Teaching Digital Image Processing and Computer Vision in a Quantitative Imaging Electronic Classroom

Milan Sonka

Department of Electrical and Computer Engineering,
The University of Iowa, Iowa City, IA 52242

ABSTRACT

In 1996, the University of Iowa launched a multiphase project for the development of a well-structured interdisciplinary image systems engineering curriculum with both depth and breadth in its offerings. This project has been supported by equipment grants from the Hewlett Packard Company. The new teaching approach that we are currently developing is very dissimilar to that we used in previous years. Lectures consist of presentation of concepts, immediately followed by examples, and practical exploratory problems. Six image processing classes have been offered in the new collaborative learning environment during the first two academic year. This paper outlines the employed educational approach we are taking and summarizes our early experience.

Keywords: Education, electronic classroom, collaborative learning, image systems engineering

1. INTRODUCTION

The applications of imaging are numerous and include manufacturing, navigation, entertainment, remote sensing, publishing, defense, space science and medical imaging. Interactive imaging, multimedia applications, and the transfer of image data over communication lines are rapidly developing areas which will revolutionize our working and living environments. These fields have now developed to the point where engineers specializing in imaging, image processing, and image analysis are needed in order for imaging to reach its full potential.

In 1996, the University of Iowa launched a multiphase project for the development of a well-structured interdisciplinary image systems engineering curriculum with both depth and breadth in its offerings, and innovative teaching of this curriculum using collaborative learning in a state-of-the-art electronic classroom. With the current teaching methodology imposed by traditional teaching facilities and approaches, students' experience in the actual processing and manipulation of image data is severely limited. Thus, the goal of the curriculum development program in image systems engineering is not simply to increase the number of courses taught in this area. *The goal is to change the educational process so as to produce engineering graduates highly qualified to participate in the imaging revolution.* In order to accomplish this goal, we are developing a comprehensive image systems engineering curriculum, utilizing advanced computing technology in a forty seat electronic classroom, that would not be feasible to implement in a traditional environment. We are fundamentally changing the teaching of this curriculum. Our goal is for our students to experience the active processing and manipulation of dynamic, true color, three-dimensional images that will be required of them in the workplace.

The University of Iowa has a long standing commitment to image systems engineering. A significant image systems engineering curriculum exists with courses offered in a variety of departments. This curriculum is now being enhanced by a broad range of research programs including image analysis and understanding, image reconstruction, and medical image processing. Recognizing the tremendous growth in this emerging area, the University of Iowa is building a highly interdisciplinary program in image systems engineering integrating instructional activities in four departments (Electrical and Computer Engineering, Biomedical Engineering, Computer Science, and Radiology) and permitting the development of innovative interdisciplinary curriculum.

Send correspondence to Milan Sonka: e-mail: milan-sonka@uiowa.edu; WWW: http://www.icaen.uiowa.edu/~sonka
Additional information about the classroom can be found at http://www.icaen.uiowa.edu/~dip/CVPR/title.html

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2. TEACHING PHILOSOPHY

In engineering education, presentation of the theoretical concepts that form the foundation for a subject should be accompanied by practical experimentation with those concepts. In engineering education, laboratory sessions are typically organized so that students can carry out such practical experiments. Unfortunately, it is often difficult to maintain synchronism between the presentation of theoretical concepts in lecture and the practical application of those concepts in lab. Usually, lectures precede practical lab experimentation by days if not weeks. Consequently, students are often required to achieve an understanding of the concepts without the important contribution of the practical labs. For example, students may need to achieve nearly full comprehension during or between lectures in order to understand the next-lecture or to solve a homework assignment. It is clear that the overall efficacy of the engineering educational process is substantially improved if laboratory experiments directly contribute to the process of learning concepts. Obviously, it is impractical to expect that whenever an important theoretical concept is covered in the lecture, the presentation would stop, students would leave the lecture hall for the lab, and after they complete the relevant experiments, the lecture would continue. Nevertheless, such an approach may well be highly effective from the standpoint of student learning.

In the past, image processing instruction has been limited to traditional lectures delivered in a traditional learning environment. Clearly, an interactive teaching approach is preferred that creates a dialogue with students and includes a number of examples and solution short problems that reinforce concepts.

In image processing classes in particular, it is important to incorporate visual presentations and overhead projectors with transparencies and slides. A computer with projection capabilities has been used to teach image processing classes at the University of Iowa for the last several years. However, despite the many advantages of this approach over using the "blackboard only" lecture mode, the available visual presentation tools remain non-interactive and do not facilitate true collaborative learning since students often remain passive recipients of knowledge in the educational delivery process. The new approach to image processing instruction reported here is based on our belief that *to maximize learning, students must become fully active participants in the learning process.*

There is no doubt that changing the role of a student from a passive recipient to an active participant requires substantial changes in the educational environment. For instance, in computer-based sciences, providing each student or each couple of students with a fully functional networked workstation that serves as a tool for educational material delivery as well as for direct experimentation has been the educational dream for years. Thanks to a generous grant from the Hewlett Packard company, such an environment has been created at the University of Iowa to support image systems engineering instruction.

