

5-1-2004

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Recommended Citation

R. J. Stanley et al., "A Web-Shareable Real-World Imaging Problem for Enhancing an Image-Processing Curriculum," *IEEE Transactions on Education*, vol. 47, no. 2, pp. 211-219, Institute of Electrical and Electronics Engineers (IEEE), May 2004.

The definitive version is available at <https://doi.org/10.1109/TE.2004.825214>

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A Web-Shareable Real-World Imaging Problem for Enhancing an Image-Processing Curriculum

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Abstract—A real-world laboratory exercise is presented for image processing and related curricula. The exercise is a traffic-monitoring problem in which a truck must be tracked as it moves across a bridge and its velocity measured. Sequential images are taken from a dedicated Web camera that views the Smart Composite Bridge on the University of Missouri–Rolla campus. The prototype bridge is a field laboratory for several interdisciplinary courses, including a Machine Vision elective. The Machine Vision image-processing elective uses the traffic-monitoring exercise to give students experience with processing complex images, tracking image markers, and applying theoretical orthographic concepts. The laboratory exercise uses an image sequence acquired during the springtime with multiple potential markers available on the truck for assignment flexibility. A wintertime image sequence with snowy conditions is also available for assignment flexibility. This paper discusses the bridge and camera resources, the traffic-monitoring laboratory exercise description, and the Machine Vision course implementation and evaluation. Two versions of the traffic-monitoring exercise, including two image sequences and orthographic MATLAB code, are available on the bridge Website.

Index Terms—Image processing, orthographic projection, real-world educational laboratory, traffic monitoring in transportation.

I. INTRODUCTION

DIGITAL image processing offers a wide range of opportunities for students to explore, learn, and discover aspects of many disciplines. The first major educational project using image processing was the IPT (Image Processing for Teaching) project. The researchers at the University of Arizona, Tucson, utilized the technological, information theory, and cognitive issues associated with image processing for its educational impact. The project results demonstrated the effectiveness of image processing in education through widespread teacher education, materials development, and follow-up support and outreach [1].

Another facet of image-processing education allows students to acquire mathematical knowledge and problem-solving skills based on applying tools for examining real-world phenomena within real-world images. The NASA CERES project [2] allowed students to make measurements of objects and to build their knowledge of the imaging tool. Other activities that make

use of object measurement are found in Network Montana Project's Website of earth science activities [3]. For example, students measure 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.

The University of Iowa, Iowa City, has explored a multiphase project for an interdisciplinary image-systems engineering curriculum using an electronic classroom. 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].

Another approach to facilitate image-processing learning is the development of program libraries to support concept learning and accommodate diverse student backgrounds [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. A similar approach has been explored at California Polytechnic State University, San Luis Obispo, using a signal and image processing tool (SIPTool) for multimedia demonstrations and development of signal- and image-processing techniques, using C/C++ programming [9]. The SIPTool provides students with an integrated environment that includes their processing routine with the image/signal acquisition and display. The following mechanisms for the SIPTool facilitate and enhance student learning [9]:

- 1) the capability to visualize complex relationships;
- 2) discovery and problem solving;
- 3) free dissemination for encouraging varied use.

In addition to the educational component for image processing discussed, there are numerous applications which utilize computer-assisted imaging technology. In transportation, image processing is used in camera-based applications, such as traffic [10]–[13] and pedestrian [14]–[16] monitoring. For these camera-based applications, two-dimensional (2-D) images must be analyzed to extract and translate three-dimensional (3-D) real-world scene information.

Education and research for transportation are becoming more interdisciplinary. Optical metrology, smart materials and structures, computer technologies, etc., are finding important

Manuscript received October 29, 2002; revised April 29, 2003. This laboratory development was supported in part by the National Science Foundation (NSF) under Combined Research-Curriculum Development Grant EEC-9872546.

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Digital Object Identifier 10.1109/TE.2004.825214

roles in improving infrastructure, vehicles, and related transportation systems. For instance, image processing can provide intelligent monitoring of traffic flows and control functions of other sensing systems. Consequently, students outside of traditional transportation fields need exposure to interdisciplinary transportation applications.

