on the project requirements. The project lab meetings take place in a computer lab setting, where students work on their projects. In these meetings, the instructor’s job is limited to checking on the student’s progress and answering technical questions that may arise.

The objectives of the course is to enable students to:

- Understand the various color systems and perform color conversions
- Design and implement effective point, area, geometric, and frame processes
- Understand the various segmentation techniques and discriminate their applications
• Understand Morphology techniques and discriminate their applications
• Perform classifications based on cost function optimization
• Design and implement various feature selection techniques
• Design and conduct image processing/vision projects using CAD package software
• Report the outcomes of projects in both oral and written communication formats.

Project-Based Learning Approach

The deductive approach to teaching is the traditional approach where an instructor shows the learners the scientific principles of a new concept followed by mathematical derivations to obtain the fundamental formulas and equations. The instructor then goes on with solving a few examples before passing the torch to the learners by assigning homework and/or lab assignments.

In the inductive learning approach\(^7,8\), the goal is to enable learners to play a bigger role in their own learning process. The instructor starts the process by posing challenges and problems to learners. The learners are then tasked (individually or in groups) to come up with solutions to the proposed problems. In order to obtain these solutions, learners will ask questions and, to some extent, seek guidance from the instructor. At the end of the process, students end up receiving the class contents from their instructor the same way they would have received it in a lecture-based deductive learning approach. The difference remains that, in inductive learning, students with a problem at hand are more motivated and actively searching for the information that is delivered. In deductive learning, on the other hand, the learners’ motivation and interest levels are much lower as they receive conceptual knowledge before they know the real-life application.

Due to the extremely applied nature of the computer vision topic, and considering the numerous studies showing the effectiveness of inductive learning\(^9\), the initial thought was to design the course and teach it using the problem-based (inductive) learning approach. After deeper thoughts, and further consultations with colleagues, many concerns regarding the student backgrounds and their levels of preparation for the course were brought up. Several colleagues noted that a minimum of a few lectures maybe necessary to lay a foundation of fundamental concepts and equip students with the right tools to start their problem solving on the right foot.

As a result of the previous discussion, the class was developed and taught using the project-based learning methodology\(^10\). This methodology is a hybrid approach combining both instruction-based (deductive) and problem-based (inductive) learning realms. Each teaching module started with a lecture followed by a project discussion. Teaching modules were all terminated by one or more project lab(s), depending on the complexity of the project.

Course Projects

The biggest challenge faced when developing the course is mapping the course contents to teaching modules and finding adequate projects to deliver and assess the students’ knowledge in each topic. This section describes the projects used in the class and the topics they covered.
I. Image Enhancement

In this project, students are given the grayscale image shown in Figure 1. Seeing that the image is too dark for any effective vision processing, the students’ assignment is enhancing the image. During their search for a solution, students are exposed to the concept of pixel manipulation. Students also learn about point processes including brightness intensification, contrast stretching, and histogram equalization. The histogram equalization technique is eventually found to provide the best results in this problem. The histogram equalized image is shown in Figure 2.

Figure 1. The original image provided to students in the Image enhancement project.

Figure 2. The image enhanced by histogram equalization in the Image enhancement project.
II. Image De-noising

In this project, students are given the noisy grayscale image shown in Figure 3.a. The students’ assignment is to de-noise the image, i.e. removing the noise or at least minimizing it with the least possible damage to the image quality. During their search for a solution, students learn about area processing. The best de-noising is achieved using either a low pass (smoothing) filter or a median filter. The project is also a good place for the instructor to introduce another useful area process, the high pass (sharpening) filter. The de-noised image is shown in Figure 3.b.

III. Edge Detection

In this project, students are given the color image shown in Figure 4.a. The student assignment is to convert the image to a grayscale image and then detect the edges in it. When searching for a solution, students will learn about color schemes and color conversion as well as the various edge detection methods. The edge detection methods include the Sobel operator\textsuperscript{11} and Canny’s algorithm\textsuperscript{12}. The mask of the detected edges is shown in Figure 4.b.

![Original Image](image1.png) ![De-noise Image](image2.png)

Figure 3. The original and the de-noised (low pass filtered) versions of the image used in the image de-noising project.

