USING ON-LINE DIGITAL VIDEO TO AUGMENT THE TEACHING OF FREQUENCY/SPATIAL FILTERING OPERATIONS

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ABSTRACT

Frequency/spatial domain transformations are one of the most difficult for undergraduate engineering and technology students to understand and apply to domain specific problems. Instructors often spend valuable in-class time remediating the student's math skills before teaching their content area.

This paper presents a methodology used by the author to augment the student's skills in a multimedia class where the students implement image processing filters dependent on frequency/spatial domain transformations. The method yielded a reduction of in-class remediation time from 21% to 4% of class time and intergraded instructional-design theory with advancements in media production in a novel way.

INTRODUCTION

Engineering and Technology students often have difficulty mastering the theoretical concept and practical application of frequency/spatial domain transformations. This concept is of profound importance in numerous technical fields including digital signal processing, image processing, and computer graphics [1].

Two courses taught by the author in the Computer Graphics Technology (CGT) department at Purdue University require students to write computer applications that manipulate video, audio, and raster images. To succeed, the students must understand the theoretical principles of spatial/frequency domain transformations and apply those principles in a practical setting. In CGT 451 "Multimedia Authoring II" and TECH 513 "Interactive Multimedia Research and Development", the students are expected to write an image processing program that implements common filters. The filters are implemented through either frequency-domain filtering or spatial-domain filtering [2].

If the student elects to implement a filter using the frequency-domain approach, the student must first determine the frequency response of the signal, which in this case is the image. The student then multiplies the obtained response with the filter's frequency response. Finally, the student transforms the results back into the spatial domain by determining the amplitude-time behavior of the obtained product.

If, on the other hand, the student elects to implement a filter using the spatial-domain approach, the student has to determine the amplitude-time response of the filter and then convolve the obtained response with the signal/image.

In either case, the students must have knowledge of performing Fourier, discrete cosine, and wavelet transformations. In mathematics courses, students often learn to perform these transformations using Fourier transforms:

$$F(u,v) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x,y)\, e^{-j2\pi(ux+vy)}\, dx\, dy$$

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As the students progress into classes where they need to apply their knowledge to practical scenarios, they typically learn to use discrete versions of these types of transformations that can be performed quickly, such as Fast Fourier Transforms and Discrete Cosine Transforms (DCT). Within the realm of image processing, DCT is of particular usefulness because it is at the foundation of many compression implementations such as the Joint Photographic Experts Group (JPEG) format. Another benefit of this transformation is that the transformation coefficient consists of only real numbers because its basis is composed entirely of cosines, as we can see below.

$$F(u,v) = \alpha(u)\,\alpha(v)\cdot \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x,y) \cos\left[\frac{(2x+1)u\pi}{2N}\right] \cos\left[\frac{(2y+1)v\pi}{2N}\right]$$

for u,v = 0, 1, 2, … N-1

This project focuses on the production and deployment of on-line supplementary instructional video materials used in CGT 451 to teach students the necessary skills to implement spatial/frequency domain filtering transformation. The materials were intended to reduce the amount of time that was being devoted by the author to remediation instruction.

STATE OF THE CLASS

While CGT students take foundation classes in mathematics and computer programming, many students were not coming into the author's class with the appropriate skills to immediately implement spatial/frequency domain transformations in their assignments. The author spent approximately twenty percent of the class-time on remediation of the student's math and computer programming skills. In particular, the students had difficulty with:

- Visualizing the spatial frequencies of an image or a video stream
  - While most of the students were familiar with the concept of temporal frequency and could visualize that phenomenon by thinking in terms of sound files, most could not discriminate between non-trivial high and low spatial frequency images (2D).
- Justifying the use of one set of basis functions over another set
  - Most students could not verbalize why it would be advantageous to use a discrete cosine transformation over a Fourier transformation in an image.
- Applying their knowledge of transformation practical problem while referencing their theoretical knowledge.

After two semesters of teaching the course, the author noticed that the students' understanding of these concepts was related to academic major that brought them to Purdue. To explore how this relationship was manifested, all of the students in the course were interviewed over a series of two semesters starting in the Fall semester of 2001. A total of sixty-one students were interviewed.

While the data collected was anecdotal, it did serve as a guide in the preparation of the on-line instructional materials. Overall, the interviews reflected the following trends:

- Students who completed four semesters of engineering studies prior to changing their major to CGT had little difficulty visualizing finite dimensional vectorspaces and transformations. These students had taken three calculus classes and one linear algebra course.
- Students who had taken a class in complex or real analysis had little difficulty visualizing infinite dimensional vectorspaces.
- Students who had not completed a linear algebra course had the most difficulty with visualization and application of frequency/spatial transformations. This held regardless of how many calculus classes they had taken or their initial major in college.
- Students who had taken the calculus classes designed specifically for Technology students had difficulty working with filtering operations that performed filtering

on multidimensional vectorspaces, such as images. They had little difficulty using pre-made libraries that implemented these transformations.