The new teaching approach that we are currently developing to teach digital image processing classes in the Quantitative Imaging Electronic Classroom clearly reflects the above stated teaching philosophy. Thanks to the new opportunities, the educational process is very dissimilar to that we used in the same classes in previous years. Lectures are built as a mixture of presentation of concepts, immediately followed by examples, and practical exploratory problems. During the presentation of concepts, students are in a *"mostly receiving"* mode. Examples serve to clarify the presented concepts and often invoke a dialogue between the instructor and students. As frequently as appropriate, examples are followed by problem solving periods that are often only 3–5 minutes long during which the students *actively* solve a problem posed by the instructor. Students create programs using visual programming approaches. Students achieve a much deeper, hands-on, practical and therefore more permanent understanding of the image processing concepts. Importantly, this teaching strategy offers direct feedback to the instructor about student learning and allows the instructor to correct conceptual errors by each individual student within the time-frame of a common lecture. Consequently, the homework assignments may be more demanding than usual without the danger of being unrealistically difficult.

3. QUANTITATIVE IMAGING ELECTRONIC CLASSROOM CAPABILITIES

The 40-seat Quantitative Imaging Electronic Classroom is equipped with 20 student Hewlett Packard C-100 Unix workstations (http://www.hp.com/). Other computer resources available to image processing students in the College of Engineering include more than 250 Hewlett Packard Unix workstations that are located in three computer labs, in faculty offices, and in research labs. Several file servers facilitate uniform home directory access from any computer in the college. Identical software is available on all student-accessible computers and some of the computer labs have 24-hour access.

The computer resources of the Quantitative Imaging Electronic Classroom include 20 student stations with 2 seats per station, one HP-UX C-240 instructor station, one Kayak XW 300 MHz dual Pentium-II PC instructor station, and one file server dedicated to image processing education (Fig. 1). All computers are networked using the 100 Mbit ethernet network with a 100 Mbit link to other College of Engineering servers and a 10 Mbit link to the outside world. A 1.2 Gbit ATM link connecting the electronic classroom and the associated research resources with the University of Iowa Hospitals and Clinics will be operational in June 1998. The Unix instructor station and one of the student stations are equipped with color CCD cameras and *Parallax XVideo 700* videocards (http://www.parallax.com/) and thus have image digitization capabilities. The other two student workstations are equipped with *HP ScanJet 4c* flatbed scanners (http://www.hp.com/). While all the student stations are otherwise identical, the instructor station can serve as a video broadcasting node and is capable of sending live video to all other workstations in the classroom or anywhere on the net using the *Uniflix* software developed by the *Paradise Software* company (http://www.paradise.com/). With the color CCD camera, an *Elmo EV-400AF* visual presenter, and two VCRs connected to the digitizer in the instructor station, live video images from any of the listed sources can be broadcast to the students' screens. This real-time video may come from videotapes, from non-transparent or transparent documents imaged using the Elmo visual presenter (books, overheads, etc.), pictures directly-drawn under the Elmo, or any other scene of interest captured by the color CCD camera.

The *Shared-X* software available with the HP-UX operating system is employed to facilitate X-window sharing. Using Shared-X, any X-window can be shared between the instructor and the student screens or among several students. Virtually an unlimited number of independent student groups may be formed. Shared-X facilitates mutual collaboration of students and the instructor since it enables two-way interaction among all participants. The owner of the Shared-X process (usually the instructor) can allow one or more students to contribute to the content of the shared window. This is especially important if *Shared-X Whiteboard* is used which allows computer-based information (pictures, computer drawings, text, etc.) to be pointed to or modified by the collaborative group participants.

The classroom is also equipped with an overhead high-resolution videoprojector. In addition, an audio system has been installed to distribute the VCR audio signal. In connection with a wireless microphone, it also helps the instructor to overcome the computer and air-conditioning ambient noise.