In this paper, a Web-accessible, real-world, image-processing laboratory exercise is presented. The exercise provides an active learning component to the Machine Vision course taught at the University of Missouri-Rolla (UMR). Realistic images and a real-world transportation problem 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, coordinate transformation, and real-world interpretation of image-processing algorithm outputs. The exercise is based on identifying and tracking markers on a truck as it moves across an on-campus bridge. Sequential images are taken from a dedicated Web camera that views the Smart Composite Bridge (SCB) at UMR. The SCB is an interdisciplinary field laboratory for education and research. Multiple potential markers are available on the truck for assignment flexibility, and varied image sequences can be readily created. The project extends the bridge field laboratory to image-processing curricula and promotes the application of image-processing techniques to the transportation and smart-structures areas. The paper discusses the bridge and camera resources, the target image processing and orthographic concepts, and the Machine Vision course implementation and evaluation. Most importantly, the laboratory exercise offers students a real-world experience, requiring the understanding and application of image-processing concepts and techniques. Access to the laboratory exercise on the Web provides a service to other institutions and universities, especially those that lack resources for developing application-oriented experiences. Two versions of the laboratory exercise, including two video-frame sequences and sample MATLAB code, are available at the SCB Website for downloading. The video-frame sequences were captured during spring and winter seasons to provide variations in the laboratory exercise to facilitate student learning. The traffic-monitoring laboratory exercise, used in the Machine Vision course, is evaluated using a survey to gauge the laboratory exercise's contribution to student learning and its effectiveness in providing a real-world experience to students.

II. TRAFFIC-MONITORING LABORATORY

The SCB at UMR is the field laboratory for the image-processing exercise. The SCB is a short-span structure of length 9.1 m and width 2.8 m. The bridge is located over a small creek on campus and is normally used by pedestrians and light vehicles. However, the bridge was designed and tested for highway loads as a cooperative product development and research effort among university, industry, and government partners [17]. As a prototype structure, it demonstrates the capabilities of advanced composite, or fiber-reinforced, polymer materials and of fiber-optic sensing technology for bridging applications [18]. The bridge, the first all-composite bridge in Missouri, has



Fig. 1. Smart Composite Bridge at the UMR. The location of the dedicated Web camera is indicated on the building in the background.

a smart-structures [19] emphasis with permanent fiber-optic strain sensors for *in situ* monitoring of flexure and shear strain. The bridge technology is used as a field laboratory for an National Science Foundation (NSF)-sponsored, interdisciplinary course Smart Materials and Sensors. 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 are available at <http://campus.umar.edu/smarteng> [20], [21]. The Web-accessible, traffic-monitoring laboratory exercise extends the bridge field laboratory to image-processing curricula and is a preliminary research step toward integrating image-processing and sensing technologies for bridge monitoring.

A dedicated Web camera provides an online imaging capability as part of the bridge research initiative. The camera is an Axis 200+ Web Camera (Axis Communications Model Number 0064-9) containing a 768×582 24-b digital color charge-coupled devices (CCD) camera and a self-contained Web server (32-b reduced instruction set computer (RISC) processor) [22]. A zoom lens and outdoor housing complete the system. The camera views the bridge from an oblique angle at approximately 61.8-m distance. Fig. 1 shows the bridge and the camera, highlighted with the white box, mounted on the Electrical and Computer Engineering Building. The resulting real-world images have several interesting features. Trees and railings obscure part of the bridge; sunlight and shade change the background lighting; and seasonal coloration changes the overall background.

III. TRAFFIC-MONITORING EXERCISE FOR MACHINE VISION COURSE

A. 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, image segmentation, and pattern recognition. Course components integrate lecture, laboratory exercises, and a semester project for practical application. The following three educational objectives

provide the foundation for incorporating the traffic-monitoring exercise into the Machine Vision course:

- 1) providing students with real-world image analysis experience;
- 2) augmenting student learning based on incorporating an active learning laboratory exercise;
- 3) expanding the interdisciplinary scope for using smart-structures bridge technology.

The Machine Vision course utilizes MATLAB, primarily the image processing toolbox, for implementing several laboratory exercises and a group 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 such as histogram equalization. MATLAB also provides a programming environment to extend existing algorithms to address more complex problems.

