

Integration of Real-World Problems into an Image Processing Curriculum*

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An image processing curriculum requires a hands-on environment to facilitate student learning of theoretical concepts and techniques. Software tools including Matlab[®] allow students to focus on concepts and techniques without requiring significant attention to learn to use the tools. Laboratory exercises and projects are commonly used to provide students with a hands-on experience in imaging-related courses. Exercises and projects based on real-world problems which use realistic imagery further enhance student learning and skill development beyond the classroom. Survey results are presented to evaluate student responses to real-world problem-based exercises and projects performed in a Machine Vision course taught at the University of Missouri-Rolla.

INTRODUCTION

STUDENTS HAVE THE opportunity to explore and learn facets of many disciplines from digital image processing. Several educational projects using image processing have been explored. At the University of Arizona, the Image Processing for Teaching (IPT) project was investigated to utilize the technological, information theory and cognitive issues associated with image processing for its educational impact. Results from the project demonstrated the effectiveness of image processing in education through widespread teacher education, materials development, and follow-up support and outreach [1].

The NASA CERES project [2] allowed students to make measurements of objects and to build their knowledge of the imaging tool. The Network Montana Project Website of earth science activities [3] makes use of object measurement for activities such as measuring the diameter and the area of a volcano using image-processing techniques. The application of image processing allows students to learn beyond what is taught in the classroom.

A multiphase project for an interdisciplinary image systems engineering curriculum using an electronic classroom has been investigated at the University of Iowa. The goal for students was to 'experience the active processing and manipulation of dynamic, true color, three-dimensional images that will be required of them in the workplace' [4]. The curriculum encompasses image analysis and understanding, image reconstruction, and medical image processing. The basic approach is to use theoretical concepts for the subject as the foundation, which is augmented by practical experimentation. The electronic classroom and

coursework is hands-on, using a visual programming environment called Khoros/Cantata [5–7].

Program libraries have been developed to support concept learning and accommodate diverse student backgrounds to facilitate image processing learning [8]. Laboratory experiments for image processing are based on becoming familiar with class libraries for image processing (CLIP) for programs that are compact and fast. Cal Poly State University investigated a similar approach using a Signal and Image Processing Tool (SIPTool) for multimedia demonstrations and development of signal and image processing techniques based on C/C++ programming [9]. The SIPTool provides students with an integrated environment that includes their processing routine with the image/signal acquisition and display. There are several mechanisms for the SIPTool that facilitate and enhance student learning: 1) the capability to visualize complex relationships, 2) discovery and problem-solving, and 3) free dissemination for encouraging varied use [9].

Previous work at the University of Missouri-Rolla (UMR) focused on the development of a real-world traffic monitoring laboratory exercise for the 'Machine Vision' image-processing elective course [10]. Two versions of the traffic monitoring problem are based on identifying and tracking markers on a truck as it moves across an on-campus bridge at UMR through a sequence of video frames to compute the velocity of the truck. For velocity calculation, the students are required to determine the three-dimensional real-world coordinates of the marker position on the truck from the two-dimensional image coordinates of the marker position based on an orthographic projections technique.

The Smart Composite Bridge (SCB) at UMR provided the field laboratory for traffic monitoring exercise development. The bridge technology is

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used as a field laboratory for an NSF-sponsored, interdisciplinary course 'Smart Materials and Sensors' [11, 12]. Curriculum development for the Smart Materials and Sensors course integrated interdisciplinary education and experience based on combining several related fields, including materials, manufacturing, sensing, signal-processing, and structural analysis. Project and course documentation for the Smart Materials and Sensors course and traffic monitoring laboratory exercises developed for the Machine Vision course are available at <http://campus.umn.edu/smarteng> [12, 13]. The web-accessible, traffic-monitoring laboratory exercise extended the bridge field laboratory to image-processing curricula and is a preliminary research step toward integrating image-processing and sensing technologies for bridge monitoring.