- All students had difficulty discriminating between the benefits and detriments of using specific function basis.
- All the students had difficulty verbalizing how to apply spatial/frequency domain transformations in CGT domain specific problems.

With this information, it became evident the author could shift some in-class remediation activities to Internet based instructional modules that focused on teaching linear algebra concepts within CGT specific domain areas in order to increase the available amount of class time for domain specific filtering activities.

The author decided to create a series of on-line asynchronous videos that would be used primarily for delivering remediation. The primary purpose of the supplemental materials was to equip the students with the necessary skills to perform filtering operations based on spatial/frequency domain transformations in CGT domain specific areas. In-class time would be used for activities that focus on applying spatial/frequency domain transformations to specific filtering operations. Thus, the on-line and in-class activities would compliment each other. To help the student with their visualization skills, the lessons would need to use animation and multi-layer video compositing. The materials developed contained both mathematical and computer graphics content.

Based on the questions posed by the students in previous semesters, the following topics were identified for the lessons: liner dependence, projections, subspaces, inner product spaces, and transformations.

METHODOLOGY

With the content identified, the author concentrated on implementing an instructional methodology that presented the selected content within the frame of reference of the student's knowledge base. While all of the students had taken math courses that utilized their ability to visualize abstract concepts and constructs, they had problems applying their visualization skills to domain specific areas.

A combination of computer graphics and live video could help with the visualization skills but not with applying their knowledge to the CGT domain. For that task, the author relied on an adaptation of the Dick and Carrey instructional model and on structuring the lessons as reflected in Table 1. The structure depicted helped to insure the materials properly linked general knowledge to CGT specific problems. The

Step	Description
1	A practical CGT question is posed to the student.
2	The practical question is rephrased in terms of a mathematical question.
3	The mathematical question is solved.
4	The answer to the mathematical question is interpreted in terms of its theoretical mathematical meaning.
5	The answer to the practical question is extracted from the answer to the mathematical question.

Table 1. Structure of developed lessons

adaptation of the Dick and Carrey model helped to insure the instructional components, such as the assessment items and instructional objectives, were properly structured and executed [3].

Table 2 portrays the application of the structure in Table 1 to an off-line remediation lesson on linear dependence. A sample of this lesson can be found at http://sotdev2. tech.purdue.edu/umds/demo_dl.zip.

PRODUCTION

To fully exploit the instructional power of the video medium, each lesson was created at HDTV resolution and utilized virtual set technology, live video, and computer generated images. Figure 1 shows a sample frame from the lesson whose structure is reflected in Table 2.

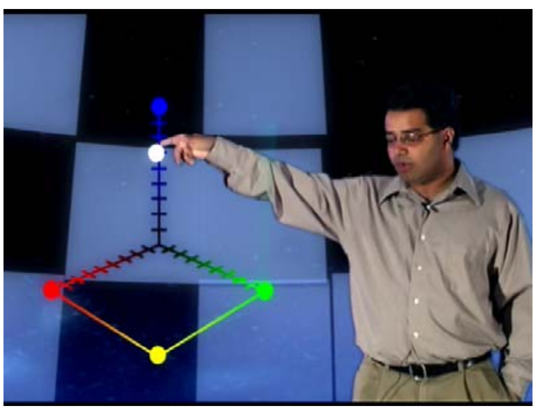

Figure 1. Sample Frame

While video is one the most powerful communication mediums, most on-line learning initiatives do not maximize the instructional power of the medium. A cursory look at these initiatives finds that most utilize a combination of video of the instructor with synchronized presentations of PowerPoint slides. Dastbaz found that this is not very effective or efficient [4]. This ineffectiveness holds even when following recommendations for using PowerPoint in the classroom, such as those provided by Howell [5].

The most effective use of instructional video comes from showing animations and moving illustrations of the concepts presented while the instructor is conducting the lecture. For each instructional objective presented in a lecture, one must ask, "What is the most effective way to communicate this objective to my audience using video as a medium?" Seldom is the answer to this question "a PowerPoint Slide" or "video of the instructor writing on the overhead projector." Creating effective on-line learning instruction carries with it the same requirements as creating high-quality instructional television shows such as those we see on NOVA or the Discovery Channel.