4. IMAGE SYSTEMS ENGINEERING CLASSES

The Quantitative Imaging Electronic Classroom opened in the fall of 1996. During the first two years 1996/97, six image systems engineering classes were completely re-designed or developed to utilize the capabilities of the new environment:

- Digital Image Processing
  This first undergraduate class provides basic information about the image processing field. The main topics include: Properties of digital images, data structures for image processing and analysis, preprocessing, segmentation, image transforms, and image compression. Details are given in Section 4.1.
- Advanced Digital Image Processing
  This course is designed to offer a deeper theoretical coverage of image processing. The following topics are covered; image restoration, image compression, wavelets, stochastic image modeling, color imaging and image processing, mathematical morphology, 3-D image processing, 3-D visualization.
- Image Analysis and Understanding
  This graduate course deals with mathematical foundations and practical techniques of digital image analysis and understanding; image segmentation (from edges and regions), object description (from boundaries, regions,

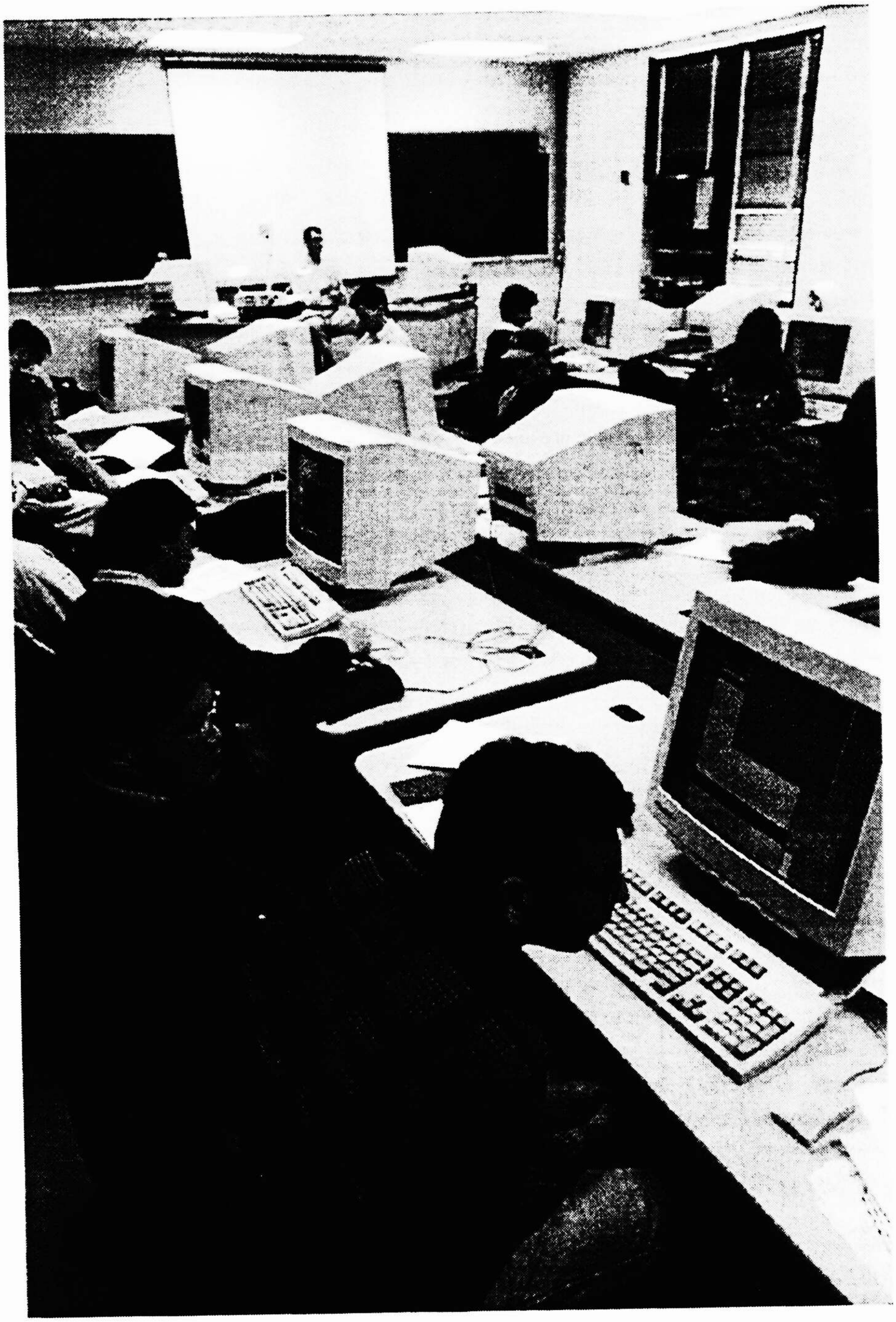

Figure 1. The Quantitative Imaging Electronic Classroom in the College of Engineering at the University of Iowa that was funded by several grants from the Hewlett Packard Company.

scale, scale insensitive descriptions, 3D shape, texture), pattern recognition (statistical and syntactic methods, cluster analysis), image understanding (knowledge representation, control strategies, matching, context, semantics), image analysis and understanding systems. The textbook used is *Sonka, Hlavac, Boyle: Image Processing, Analysis, and Machine Vision, 1st edition Chapman and Hall 1993, 2nd edition PWS, 1998* [1,2]. Each student is required to complete a laboratory project consisting of a sequence of image analysis steps resulting in image interpretation. Thus, the course emphasizes hands-on image analysis experience.