Curriculum development for the Machine Vision course at UMR has focused on further integration of interdisciplinary education and experience through exposing students to application-based problems using real-world imagery. The exercises provided an active learning component to the Machine Vision course based on the capability and flexibility of a Matlab[®] image-processing environment. Realistic images and real-world problems expose students to complex image features, facilitate flexibility in assignments and solutions, and give an application orientation. The image-processing concepts emphasized include object segmentation, object labeling, edge detection and enhancement, feature extraction, coordinate transformation, and real-world interpretation of image-processing algorithm outputs. In this paper, the use of laboratory exercises and projects using real-world problems and imagery in the Machine Vision course is assessed using a survey to evaluate the impact on student learning and the effectiveness in providing a real-world experience to students. The remainder of the paper is organized into the following sections: 1) laboratory exercises and projects using real-world imagery in the Machine Vision course, 2) course implementation and evaluation, 3) public accessibility of laboratory exercises, and 4) conclusions.

LABORATORY EXERCISES AND PROJECTS USING REAL-WORLD IMAGERY FOR THE MACHINE VISION COURSE

Machine vision course description

At UMR, the Machine Vision undergraduate and graduate course introduces students to image formation, filtering, template matching, edge and boundary detection, and image segmentation and pattern recognition. Course components are lecture, laboratory exercises, and a semester project for practical application. Three educational objectives provide the foundation for incorporating real-world problems into the laboratory

exercises and projects for the Machine Vision course, including: 1) to give students real-world image analysis experience, 2) to augment student learning by incorporating active learning laboratory exercises, and 3) to offer students an interdisciplinary scope for learning image processing curricula.

The Machine Vision course utilizes Matlab[®], primarily the Image Processing ToolBox, for implementing several laboratory exercises and an individual semester project. These exercises provide students with practical application of the image-processing concepts and techniques presented in lecture and in course materials. Matlab[®] provides built-in functions for illustrating many image-processing algorithms, such as edge detectors and image-enhancement techniques. Matlab[®] also provides a programming environment to extend existing algorithms to address more complex problems. Undergraduate and graduate students in the Electrical and Computer Engineering programs at UMR are exposed to Matlab[®] in other courses, allowing the students to focus more on the imaging concepts and techniques than on learning the programming environment.

Many real-world problems, applications, and imagery were presented in the lecture, the laboratory exercises, and projects in order to provide a multidisciplinary environment for student learning. The real-world problems incorporated into the Machine Vision course for the fall semester 2002, included:

- human white blood cell image analysis for performing white and red blood cell counts;
- cervical vertebrae analysis in x-ray images to assess vertebrae features characteristic of osteoarthritis;
- radio-probe microarray image analysis to evaluate gene expression characteristic of breast cancer; and
- vehicle tracking for traffic monitoring using orthographic projections to obtain three-dimensional real-world position information.

The purpose of the laboratory exercises and project is to engage students, using active learning, in practices that will be used beyond the course to facilitate life-long learning. The integration of real-world problems must provide individualized, significant activities while accommodating the visual presentation of course concepts and techniques. Also, the problems must be compatible with collaborative assignments and peer evaluations.

Description of laboratory exercises

Eight laboratory exercises were used in the Machine Vision course for the fall semester 2002, with five of the eight exercises using real-world imagery. Students implemented all exercises and projects using Matlab[®], with the initial laboratory exercise providing students with a tutorial of basic Matlab[®] commands and image processing

operations. The imaging concepts addressed in the laboratory exercises include image inversion, color conversion, image enhancement, object segmentation, object labeling, object feature calculation and evaluation, edge detection, mathematical morphology, orthographic projections, and image coordinate transformations. A wide range of imagery was used to perform these laboratory exercises. Figure 1 presents examples of images used for some of the laboratory exercises. Figure 1a contains a white blood cell image for performing image inversion, color transformation, object segmentation, and mathematical morphology operations for noise removal. Figure 1b shows a radio-probe microarray image applying image enhancement and thresholding techniques to segment individual 'spots' Fig. 1c gives an image of a cervical spine x-ray image applying image enhancement and edge detection techniques to find the edges of the individual vertebra.

Figures 1d and 1e present two image frames used for tracking a truck as it moves across the bridge. Students performed two laboratory exercises using these images. First, students were required to segment a marker on the truck in consecutive two-dimensional image frames and track its three-dimensional real-world position using an orthographic projections technique presented in [10]. Second, students were required to determine the variation in real-world position and velocity of a truck in consecutive image frames based on manual and automated segmentation techniques.