In this study one extends the existing applications for the bridge technology to the Machine Vision course. Image analysis techniques are applied to a sequence of video frames acquired from the bridge project Web camera. The bridge/laboratory exercise was used near the end of the course to give students a more comprehensive problem. The exercise provided students with a unique experience of real-world, 3-D, and complex natural scene analysis not seen with the other course laboratory exercises.

For engineering education, the theoretical concepts provide the foundation for the subject with augmentation of practical experimentation for these concepts through projects or laboratory exercises. For image-processing curricula, there is difficulty presenting real-world examples that demonstrate image-processing concepts in an active learning environment. In traditional lecture/laboratory courses, there is often a significant time delay or misalignment between when the theoretical concept is presented and when the practical experimentation occurs.

The goal with the laboratory and project exercises is to engage students, using active learning in practices that will be used beyond the course to facilitate lifelong learning. Particularly with image processing, a relatively easy interface is needed to allow students to evaluate and understand algorithms and techniques in their application to image-processing problems. Equally important is the presentation of course concepts and techniques visually. The understanding, application, and synthesis of theoretical concepts by individual students; the capability of students to work and learn in team projects; and the evaluation of work performed by peers are also important factors in the development of curricula for undergraduate and graduate courses. Thus, active learning must be initiated and conducted to facilitate learning in the context of the individual student and in a teamwise basis.

B. Real-World Laboratory Exercise Description

The laboratory exercise using the bridge project Web camera is based on analyzing a sequence of video frames containing a moving truck. Fig. 2 presents an example frame acquired from the mounted Web camera and is representative of the frames



Fig. 2. Frame acquired from dedicated Web camera of the SCB. The traffic-monitoring exercise uses the right parking light of the truck as a marker for tracking.

captured in the sequence. In Fig. 2, the truck is positioned with its longitudinal axis parallel to the sides of the bridge's deck. The truck maintains the parallel movement at a fixed distance from the bridge's deck as the truck moves across the bridge in the captured frames, moving from right to left. Fig. 2 contains a 2-D representation for the truck on the bridge. The laboratory exercise requires students to determine the velocity of the truck from the sequence of captured frames. For velocity calculation, common markers on the truck must be identified in each frame, and the 2-D image of the bridge scene must be projected to three dimensions. The truck markers can be segmented using color thresholding. The truck contains several color markers, including a red ball on the antenna, a yellow ball located in the driver's side rear wheel, reflective tape located on the driver's side-view mirror, a flashlight located on the driver's side-view mirror, and the truck's parking lights turned ON. The red ball, yellow ball, and parking lights can be seen on the truck in Fig. 2. The other markers are blocked by the tree in front of the truck.

Sequences of frames are available for spring and winter seasons. Each sequence of frames begins with the truck on the southwest side of the bridge. The truck travels parallel with the sides of the bridge deck as it moves toward the northeast side of the bridge. For the parallel movement, the truck remains a fixed distance from the northwest and southeast sides of the bridge deck. The markers or reference positions on the truck remain a fixed distance above the bridge deck. Twelve frames of the truck movement were captured in increments of 3 ft across the bridge. A simplified variation-of-the-orthographic projection technique translates the reference position locations from the individual frames from 2-D image position to 3-D spatial locations [23]. A detailed presentation of the transformation procedure and its derivation is given at the Website [21] (<http://campus.umn.edu/smarteng>) in the document entitled "Detailed Traffic-Monitoring Image-Processing Algorithm Description" along with two versions of the laboratory exercise and image data. The student version of the laboratory exercise performed in the Machine Vision course is presented in the following Section III-C, "Traffic-Monitoring Laboratory Exercise for the Machine Vision Course."