![Original Image](image3.png) ![De-noise Image](image4.png)

Figure 4. The original color image and the grayscale image used in the edge detection project.
IV. Geometric Processing

In this project, students are asked to perform the pre-processing for a card identification system. The pre-processing is a sequence of necessary steps that makes it possible for the card identification system to identify the value and the type of the card. These steps include the already covered edge detection to identify the location of the card in the frame. The next step is to rotate the card by an angle $\alpha$ around its center ($\alpha$ and the center coordinates are determined using the detected edges). The final step is to crop the rotated card out of the whole image. A color image of a playing card on a black background is shown in Figure 5.a. The mask of the detected edges is shown in Figure 5.b and the rotated, cropped mask is shown in Figure 5.c.

V. Color-Based Segmentation

In the first of two segmentation projects, students are given an image of objects with various shapes and colors. Their first task is to determine the positions and the contours of the various objects using their newly acquired edge detection skills. The second step is to discriminate the objects of a particular color of interest and segment it out of the image. Figure 6.a shows the original image and Figure 6.b shows the mask representing to the detected red object(s).
VI. Area-Based Segmentation

In the second segmentation project, students are asked to classify objects of similar colors in an image. In this type of problems, since the color will not be helpful, students will have to identify another feature to discriminate their object(s) of interest. In this particular project, the objects to classify are the U.S. monetary coins shown in Figure 7. While most of the coins have very similar colors, they all have different sizes which makes the object area an attractive discrimination criterion. While working on this project, students will also learn about morphology and particularly, the use of erosion and dilation in the elimination of blobs in the segmentation masks.

![Figure 6. The image and the mask obtained in the color-based segmentation project.](image.png)

![Figure 7. The U.S. monetary coins used in the area-based segmentation project.](image.png)

VII. Pattern Recognition

In this project, students are asked to recognize the traffic sign shown in the image in Figure 8. The recognition starts with identifying the object of interest (traffic sign) and then recognize the type of sign it represents. In other words, students will have to classify the identified sign in Figure 8 with its closest match in the signs database shown in Figure 9. In order to do that, students will identify a set of discriminating features to distinguish the possible signs from one another. Once the features are identified, the nearest neighbor method\(^\text{13}\) can be used to classify the detected sign as one of the known signs in the training data base.
Course & Projects Coverage

To summarize, students taking this course will have to achieve a total of seven projects over the span of the semester, resulting in a rate of one project every two weeks. It is extremely critical to ensure that the assigned projects cover all the course objectives and the material to be taught. Table 1 shows the list of topics that were taught in the traditional lecture-based version of the course (offered in previous years). The table also shows the list of the projects and the course-topic mapping to ensure that all topics are adequately covered. As can be seen in the table, each course topic is covered at least in one of the course projects.

<table>
<thead>
<tr>
<th>Lecture-based Topic</th>
<th>Project-based Project</th>
<th>Covered Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Pixels, images, and matrices</td>
<td>Image enhancement</td>
<td>1, 2, and 3</td>
</tr>
<tr>
<td>2 Grayscale, binary, and color images</td>
<td>Image de-noising</td>
<td>1, 2, and 4</td>
</tr>
<tr>
<td>3 Point processes</td>
<td>Edge detection</td>
<td>1, 2, 4, and 6</td>
</tr>
<tr>
<td>4 Area processes</td>
<td>Geometric Processing</td>
<td>1 and 5</td>
</tr>
<tr>
<td>5 Geometric processes</td>
<td>Color-based segmentation</td>
<td>1, 2, 6, and 7</td>
</tr>
<tr>
<td>6 Edge detection</td>
<td>Area-based segmentation</td>
<td>1, 2, 6, 7, and 8</td>
</tr>
<tr>
<td>7 Image segmentation</td>
<td>Pattern recognition</td>
<td>1, 2, 9, and 10</td>
</tr>
<tr>
<td>8 Morphological processes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Feature extraction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Pattern recognition</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. List of topics taught in a lecture-based version of the course and the mapping of these topics to the various projects in the project-based version of the course
Course Evaluation

During the last week of class, students are asked to fill out a web-based survey assessing their learning experience. A total of 13 out of 14 students enrolled in the course participated in the survey. In each question, students were given a statement and were asked to indicate their degree of agreement with it. The possible options given included strongly agree, agree, neutral, disagree, or strongly disagree for each statement. Table 2 shows a list of the statements and the distributions of the responses received in the survey.