Description of projects

A complex project had to be defined and performed by each student. These individual projects required students to develop, implement, and evaluate image analysis algorithms for image sets containing two to three images. An applications context was required in which students identify a 'benchmark' to compare and evaluate their results. Students were given the opportunity to explore techniques presented in class or to search the literature and find an algorithm/technique to implement over an image set of their choice. Students were given access to a database of images, including the images in Fig. 1, or the students could acquire their image sets. Project documentation in the form of reports and 12 minute PowerPoint presentations provided the motivation for their projects, experimental designs, experiments performed, experimental results, and conclusions. Some of the project topics included:

- recognizing numbers on license plates using an Euler number approach;
- evaluating redness thresholds for the detection of malignant melanoma in dermatology skin lesion images;
- evaluating thresholding techniques for text segmentation in digital photographs;

- segmenting and analyzing 'spots' in microarray images;
- evaluating image enhancement and edge detection techniques in cervical spine x-ray image analysis;
- comparing edge-detection techniques for finding edges on cervical vertebrae;
- applying symmetry features to detect anomalies in cervical vertebrae; and
- detecting lines in luminance images using the Hough transform.

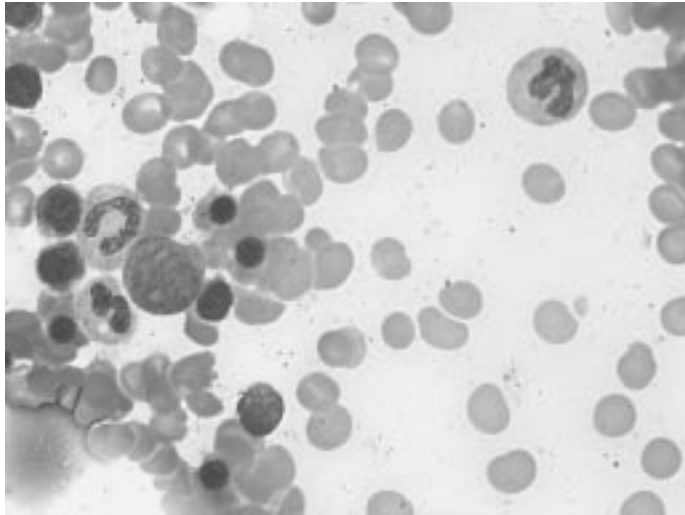
The range of presentations and associated peer (student) evaluations further reinforced the interdisciplinary orientation of the course.

COURSE IMPLEMENTATION AND EVALUATION

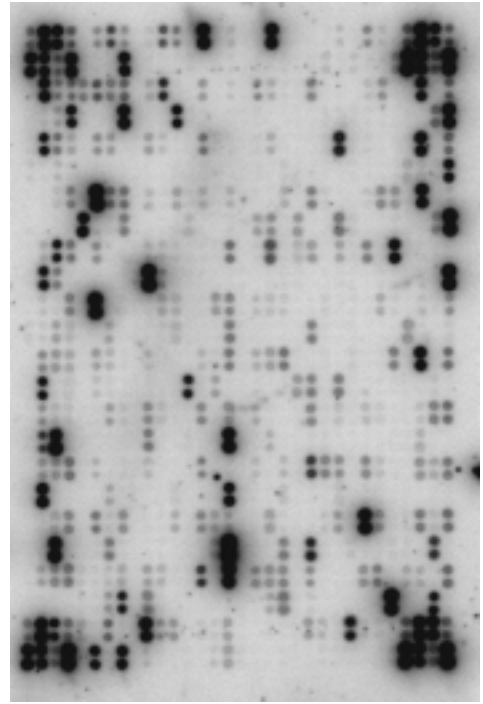
The Machine Vision elective course had 28 students (27 graduate and 1 undergraduate) for the fall semester 2002. Grading was based on two regular examinations and a final comprehensive examination, eight laboratory exercises, three homework assignments, a class presentation and a final project. The students performed all the laboratory exercises and projects using Matlab[®]. The traffic-monitoring exercises were the last laboratory exercises in the course and used the most complex images. Students were required to provide proposals for the individual projects at mid semester and submit final reports and give presentations of their projects at the end of the semester.