- Physics and Analysis of Medical Images I
  This is the first of a two-course sequence of classes that provide information about the physics of medical imaging modalities, and the image processing techniques used to analyze the images. The first portion of the course is a description of the physics of X-ray and other ionizing radiations. The course describes the interaction of these energy forms and human tissue. The techniques of deriving images from these radiation modes are described. The relationship between the physics and image quality is described. Methods of image enhancement, border enhancement, and object definition are described. The students are required to implement some enhancement algorithms, and test these with images obtained from the modalities studied in class. Topics include: Interaction of radiation with matter, physical principles of medical imaging modalities (X-ray, CT, nuclear medicine, PET); medical image reconstruction (back projection), image enhancement and analysis (digital image processing), and clinical interpretation of images. The textbook used is *Gonzalez, Woods: Digital Image Processing, Addison Wesley, 1992* [3].

- Physics and Analysis of Medical Images II
  This is the second of a two-course sequence of classes that provides information about the physics of medical imaging modalities, and the image processing techniques used to analyze the images. The description of the physics of various modalities commonly used in medical imaging is continued by concentrating on the non-ionizing radiation modalities (MRI, ultrasound, thermography, etc.). The methods of constructing an image from the physical interactions of energy with living tissue are discussed. The influence on image quality of the different modalities is discussed. Techniques of medical image processing, analysis and interpretation are covered. Quantitative analyses of medical images (areas, flows, moments, etc.) are described. Automatic classification of image segments is discussed. Optimization, pattern recognition, and 3-D processing are discussed.

- Pattern Recognition in Image Analysis
  This course represents an advanced course in pattern recognition. The following topics are covered; adaption, learning, description; statistical pattern recognition (classifiers, optimal classification schemes, feature extraction, learning, applications); syntactic pattern recognition (grammars, grammar inference, applications), neural networks for recognition; fuzzy logic for recognition; non-standard and combined pattern recognition approaches. The following textbook will be used: *Schalkoff: Pattern Recognition, J Wiley, 1992* [4].
  Knowledge, heuristic, and fuzzy information concepts are introduced as possible approaches to deal with uncertainty. A computer-engineering approach to solving complex pattern analysis problems is developed. Each student is required to complete a semester-long laboratory project consisting of a sequence of pattern recognition steps resulting in image interpretation. Hands-on pattern analysis experience is thus emphasized.

In addition, the electronic classroom is being used for supervised labs in non-imaging engineering courses including core programming courses, signal processing classes, specialized graduate classes, and image processing seminars.

4.1. Digital Image Processing – Case Study

The Digital Image Processing course is the first imaging course taught in the electrical engineering curriculum at Iowa. It is usually attended by juniors, seniors, and first-year graduate students. The signal processing prerequisites include *Linear System Analysis* and *Signals and Systems*. Programming courses are also required as pre-requisites. Thus, the students have a good knowledge of single-dimensional continuous and discrete signals, continuous and discrete Fourier transforms, Laplace and z-transforms, filtering and sampling, as well as a solid C-programming background.

All basic information about the class is available on the class web homepage http://www.icaen.uiowa.edu/~dip/. The class homepage includes class news, general information on the course, course policies, syllabus, web-based lecture material, homework assignments, grades, hints to practical experiments, and exam information. Additionally, technical information about using the electronic classroom, about the image processing package Khoros/Cantata [5–7], and links to other image processing courses taught at the University of Iowa are provided.

In the next paragraphs, the following parts of the course will be discussed in more detail; syllabus, lectures; homeworks, and exams.

4.1.1. Syllabus

The textbook *Sonka, Hlavac, Boyle: Image Processing, Analysis, and Machine Vision, 1st edition Chapman and Hall 1993, 2nd edition PWS, 1998* [1] was used. The same textbook is used for this class and the graduate *Image Analysis and Understanding* course. The following topics were covered:

- Introduction
- The digitized image and its properties
  - Image functions
  - Image digitization (sampling, quantization, color)
  - Digital image properties (metric and topological properties, histograms, image noise)
- Data structures for image processing and analysis
  - Levels of image data representation
  - Traditional image data structures (matrices, chains)
  - Hierarchical data structures (pyramids, quadtrees)
- Image preprocessing
  - Pixel brightness transformations
  - Geometric transformations
  - Local preprocessing (smoothing, edge detection, zero crossings of the second derivative, scale, Canny edge detection)
  - Image restoration
- Segmentation
  - Thresholding (threshold detection, multispectral thresholding)
  - Edge-based segmentation (edge image thresholding, edge relaxation, border tracing, edge following as graph searching, edge following as dynamic programming, Hough transform, region construction from borders)
  - Region growing segmentation (merging, splitting, split and merge)
  - Matching
- Linear image transforms (Fourier transform, Hadamard transform, discrete cosine transform, filtering)
- Image data compression (discrete image transforms in image compression, predictive compression, vector quantization, pyramid compression, comparison of compression methods, JPEG, MPEG)

4.1.2. Lectures

The aim of the Digital Image Processing course is to provide a theoretically solid introduction to digital image processing. Simultaneously, the students are required to achieve a good level of practical experience, image processing problem solving intuition, and a feel for the practical applicability of image processing methods. To accomplish the stated goals, the electronic classroom environment facilitates implementation of the lecture-example-experiment scheme outlined in Section 2.

To enable unified in-class lecture delivery; in-class experimentation; lecture material access outside class; after-the-fact replay of lectures; independent practical exploration; as well as easy access to homework/project assignments, test image archive, and image processing software tools, we have selected the World Wide Web to be the primary vehicle for class material delivery. The *Khoros* image and signal processing software package (http://www.khoral.com/) was selected for use in the class. Khoros combines the availability of a large number of existing and freely available image processing modules with an ease of creating prototype image processing applications by combining such modules, and the ability to add C-based image processing routines and modules.

Each lecture started with the students logging onto their class workstations using their college-wide accounts. Lecture material that was pre-prepared was delivered to them via an instructor-controlled and shared *Netscape* window (http://home.netscape.com/). The students were not allowed to start their own Netscape, rather the instructor used the mouse-driven text highlighting and Shared-X pointer tools to mark and/or emphasize the key sentences of the web-delivered lecture. Fig. 2 gives an example of web-delivered lecture material dealing with matching-based segmentation and predictive compression, respectively.

Whenever appropriate, an additional *Whiteboard* window was shared with students that facilitated two-way interaction between the instructor and the students. Using the whiteboard facilitated efficient step-by-step explanation of image processing algorithms. Another lecture material delivery mode allows real-time transmission of hand-drawn pictures or live videosignal to students' screens. This mode enables free-hand drawing and/or formula handwriting and is achieved using the Elmo visual presenter, the Parallax digitizer and the Uniflix video distribution software (http://www.paradise.com/). Thus, live video images including videotaped movies can be delivered to students' screens over the network.

After the conceptual part of a lecture topic was presented and explained, applications of the concepts to image processing problems were presented. Two modes of presentation were utilized:

1. Instructor-presented Khoros workspaces or in-house prepared software packages were used with the application control window (e.g., Khoros Cantata workspace) and the image windows being shared with the students.

2. Students actively started the Khoros Cantata, opened a pre-prepared workspace and ran it. Usually, the students were given several minutes to explore on their own the role of changing processing parameters and were asked to answer questions that required a deeper understanding of the image processing concepts being discussed. One example of the exploratory problem accompanying the lecture topic on Canny edge detection follows, see Fig. 3.

<u>Canny Edge Detection In-Class Experiment</u>

1. From cantata, open the canny.wksp.

2. You will see that the workspace provides comparison of the Canny edge detector (its variation, to be exact) and the Sobel edge detector.
   Remember, there are 2 basic types of parameters in the Canny edge detector
   scale ... smoothing constant sigma (in our workspace, asymmetric smoothing is allowed, there are 2 smoothing constants - set them to equal values, use 5x5 or 7x7 mask size)
   thresholds for hysteresis thresholding
   In the provided implementation, an additional parameter can be set - the minimum length of an edge response.