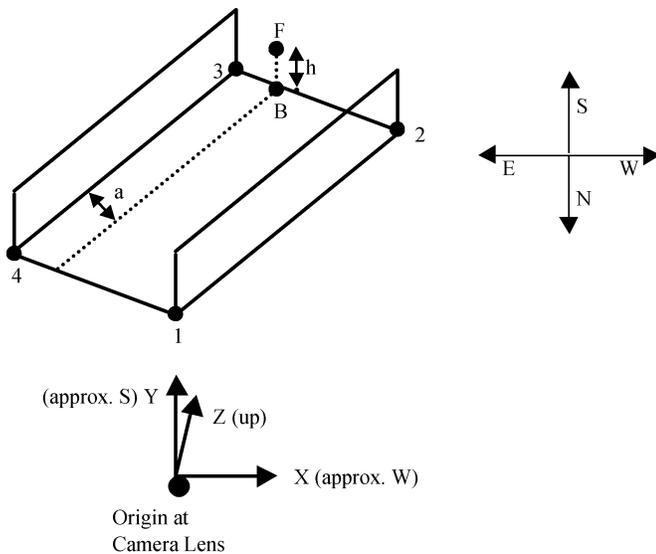


Fig. 3. Schematic of bridge deck with reference points labeled for use in 2-D to 3-D coordinate transformation. Coordinate axes and direction legend are shown. Dotted line within bridge deck represents path that right wheels of truck follow for crossing bridge, starting at point B.

Fig. 3 shows a schematic of the bridge deck and 3-D coordinate system. In Fig. 3, the XYZ axes are drawn to show the orientation of the coordinate system. The real-world coordinates of the bridge deck corner positions (labeled 1–4) are surveyor measurements in meters with respect to the origin of the camera lens. A directional legend is also provided in Fig. 3 to assist in referencing the labeled positions. Note that all calculations required in the presented coordinate transformations are based on the bridge corner positions labeled 1–4, the starting ground position of the truck marker, and the starting actual position of the marker, e.g., the truck’s right front parking light. The coordinate transformation procedure from the 2-D image coordinates to the 3-D actual coordinates consists of the following tasks:

- 1) identifying required real-world coordinate bridge corner locations;
- 2) deriving real-world coordinates for reference points B and F;
- 3) determining the image coordinates for the centroid position of the truck’s right parking lights at the truck’s starting position;
- 4) transforming the segmented front right parking light centroid position to its real-world coordinate within the various image frames.

The real-world position of the truck’s right front parking light is used for tracking the truck’s position from video frame to video frame for velocity calculation. Two required parameters for performing the transformation calculations, labeled on Fig. 3, are 1) the height of the truck’s right parking light above the bridge deck, denoted as h , and 2) the perpendicular distance of the right parking light from the bridge side 3–4, denoted as a . The parking light centroid image location transformation to its corresponding real-world position is described at the Website.

The laboratory exercise requires students to compute the velocity of the truck moving across the bridge as seen in the sequence of image frames. The algorithm listing the necessary steps to compute the truck’s velocity is given in Fig. 4. The first

required step is to measure manually the real-world distances, h and a , while the truck is physically at its starting position. After making these measurements, a sequence of image frames for the moving truck are captured. A marker on the truck is chosen for tracking the truck through the image frame sequence. Note that the same truck marker must be used in each image frame. Based on color analysis, the truck’s parking lights provided the most consistent marker for segmentation. Image-processing operations, in particular color thresholding, are performed to segment the front right parking light from the image frames. Object labeling is required for tracking the left and right parking lights. The object centroid must be determined for maintaining the relative position of the truck within each frame, using the image-to-real-world (2-to-3-D) transformation. Comparing the 3-D position changes over the sequence of frames provides the velocity of the truck. The velocity can be computed with respect to the left and right parking light. The truck’s velocity between frames is computed using the Euclidean real-world distance between consecutive frames and the image frame capture rate.

C. Traffic-Monitoring Laboratory Exercise for the Machine Vision Course

In this section, the laboratory exercise used in the Machine Vision course at UMR is presented for the traffic-monitoring image-processing application described in Section III-B, “Real-world Laboratory Exercise Description.” The application tracks a moving truck across video frames for determining the truck’s velocity, requiring the transformation and interpretation of 2-D images for a 3-D scene. A projections-based technique is used for the image-to-real-world-coordinate transformation. The laboratory exercise used the springtime sequence of video frames, as illustrated in Fig. 2.