Twenty-two of the 28 student participants completed a Laboratory/Project Evaluation Questionnaire. The questionnaire examined the contribution of the real-world imagery-based laboratory exercises and individual projects to student learning in the course and in the effectiveness of the exercises and projects in providing a real-world experience for the students. Figure 2 presents part A of the questionnaire, and Fig. 3 contains parts B and C of the questionnaire. In part A of the survey, students were asked about the appropriateness of the laboratory exercises and the individual project for the course. In part A, the number of students responding for each choice of each question is provided in the blank next to each choice. In part B of the survey, students were asked to respond to statements, using a 1 to 10 scale, with 1 representing strongly disagree and 10 representing strongly agree. In the response blank for each statement, the average student number response is provided. For part C of the survey, students provided open-ended responses to evaluate the laboratory exercises and project for the Machine Vision course.

Several observations can be drawn from the survey results. First, the survey results emphasize the graduate student perspective, with only one undergraduate student completing the survey. The



(a)



(b)



(c)



Fig. 1. Image examples used in laboratory exercises and individual projects in the Machine Vision course: (a) white blood cell image; (b) radio-probe microarray image; (c) cervical spine x-ray image; (d) reference frame for truck moving across bridge; and (e) next in sequence following (d) for truck moving across bridge.

majority of the students enrolled in the Machine Vision course have minimal image-processing experience. The laboratory exercises and projects are intended to help students gain hands-on experience in understanding the Machine Vision course

material. The survey results indicated that students viewed laboratory exercises and projects as helpful in understanding the Machine Vision course material, as seen from the student responses to items 1 and 2 of part A. Students learn about the subject

Machine Vision

Laboratory/Project Evaluation Questionnaire

How you answer the following questions will in no way influence your grade in the class. However, it is important that you answer as honestly as accurately as possible to help improve future classes.

PART A

Pick the best choice for each statement.

The laboratory exercises ...

- 22** contributed to my understanding of course material.
 0 did not contribute to my understanding of course material and the exercises should be deleted.
 0 did not contribute to my understanding of course material and the exercises should be redefined.
 0 no opinion

The course project ...

- 21** contributed to my understanding of course material.
 0 did not contribute to my understanding of course material and the project should be deleted.
 0 did not contribute to my understanding of course material and the project should be redefined.
 1 no opinion

The concepts and skills needed for the laboratory exercises and the project ...

- 19** were adequately introduced in the course lectures.
 2 were not adequately introduced in the course lectures.
 0 were excessively discussed and took too much time from other course activities.
 1 no opinion.

Additional examples of programs and applications incorporated in lectures ...

- 6** would be beneficial, but the laboratory exercises and project assignments would have the same value.
15 would be beneficial and would make the laboratory exercises and project assignments more valuable.
 1 are not needed.
 0 no opinion.

The laboratory exercise concerning the campus bridge ...

- 9** was about equal in value as a learning experience compared to the other laboratory exercises.
 10 was more valuable as a learning experience than the other laboratory exercises.
 3 was less valuable as a learning experience than the other laboratory exercises.
 1 no opinion

The laboratory exercise using medical images ...

- 12** was about equal in value as a learning experience compared to the other laboratory exercises.
 9 was more valuable as a learning experience than the other laboratory exercises.
 1 was less valuable as a learning experience than the other laboratory exercises.
 0 no opinion

Fig. 2. Part A of the Laboratory/Project Evaluation Questionnaire completed by student participants. The student responses are shown in bold.

more effectively, supplementing the lecture with laboratory exercises to apply and extend theoretical materials presented in the classroom. This is observed with the average student response of 8.5 from item 15 of part B and is consistent with student responses from previous studies [10]. The purpose of introducing additional laboratory exercises that use real-world images and present real-world problems is to enhance the student learning experience from the perspective of personal satisfaction and professional development. Similarly, students

viewed the traffic monitoring laboratory exercises and laboratory exercises using medical images as valuable to their learning experiences in the course, with 9 and 12 students indicating that the traffic monitoring and medical imaging-based laboratory exercises, respectively, provided more benefit than the other laboratory exercises.