This production methodology was ideal for creating highly visual content that could aid with the student's visualization skills, but the author needed to find an economical way to

Step	Description
1	Are the colors Red, Green, and Blue the only primary additive colors?
2	Is there any basis to R^3 that is not <1,0,0>, <0,1,0>, <0,0,1> ?
3	Video shows that additional sets of basis vectors are possible.
4	Yes. There is an infinite number of basis for R^3.
5	No, the colors red, green, blue are not the primary colors for additive color space. There is an infinite number of colors that can serve as primary colors because the primary colors correspond to basis for R^3.

Table 2. Structure applied to a specific remediation lesson

accomplish it. This level of production is rarely seen in on-line learning because of its high cost and lengthy production times. Television producers employ the help of editors, animators, scriptwriters, and compositors to produce content.

The author assigned a group of five undergraduate students to the project. Three members of the team were assigned to video compositing. Their primary responsibility was to use compositing tools such as After Effects or Combustion to create two dimensional animations. The final two members were responsible for creating 3D animations and graphics using 3D Studio Max and AliasWavefront Maya.

To orchestrate the interaction of the media assets, a television style script was created. The primary purpose of this script was to guide the media creation efforts of the production team. The author was filmed while he lectured in a traditional classroom. From this video, a script of the instructor's lesson was created through the use speech recognition software. One of the team members identified instructional objectives and media requirements. PowerPoint slides of the instructor's notes and illustrations were then created in anticipation of the production process. These slides would be used as place holders during the production phase and replaced with broadcast quality graphics during the post-production phase.

With the script and slides prepared, the team proceeded to film the video of the instructor that would be used in the final product. The instructor's video was shot in a blue room to allow us to replace the instructor's environment. Using the chroma-keying process, the blue environment around the instructor was removed and replaced with computer-generated graphics.

The videos were shot with a JVC GR-HD1, because it captures High Definition (HD) video relatively inexpensively. A benefit of this camera is that for a few thousand dollars it can capture video at a resolution of 1280x780 pixels. Standard television is typically digitized at 720x480 or 640x480. Thus, this can achieve a considerable increase in the resolution of the content at a relatively low price point.

We had the instructor refer to the PowerPoint slide and used Camtasia to capture the computer's desktop to a digital video file. This scenario generated two video files. One video file was of the instructor in the blue environment. The second file was of PowerPoint slides and software demonstrations captured by Camtasia from the instructor's computer. To facilitate editing, we shot everything in a single take. Thus, the two videos were synchronized in time. This yielded tremendous savings when it came to editing the content. The media producers could reference the live video to see the actions of the instructor while observing any drawings or illustrations created by the instructor by looking at the Camtasia video. The net result was that the media creators seldom had to consult the instructor after the video session.

The videos were then edited, composited, and compressed using Adobe After Effects at multiple data-rates ranging from 1 megabit per second to 7 megabits per second. The files were then placed on Windows Media Server. The author considered using MPEG-4, but at the time when the project was created, Windows Media yielded better quality at a smaller data-rate.

The production methodology implemented freed the instructor from the responsibilities creating his media assets while still allowing him to maintain control on the quality of the instructional videos produced. This is significant because instructors often express concerns about the additional preparation time that accompanies the creation of on-line materials [6-8].

RESULTS

While the methodology used to develop and deploy the lessons does not allow us to isolate the effects of the material on the CGT 451 student population, it is still possible to make observations that can be used to see if there was a decrease in the amount of time spent on in-class remediation activities after the deployment of the lessons.

The lessons were produced and deployed during the Spring 2003 semester. The instructor tracked the data portrayed in Table 3, during the semesters immediately preceding the deployment and during the Spring 2003.

Activity	Fall 2002	Spring 2003
Amount of in-class time spent on remediation activities	21%	4%
Number of mistakes on projects that clearly show a lack of prerequisite knowledge [average per student]	87	28
Number of mistakes on tests that clearly show a lack of prerequisite knowledge [average per student]	37	16
Number of office visits where students asked questions that covered prerequisite knowledge [total]	57	19
Average grade on CGT 451 project 1	84	85
Average grade on CGT 451 project 2	82	79
Average grade on CGT 451 project 3	77	76
Average grade on CGT 451 midterm examination	74	77
Average grade on CGT 451 final examination	72	70

Table 3. Comparative Data

Two indications are reflected in the data. First, there was a decrease in the amount of time spent by the instructor conducting remediation activities both in-class and during office hours. Second, the performance of the students did not decrease as the amount of in-class time spent on remediation activities was reduced. The average grades on the three major projects and tests remained approximately the same and the number of mistakes that could be attributed to lack of prerequisite knowledge decreased.

Thus, while we cannot say with certainty that the on-line lessons helped to reduce the amount of time spent on remediation activities related to spatial/temporal transformations, we can say that there was a decrease in the amount of in-class remediation activities while the student's performance remained approximately the same.