Students can be required to perform all or part of the operations listed in Fig. 4. For the initial implementation, the authors for this paper were responsible for performing Steps 1–3 (Fig. 4), which included deriving and implementing the image-to-real-world-coordinate transformation, determining transformation parameters, and acquiring the image frame sequence. Students were provided with MATLAB code which implemented the technique to transform image-to-real-world coordinates. Students were required to implement MATLAB code to complete Steps 4–6 (Fig. 4) using the MATLAB routines provided to perform coordinate transformation based on segmentation of the left and right front parking lights. Color thresholding was used for segmenting the parking lights (left and right), where students manually selected red, green, and blue color ranges characteristic of the parking lights. Students used the real-world coordinates for the left parking light centroid position for velocity calculations. For velocity calculations, students were provided with a sequence of three consecutive image frames, from which students selected two image frames for velocity determination.

IV. COURSE IMPLEMENTATION AND EVALUATION

The traffic-monitoring exercise was incorporated into the Machine Vision course for fall semester 2001. The Machine Vision elective course had 22 students of which 18 were

- 1) Manually determine image to real-world transformation parameters a and h from truck's starting position
- 2) Obtain sequence of image frames
- 3) Choose marker on truck to track truck position
- 4) Determine real-world position of marker centroids for image frames in sequence
 - a) Perform image-processing operations to segment marker
 - b) Determine centroid position of marker
 - c) Determine real-world coordinates of image frame centroid position
- 5) Compute real-world distance traveled between marker centroid positions in consecutive frames
- 6) Determine truck's velocity using consecutive frames and the frame capturing rate

Fig. 4. Algorithm listing the steps to compute the truck's velocity from sequence of image frames.

graduate students and four were undergraduates. 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 traffic-monitoring exercise was the last laboratory exercise in the course and used the most complex images. For the pilot traffic-monitoring laboratory exercise, the students performed the laboratory exercise described in Section III-C, "Traffic-Monitoring Laboratory Exercise for Machine Vision Course." They applied color thresholding to segment and track markers in the image sequence and used existing MATLAB code for the coordinate transformation, and then they calculated the truck velocity.

All 22 student participants completed a laboratory/project evaluation questionnaire. The questionnaire examined the contribution of laboratory exercises and the group project to student learning in the course. The purpose of the evaluation was to inspect the bridge laboratory exercise's contribution to student learning and its effectiveness in providing a real-world experience to students. Fig. 5 presents Part A of the questionnaire, and Fig. 6 contains Parts B and C of the questionnaire. In Part A of the survey, students were asked about the appropriateness of laboratory exercises and the group 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 1–10 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, students, in general, had a favorable experience from the real-world traffic-monitoring exercise. For item 5 of Part A, 14 of the 22 students viewed the bridge exercise similarly to other laboratory exercises performed in the course. Four of the students believed that the bridge exercise provided a more valuable learning experience than the other laboratory exercises in the course, and three of the students thought that the bridge exercise was less valuable as a learning experience than other exercises. Part of the reason for the mixed student response to the bridge exercise was manifested in the open-ended responses in Part C. A specific comment from several students to item 2 of Part C was that too much of the work with the projections technique had been done for them, thereby, reducing the application impact of the 3-D scene analysis.

Second, students believed that applying concepts from the classroom to real-world images enhanced the educational value of the course. In particular, the traffic-monitoring exercise provided students with a real-world application of the concepts and techniques presented in the Machine Vision course. From item 2 of Part C, about a third of the students indicated that they enjoyed the experience of working with real-world images for applying image-processing techniques. Responses from several items from Part B of the survey support student enjoyment working with real-world images. From Part B, the average student response to item 7 of 8.3 indicates that students prefer performing laboratory exercises using realistic images and image-processing situations. The average student responses in Part B to items 14 and 15, of 7.0 and 7.2, respectively, show that students have a favorable learning experience performing exercises using real-world images. In addition, high average responses of 7.7 and 8.3, respectively, were obtained for items 2 and 4 in Part B. Hence, the students believed that the laboratory exercises and group project greatly contributed to their learning experience.

These evaluations support the premise that active learning exercises, especially those with application-oriented images, promote learning and student satisfaction. The real-world exercise provided insight to actual applications of the course material as seen from the perspective of practicing professionals in the field. Based on the comments, a higher difficulty version of the exercise was created to further involve students in the coordinate transformation requirements, and more in-class tutorial preparation is planned for the exercise content. The more difficult version of the laboratory exercise is described in the Section V, "Public Access to Laboratory Exercise." In addition, the exercise will be modified for the Smart Materials and Sensors course to demonstrate the control of sensor measurements using image processing.