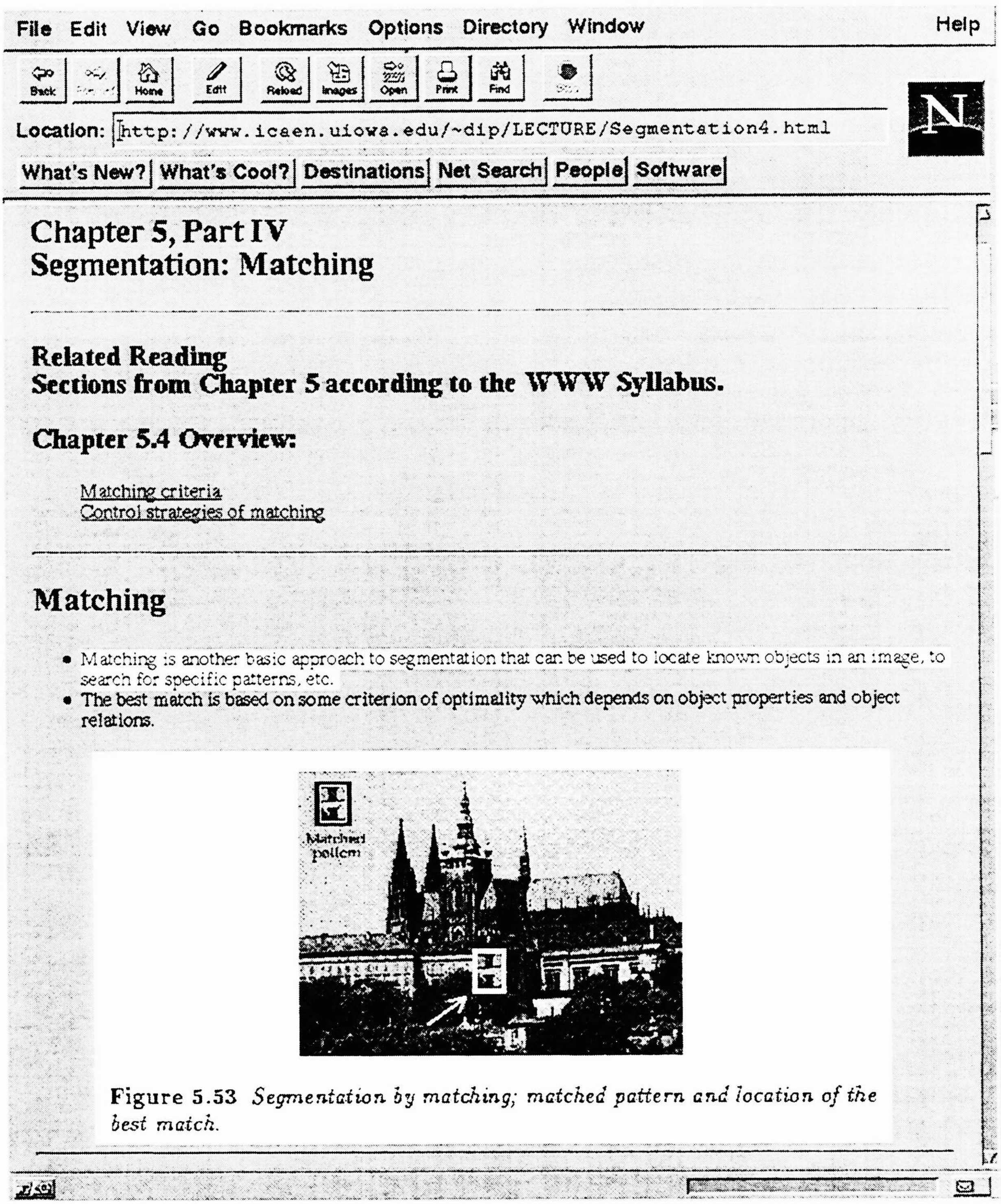

Figure 2. Example of web-based lecture delivery. The figure shows a shared screen used by the instructor during the lecture – usage during class is similar to use of overhead transparencies. However, the screen is broadcast from the instructor's station to the students' screens. Note the interactive highlighting feature. The web-based material can be accessed after the lecture from any web-networked computer.

3. Experiment with the parameter setting - experiment with the following images:
   hand.pgm
   castle.kdf ... you will have to convert this file to "byte" format first

4. Try to get the most appropriate parameters for edge / border detection of finger bones in the hand.pgm image

5. What is the rationale for the 'edge response length' parameter?

The complete set of lecture material that was used in the Digital Image Processing class (and also in Image Analysis and Understanding) can be found in http://www.icaen.uiowa.edu/~dip/LECTURE/lecture.html The contents page
http://www.icaen.uiowa.edu/~dip/LECTURE/contents.html includes convenient links to individual lecture topics, exploratory problems, and homework assignments.

When using the lecture web pages, it should be kept in mind that they are a lecturer's tool and are not intended to replace the textbook. They help to reinforce the main points made during the lecture and show the general outline of the lecture. Additional explanatory material is frequently created as needed during the lectures. This material is presented via the shared whiteboard or using the Elmo visual presenter to deliver instructor-drawn images to the students' screens. Thus, the textbook is still necessary for the students to achieve a full understanding of the course material.

4.1.3. Homeworks

Programming homeworks were assigned every week. In the first several weeks of the semester, homework assignments included design of simple image processing applications using the visual programming capabilities of Cantata (part of Khoros).