While the sample size was relatively small, the results show that students were very happy with the learning experience (questions 1, 2, and 4). While still overwhelmingly positive, students' responses were a little less enthusiastic when asked about the quality of the course and the workload associated with it (questions 3 and 5). Considering the project-based learning nature of the class, survey questions about the projects (referred to as “lab assignments” in the survey) are of particular importance. The encouraging feedback obtained from questions 6 and 7 demonstrated that the selected projects impressively served their purpose. It was also encouraging and reassuring to see that every single student taking the survey either strongly agreed or at least agreed that the professor’s teaching method both stimulated their interest (question 8) and helped their learning (question 10).

Instructor’s Reflections

From an instructor’s perspective, the main two concerns have been the degree of match between the projects and the topics covered in class and the way the students would receive the “new” method of learning. For the first main concern, it was very pleasant and assuring to see that students overwhelmingly felt that the projects facilitated their leaning and that the projects and the lectures reinforced one another (Questions 6 & 7).

When it comes to the way students received the new learning approach, the feedback was a little dimmer but still positive overall. Two students in question 5 were not sure if the course was great. Generally, the feedback received on that particular question cannot be considered negative. However, the significant mismatch between the feedback in that question and the quality of the professor (Questions 5 & 12), may indicate that students would prefer to have the same professor in a traditional lecture-based course. These feelings were verbally conveyed several times during the class. Multiple students (who took previous course(s) with the instructor) expressed their dissatisfaction with the project based nature of the course with comments like: “you did great job lecturing in the (fill in the blank) course, why can’t you do the same in this course?”

The students’ resistance to the new learning approach was not always polite and courteous, especially at the beginning of the semester. In the 4th week of class, in an informal white paper survey, several students submitted frustrated comments including: “if I wanted to learn it by myself, I wouldn’t come to school”, “why do I have to pay for a course where I have to learn the material on my own?”, and “isn’t it your job to teach us how to solve these problems.” This type of reaction must be expected and must be addressed properly. Time was invested in multiple occasions during class meetings to explain that the project-based learning approach is used
because research shows that it creates a better learning experience in the long run and that it does not require less preparation on the instructor’s side.

In another related issue, students were exceptionally convinced that project-learning creates a larger workload on the student’s side. This misconception was addressed multiple times during the semester to explain to the students that the workload is the same and that learning (whether deductive or inductive) requires the same amount of work, and that the only difference between the two is the chronological order of the learning activities. As the semester progressed, students appeared to gradually believe this to be the reality. This was reflected in the feedback in Question 3 of the survey where not a single student felt that they are overburdened with workload in the class. A total of 11 students either agreed or strongly agreed that the workload for the class was comparable to other courses with equal credit and 2 students were neutral.

Table 2. Results of end-of-semester survey assessing student learning experience

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. This course enhanced my problem solving abilities</td>
<td>9</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2. The classroom environment enhanced my learning</td>
<td>7</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3. The workload for this course was comparable to other courses with equal credit</td>
<td>6</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4. Overall, my learning experience has been Excellent</td>
<td>9</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5. The course (set aside your feelings about the professor) is excellent</td>
<td>6</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6. The lab assignments facilitated my learning experience</td>
<td>10</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7. The lab and course material reinforced one another</td>
<td>10</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8. The professor stimulated my interest in the subject</td>
<td>10</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9. The professor was well prepared for class</td>
<td>11</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10. The professor’s teaching method helped me learn</td>
<td>9</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11. The professor was available for help outside the class</td>
<td>9</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12. The professor (set aside your feelings about the class) is excellent</td>
<td>12</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Conclusion

This paper described my experience in developing and teaching a project-based computer vision course for undergraduate electrical and computer engineering students. The innovative project-based learning approach was adopted because of its ability to combine both lecture based and problem based learning approaches in teaching the course.

The paper described the class objectives as well as the projects that were developed to achieve those objectives. The paper also discussed the student feedback received at the end of the course as well as the instructor’s reflections on the experience in both developing and delivering the course.

Bibliography