Finally, the transportation exercise provides the foundation for more complex projects involving the Digital Image Processing undergraduate and graduate course at UMR. The Digital Image Processing course provides students with fundamentals of human perception, image enhancement, image restoration, channel and source coding, and sampling and quantization. Variations of the transportation exercise can be incorporated into the course to address several course objectives, including the following:

- 1) obtain a broad exposure to and understanding of various applications of image processing in industry, medicine, and defense;

Name _____

Machine Vision Laboratory/Project Evaluation Questionnaire

1. 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 ...
 21 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.
 1 no opinion

The course project ...
 22 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.
 0 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.
 1 were excessively discussed and took too much time from other course activities.
 0 no opinion.

Additional examples of programs and applications incorporated in lectures ...
 7 would be beneficial, but the laboratory exercises and project assignments would have the same value.
 14 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 (#8) ...
 14 was about equal in value as a learning experience compared to the other laboratory exercises.
 4 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

Fig. 5. Part A of laboratory/project evaluation questionnaire completed by student participants. The student responses are shown in bold.

- 2) acquire an appreciation for image-processing issues and techniques and be able to apply these techniques to real-world problems;
- 3) be able to conduct independent study and analysis of image-processing problems and techniques;
- 4) learn signal processing algorithms and techniques for image enhancement and image restoration, including spatial processing, frequency processing, and morphological processing.

For image sequences acquired from different times of the year, students can apply and develop image-enhancement techniques to facilitate marker identification for object tracking.

V. PUBLIC ACCESS TO LABORATORY EXERCISE

The traffic-monitoring exercise has been incorporated into the Smart Composite Bridge Website (<http://campus.umr.edu/smarteng>) [21] in order to provide access for students taking courses at UMR and to provide other institutions access to the exercise. From the previous

section, student responses to the bridge exercise emphasized the differing degrees to which students were challenged and the receptiveness of students to a real-world application of image-processing techniques. Two versions of the bridge exercise are provided at the Website. One version provides the same exercise as implemented in the Section III-C, "Traffic-Monitoring Laboratory Exercise for Machine Vision Course." For the Machine Vision course exercise version, the necessary MATLAB code and a laboratory exercise assignment handout are provided that describe and implement the transformation of the 2-D bridge scene image coordinates to the 3-D bridge scene coordinates. The second version of the laboratory exercise is more challenging. In the second version, students are still required to segment and track the truck markers. In addition, students must develop the coding for the coordinate transformations given the survey information for the camera and the bridge. Again, the truck's velocity is determined from the real-world distance traveled between image frames and the frame-capture rate.

The traffic-monitoring link of the "Educational Resources" page of the Website (<http://campus.umr.edu/smarteng/bridge/>

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

-
- 3.6** 1. The laboratory exercises were difficult.
7.7 2. I learned a great deal of information from the laboratory exercises.
5.3 3. The project assignment was difficult.
8.3 4. I learned a great deal of information from the project assignment.
4.2 5. I found the programming component of the laboratory exercises and project difficult.
3.8 6. I had difficulty defining a project topic.
8.3 7. I prefer laboratory exercises involving realistic images and image processing situations.
7.6 8. I learn better by making my own modest programs rather than by using or modifying complex codes.
5.9 9. Laboratory exercises that use existing codes should be fully explained in lecture.
7.3 10. I prefer exercises with multiple approaches to solutions over those that require a particular approach.
7.8 11. The later laboratory exercises effectively built on the earlier laboratory exercises.
7.8 12. The laboratory exercises were effective in aiding me to recognize how much I know and don't know.
6.4 13. The laboratory exercises should be a larger part of the course grade.
7.0 14. The campus-bridge exercise (#8) was effective because it used realistic images.
7.2 15. I would prefer more exercises like the campus-bridge exercise (#8).
-

PART COpen Ended Evaluation

-
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 (#8).
 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.