In the 4-th and 5-th weeks of the semester, several lectures that were accompanied by practical exercises were given introducing modular C-based Khoros programming, including the user interface construction, input parameter definition, and utilizing the Composer capabilities of Khoros. Subsequently, homework assignments became more challenging and included development of new image processing modules not previously available in Khoros. While further improvement of students' C-programming skills is not the primary goal of this class, C-programming proficiency is considered a necessary part of image processing engineering education and Khoros provides a good environment to achieve this subgoal. Thus, later homeworks usually required students to build a specific image processing application that was a mixture of existing Khoros modules and one or more image processing modules programmed by the student.

During the 15-week semester, twelve programming homework assignments were completed by the students. All the homeworks were submitted electronically without a single sheet of paper passed from the students to the instructor - you may note the submission instructions that accompany each homework assignment
(http://www.icaen.uiowa.edu/~dip/LABS/labs.html).

4.1.4. Exams

The fact that students have direct access to a computer during exams substantially extends the options for exam. Two one-hour midterm exams and one two-hour final exam were administered during the semester. All the exams consisted of three parts - multiple choice questions, short answer questions, and practical image processing problem solving questions. While the first two options are quite standard, the third one is a novel approach to student testing and facilitates asking practical image processing questions and testing students' image processing skills during the exam. The practical questions asked during the exams did not include writing C-based image processing modules. Rather, the questions were directed at building Cantata workspaces from existing image processing modules, the objective being to solve a stated image processing task. We have found the practical skills testing option to be extremely useful since it further emphasized the importance of homework programming assignments.