Second, part of the reason that students did not more significantly benefit from the traffic-monitoring exercises is that students felt that too much of the work had been done for them for the

PART B

Please use the following scale to respond to each of the statements in Part B:

Strongly Disagree 1 ... 2 ... 3 ... 4 ... 5 ... 6 ... 7 ... 8 ... 9 ... 10 **Strongly Agree**

-
- | | | |
|------------|-----|---|
| <u>4.6</u> | 1. | The laboratory exercises were difficult. |
| <u>8.4</u> | 2. | I learned a great deal of information from the laboratory exercises. |
| <u>4.6</u> | 3. | The project assignment was difficult. |
| <u>8.7</u> | 4. | I learned a great deal of information from the project assignment. |
| <u>3.7</u> | 5. | I found the programming component of the laboratory exercises and project difficult. |
| <u>5.0</u> | 6. | I had difficulty defining a project topic. |
| <u>8.5</u> | 7. | I prefer laboratory exercises involving realistic images and image processing situations. |
| <u>3.5</u> | 8. | I prefer laboratory exercises using a single, static image rather than one using multiple images. |
| <u>7.7</u> | 9. | The campus-bridge exercise provided an academic experience versus a real-world experience. |
| <u>8.7</u> | 10. | I learn better by making my own modest programs rather than by using or modifying complex codes. |
| <u>7.4</u> | 11. | Laboratory exercises that use existing codes should be fully explained in lecture. |
| <u>8.2</u> | 12. | I prefer to write my own code rather than extend the code of others. |
| <u>8.2</u> | 13. | I prefer exercises with multiple approaches to solutions over those that require a particular approach. |
| <u>6.9</u> | 14. | The later laboratory exercises effectively built on the earlier laboratory exercises. |
| <u>8.5</u> | 15. | The laboratory exercises were effective in aiding me to recognize how much I know and don't know. |
| <u>8.6</u> | 16. | The laboratory exercises should be a larger part of the course grade. |
| <u>8.0</u> | 17. | The campus-bridge exercise was effective because it used realistic images. |
| <u>7.2</u> | 18. | I would prefer more exercises like the campus-bridge exercise. |
| <u>8.2</u> | 19. | The exercises using medical images were effective because of the realistic images. |
| <u>7.3</u> | 20. | The error analysis performed in the campus-bridge exercise was a valuable learning experience. |
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PART C**Open Ended Evaluation**

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1. Comment on the amount of new information you learned through the laboratories and note the laboratory exercise that you thought was most effective.
 2. Comment on the educational value of the laboratory exercise concerning the campus bridge.
 3. Comment on the educational value of the class project.
 4. Please make any further comments that will aid in evaluating the effectiveness of the laboratory exercises and projects, and in improving them for future classes.
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Fig. 3. Parts B and C of the Laboratory/Project Evaluation Questionnaire completed by student participants. The student responses are shown in bold.

orthographic projections technique. This is consistent with previous student preferences for the traffic-monitoring exercise to track the movement of the truck in consecutive image frames [10]. Two versions of the traffic-monitoring exercise for tracking the truck in a sequence of video frames have been implemented for different difficulty levels. In one version of the laboratory exercise, the algorithm to convert the two-dimensional image coordinates of the truck marker position (parking light) to the three-dimensional real-world position is implemented and provided to students to perform the exercise. In a second, more difficult, version of the laboratory exercise, the students are required to implement the coordinate transformation algorithm (see 'Conclusions' section below) for web-accessibility of those laboratory exercises. The survey responses appear to show that students

would gain more from the truck-tracking aspect of the traffic-monitoring problem by performing the second, more difficult, version of the laboratory exercise.

Student requirements for translating theoretical concepts into practical implementations are more rigorous for graduate courses than for undergraduate courses. The survey results reflect the expectations for students in a graduate course, which is consistent with the student population in the Machine Vision course for the fall semester 2002. The traffic-monitoring laboratory exercise was integrated into the Machine Vision course curriculum in a similar fashion to the other laboratory exercises used in the course, whereby students were presented theoretical concepts in lecture and were required to apply those concepts to real-world and practical applications. Many of the

operations, algorithms, and techniques presented in lecture were encapsulated in Matlab[®] functions that students applied in performing laboratory exercises such as edge operators, morphological operations, and Euler number calculation. This approach allows students to learn and apply theoretical concepts and techniques without requiring substantial translation from theory to implementation, which is more appropriate for an undergraduate course.