In addition to tracking comparative data, the author also tracked the actual usage of the lessons by using dynamic web technologies. No authentication mechanism was used on the web content serving the pages. However, persistent cookies were used to track repeated visits from the same user. Therefore, the tracked data could be used to track repeated usage by the same anonymous user, but not to identify any specific student.

The author tracked (1) the number of requests for all video files in relation to project due dates and examination dates, and (2) whether or not the students watched the entire lesson or used the index to jump to specific portion within a single video clip. Figure 2 portrays this data.

The collected data seems to indicate that most students used the on-line resources as a just-in-time (JIT) educational aid. This is supported by the fact that most of the uses to the system occurred when the students faced major deadlines and that most students did not watch entire video clips. The students watched an entire video lesson only 24 percent of the time; they primarily watched only the portions of the video clips they needed to complete their project or prepare for their test.

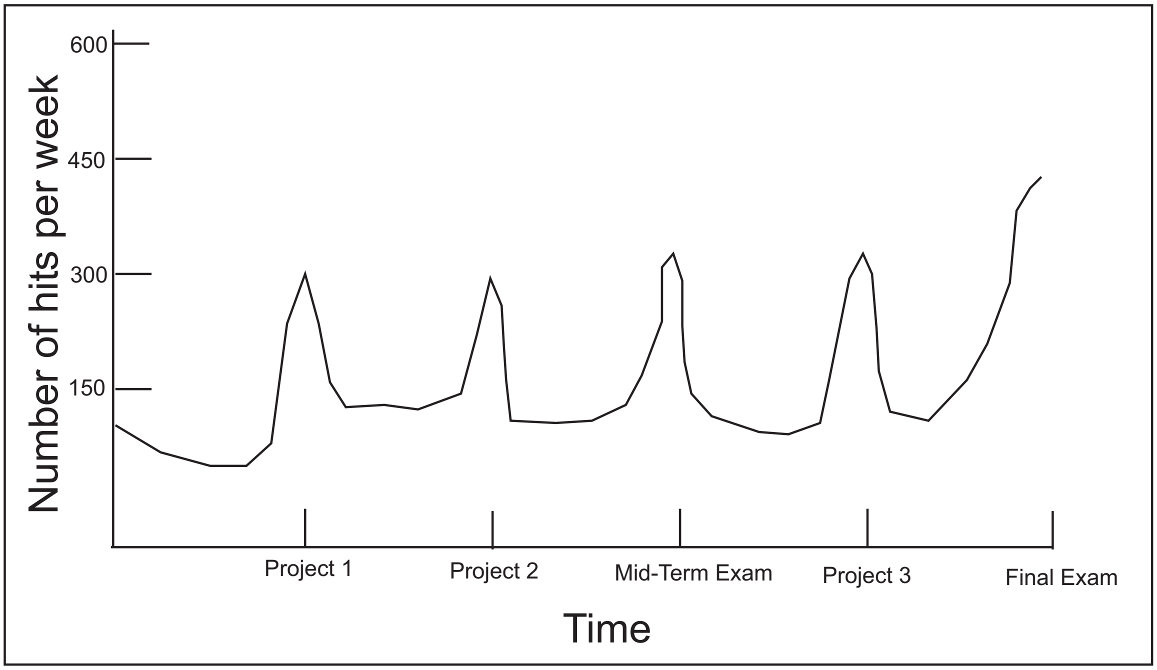

Figure 2. Usage of Materials

A surprising finding was that the peak usage of the system did not decrease as students progressed through the semester. The author expected that as the students progressed through the semester, they would no longer need to reference remediation materials in order to complete their tasks. Yet, the data shows that this was not the case.

CONCLUSION

While the concept of spatial/frequency domain transformations is difficult for students to master from both a theoretical and application perspective, it is possible to alleviate the amount of in-class remediation activities the instructor undertakes in engineering and technology classes by providing the students with an on-line set of lectures that can be used as a just-in-time reference.

For years, educators have provided out of class resources to students in terms of reading materials, on-line interactive exploratory activities, and even video based materials. In general, these initiatives have enjoyed limited success due to inconsistent instructional design practices and media that do not fully exploit the power of their medium.

Within this project, the two major stumbling blocks for students, as they tried to apply spatial/frequency domain transformations to image processing filters, was the student's mathematical background and the student's inability to visualize transformations in multi-dimensional space. They also had difficulty applying their general knowledge in solving domain specific problems.

This was alleviated by conducting a needs assessment, in terms of interviews and observations that pinpointed the weaknesses of the target learner population. Videos were then created using the latest advancements in computer graphics and digital video technology.

In the end, the approach presented in this paper can be used for helping to teach any abstract material in the engineering and technology areas where students have visualization problems and in situations where valuable class time is spent on remediation activities.

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