Fig. 6. Parts B and C of laboratory/project evaluation questionnaire completed by student participants. The student responses are shown in bold.

index.html) provides the needed documentation. A readme file contains the following:

- 1) the directory where the springtime image sequence (.tif images) can be downloaded (image frames used in the Machine Vision laboratory exercise);
- 2) the directory where the wintertime image sequence (.tif images) can be downloaded;
- 3) an overview of the laboratory exercise used in the Machine Vision course and requirements for performing the exercise (Laboratory Exercise 1);
- 4) an overview of the more challenging laboratory exercise and requirements for performing the laboratory exercise (Laboratory Exercise 2);
- 5) directory information where the laboratory exercises can be downloaded with associated MATLAB code;
- 6) the derivation of the image to real-world coordinate transformation process in the document entitled "Detailed Traffic-Monitoring Image-Processing Algorithm Description."

A sample solution for Laboratory Exercise 1 is also available at the Website with the laboratory assignment and required MATLAB code for that exercise.

The traffic-monitoring exercise used in the Machine Vision course, and the more advanced exercise available at the Website are intended for junior/senior undergraduate or graduate level graphics or image-processing-related courses. The spring- and winter-image sequence options and the different markers on the

truck in the spring sequence provide many realistic variations of the laboratory exercise, allowing students to explore different image segmentation techniques.

In order to download the laboratory exercise, the individual downloading the exercise is requested to complete a survey with contact information. After using the exercise materials, the instructor using the exercise is requested to complete a follow-up survey documenting the version of the laboratory exercise used, its actual utilization as a laboratory exercise, the adequacy of the documentation, and recommendations for improving the exercise. Making the exercise available to other institutions serves two important purposes. First, having the exercise available to other institutions provides the opportunity for other students to examine a real-world image-processing problem. Second, with other institutions using the exercise, feedback will fuel refinement for enhancing this learning resource for students.

The image frame sequence used for the laboratory exercise in the Machine Vision course was acquired during the spring, with Fig. 2 showing an example of one of the acquired frames. For the wintertime sequence of image frames with a snow-covered background, the distances from the southeastern railing (**a**) and the bridge deck (**h**) were preserved for the left front parking lights. As a result, the image to real-world transformation algorithm and MATLAB code provided at the Website can be used for the two versions of the laboratory exercise. The snow background in the image frames changes the color ranges for segmenting the parking lights, giving students the opportunity to

explore other segmentation approaches. Both sequences of images frames are available at the Website.

VI. CONCLUSION

A traffic-monitoring problem using complex images was incorporated into image-processing laboratory exercises. The real-world traffic-monitoring application involves the measurement of velocity for a truck by processing field images, tracking image markers, and calculating orthographic projections. Students must integrate image-processing concepts and techniques presented in the classroom to complete the exercises successfully. The exercises were implemented in a Machine Vision course. The participating students generally 1) felt that realistic images and applied problems enhanced the course learning experience and 2) believed that laboratory assignments have a strong impact on learning image-processing concepts. The SCB and the dedicated camera are valuable resources in developing meaningful hands-on assignments. The current version of the exercise can be varied by looking at other markers, by assigning part or all of the orthographic coding and by supplying alternative images with different conditions, e.g., winter background versus spring background. In addition, other exercises and course projects are possible in which the students generate their own tailored images.

The project extends the bridge field laboratory to image-processing curricula and promotes the application of image-processing techniques to the transportation and smart-structures areas. An orthographic-projection approach is used to measure 3-D objects from a 2-D image. Two downloadable versions of the traffic-monitoring exercise are available through the SCB Website [21] to facilitate student learning at other institutions. The site includes assignment guidelines, image files (two options), and sample MATLAB code. Different image sets and sample programs will be included in the future. In addition, further research and educational capabilities are under development [24]. Measurements of load position by image-processing algorithms can be linked to the *in situ* strain sensors in the bridge. Coordinated image and sensor systems can contribute to smart-structures technology in which structural performance can be more readily monitored and interpreted.

ACKNOWLEDGMENT

The authors would like to thank the Instructional Software Development Center at UMR for providing programming resources for laboratory development. The authors would also like to thank V. M. Eller for her assistance in setting up the laboratory exercises on the Smart Engineering Website.

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