The third observation that can be drawn from the survey results is that students preferred using realistic images in real-world problems, as can be observed from the 8.5 average response to item 7 in part B. From part B, the average student response for item 9 of 7.7 indicates that students experienced the traffic-monitoring project as more of an academic exercise than a real-world experience. However, students thought the traffic-monitoring exercises were effective because they used realistic images (based on the 8.0 average student response in item 17 of part B).

The fourth observation is that students prefer flexibility in performing laboratory exercises and projects. The need for flexibility is manifested in the average student responses for items 10–12 of part B, which indicates that students prefer to write their own programs to solve problems. From item 13 of part B, it can be seen that students also prefer exercises where there are multiple solutions or approaches to addressing the problem. This supports the rationale of having students propose their individual projects. Part of the real-world experience of performing the traffic-monitoring laboratory exercises is learning to use and understand code developed by others.

Finally, the real-world laboratory exercises and projects provide the basis for Machine Vision and related image-processing curricula development at UMR. Providing students with hands-on experience with interesting problems in the context of the conceptual and theoretical framework of the course curriculum is a difficult challenge. The survey results obtained for this study indicate that student learning and interest is enhanced when students are challenged with realistic problems, providing the focus for continued development of Machine Vision and image-processing related curricula.

PUBLIC ACCESS TO LABORATORY EXERCISES

From previous work, two versions of a traffic-monitoring laboratory exercise to track a moving truck across a bridge through a sequence of video frames have been provided for public access [10]. The other Machine Vision exercises and imagery used for the Machine Vision course materials presented in this study are also available for other universities and institutions to access. The

laboratory exercises are designed for implementation using the Image Processing Toolbox for Matlab[®] 6.1 or higher. The 'Machine Vision' link of the website <http://campus.umn.edu/smarteng/EducationalResources/> provides the documentation and resources required to access the laboratory exercises. The documentation and resources include the laboratory exercise description, required Matlab[®] code, and images necessary to perform the exercise.

The laboratory exercises used in the Machine Vision course are intended for junior/senior undergraduate or graduate-level graphics or image-processing related courses. The exercises are intended to be flexible to allow for different images to be used for performing the exercises (i.e. those images provided or images supplied by a user). Instructors who download the exercises are requested to complete a survey with contact information. After using one or more of the exercises, a follow-up survey is requested to document which exercises were used, their actual utilization as a laboratory exercise, and recommendations for improving the exercises. Making the exercises accessible to other institutions serves two important purposes. First, students at other institutions have more opportunity to examine real-world image-processing problems. Second, feedback from multiple institutions will facilitate refinement of this learning resource for students.

CONCLUSIONS

The integration of real-world problems with complex imagery can improve image-processing curricula. Effective applications-based exercises should be closely aligned with lecture concepts and should be assigned with little time delay. However, they must be carefully constructed so that significant and relevant experience is gained, but reasonable student solutions are possible. A Matlab[®] environment allows a focus on the imaging concepts and techniques with minimal programming difficulty. A range of application examples link foundational knowledge to context. Multiple versions of exercises can accommodate different student levels by giving assignments to undergraduates which use Matlab[®] functions and preprogrammed algorithms and by giving assignments to graduate students which require custom implementations.

This study presents Matlab[®]-based laboratory exercises and projects using real-world imagery for an undergraduate/graduate Machine Vision course at UMR. The laboratory exercises are web-accessible for other universities and institutions to access. A survey was used to assess the impact of these exercises and projects on student learning. The survey results indicated that: 1) student learning was stimulated with laboratory exercises using real-world imagery and 2) students prefer flexibility in performing laboratory exercises and projects.

Further refinements of laboratory exercises are under investigation. Future offerings of the Machine Vision course at UMR will focus on

active learning techniques to further integration of real-world exercises with theoretical concepts and techniques.

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