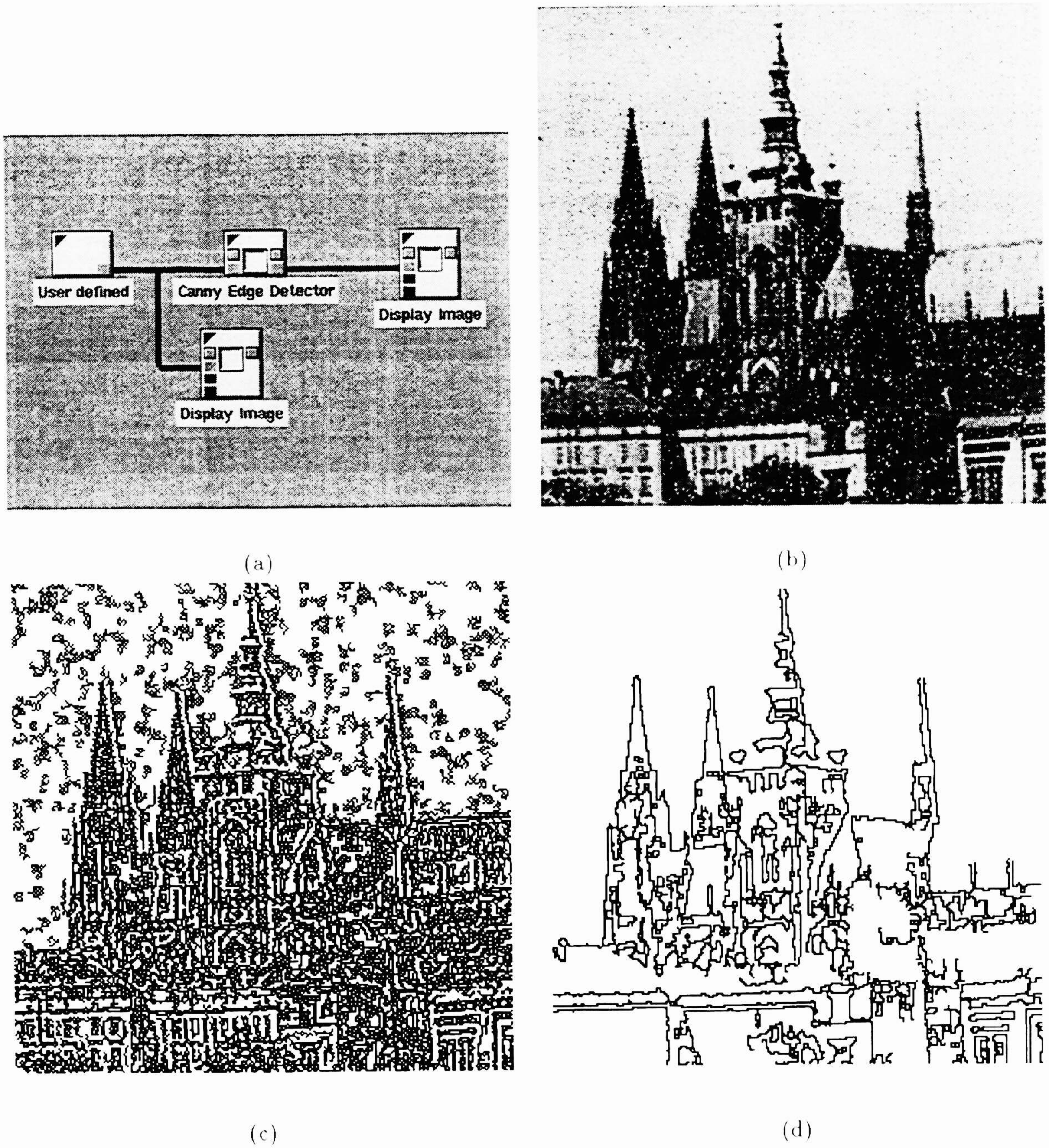

Figure 3. Example of an exploratory problem that the students were asked to solve during several minutes immediately following the conceptual presentation of Canny edge detection. (a) Khoros workspace that was provided to the students. (b) Input image provided. (c) Result of processing, pre-selected set of parameters used. (d) Result of processing, student-modified set of parameters used.

The very first midterm was distributed to the students in an electronic form. While this approach in which students used the computer editor to answer the questions and submitted the exam file using e-mail worked well, the students' feedback was that they preferred to receive a paper copy of the exam questions and answer the multiple choice and short-answer questions on paper. Therefore, the later exams followed this format with solutions to the exam's practical problems still being submitted electronically.

5. REACTIONS OF STUDENTS

Similar to most other universities, students in each class at the University of Iowa provide written anonymous course evaluations. Overall, the students were very positive about the teaching facility and they liked using the computers as an instructional tool. Probably the most important asset of the educational approach we took was the active participation of students in the lecture and the help of the electronic classroom in achieving understanding of the covered concepts. Frequently, we received recommendations from students to include even more interaction during lectures and incorporate additional practical problems. The primary way students thought they benefited from the new teaching approaches was their ability to interact with each other during guided discussions, develop practical experience during the exploratory problem solving periods in class, and share preliminary solutions of the homework assignments and projects. *Therefore, they seem to have benefited most from the collaborative character of the newly developed educational processes.*

6. DISCUSSION

There are several important issues that must be considered when contemplating use of computer-assisted collaborative environment.

Clearly, the availability of an appropriate classroom environment is a necessary precondition. We and others have found that a classroom setting in which two students share one workstation screen works well. This setting naturally supports student collaboration during practical problem solving periods.

The incorporation of practical problems within the lecture seems to be the biggest advantage of lecturing in the electronic classroom. This feature was noted by students as an important contribution to their improved learning. The fact that students can achieve basic understanding of crucial concepts during the lecture in a collaborative way and that the homework and lab assignments that follow can build on a well established foundation of understanding brings the efficiency of the learning process to a qualitatively new level. There is no doubt in the minds of the instructors teaching in the Quantitative Imaging Electronic Classroom that the students achieved substantially higher level of conceptual knowledge as well as much better practically applicable image processing skills compared to the students who took the same classes in the previous years.

Teaching materials suitable for electronic delivery and prepared with a collaborative learning environment in mind are in a short supply. While the first web-based image processing textbooks are beginning to appear (http://www.wiley.com/wileychi/electronic/hipr/), no collaborative lecture notes existed to accompany our courses. Therefore, during each semester when a new course is taught in an electronic classroom, the course instructor and the teaching assistant are under 15 weeks of continuous pressure to prepare web-based lecture material for delivery in the next lecture. The amount of work associated with building such electronic course material is tremendous [8]. In our case, complete electronic lecture notes for two classes were developed during evenings and nights preceding the lecture days (*Digital Image Processing* http://www.icaen.uiowa.edu/~dip/ and *Image Analysis and Understanding* http://www.icaen.uiowa.edu/~image/, follow the link to LECTURE MATERIAL ... the pages are password-protected but a password allowing browsing is included on the home pages). The electronic lecture preparation task would be impossible to complete within two standard-duty semesters without previously authoring a comprehensive image processing textbook [1, 2] the text and graphics of which served as a well-organized source for building the lecture material. In the second year, we have re-used most of the material prepared for the first year. Modifying and improving of the already developed electronic lecture material for the future class offerings is much less demanding.

7. CONCLUSION

To summarize, a lot of effort is still needed to bring this new and in some respect revolutionary teaching philosophy to perfection. Our first experience with digital image processing instruction in the new environment has been very positive. Using the lecture–example–experiment teaching philosophy that includes presenting all instructional material in electronic form requires an above-average effort by the instructor to develop the teaching material and teaching scenarios. However, comparing the knowledge and practical experience of the previous-years attendees and this-year attendees of the same course shows that the extra effort is warranted. The combination of the new environment and the new teaching philosophy has resulted in a substantial increase in the students' knowledge and practical experience. As one of the students put it: *"This hands-on computer teaching was effective and fun. I appreciate both the instructor's and TA's efforts."*

Acknowledgments

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