Digital Image Analysis in Geotechnical Engineering Education

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Abstract: Existing research has shown that visual input significantly contributes to learning, therefore, it is paramount to use visual tools to help demonstrate engineering concepts. One of these tools, digital image analysis, can help effectively communicate complex concepts to students in a simple and understandable format as a supplement to traditional lecturing, while simultaneously enabling students to have hands-on experience. This note describes a series of activities to incorporate digital image analysis into engineering education. The undergraduate students worked in research projects that involved image-based analysis of geomaterials. Based on these activities and the students’ response to a questionnaire, it was recognized that digital image analysis can enhance the understanding of engineering phenomena for undergraduate students. The hands-on experience and visual demonstration improved the students’ grasp of fundamental concepts in research projects. The research experience allowed the students to build a connection between the classroom and the solution of state-of-the-art engineering scientific problems. It also taught them about cooperation and teamwork, as well as academic independence.

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Introduction

A national shortage of engineering students currently exists, and the rate at which students are entering the science and technical fields is not keeping pace with the current global demand for technology. Many promising students with initial beginnings in engineering transfer to other disciplines as they move through the educational system. Unfortunately, the current educational curriculum that emphasizes behaviorist learning may be a partial cause for this phenomenon. Today’s students have to commit significant effort over a long period of time before their skills become relevant in the current engineering job market. In order to develop the potential of undergraduate students as emerging professionals, it is necessary to strengthen the curriculum by incorporating projects that exploit and cultivate their skills and provide them with hands-on experience by taking advantage of the recent advancements in information technology (Davidson and Ambrose 1994).

Existing research has shown that visual input contributes to learning significantly; therefore, it is paramount to use visual tools when possible to help demonstrate engineering concepts (Martini 1999; Grigg et al. 2005). One of these tools is digital image analysis. Digital image processing techniques were developed by computer engineers and have been traditionally used by other branches of engineering in various research projects (Bhatia et al. 1993; Jang et al. 1999; Masad et al. 2002; Aydilek et al. 2002). With current advancements in imaging technology, such methodologies can help effectively communicate complex concepts to students in a simple and understandable format as a supplement to traditional lecturing. This new approach to civil engineering education will enable students to have hands-on experience, as well as to conceptually visualize materials in a broader context.

The objective of this note to present a study for utilizing digital image processing techniques to conduct undergraduate research. The study is based on the writer’s experience at two institutions: the University of Maryland and the University of Wisconsin. The effectiveness of this information technology-oriented education methodology, based on student evaluations, is also presented.

Implementation

Several undergraduate students at the University of Maryland and the University of Wisconsin were included in two separate projects that involved image analysis-based evaluation of geotechnical engineering materials. At least two undergraduate students were hired at a time in order to assign them to different aspects of the same project. Such interdependence fostered significant cooperation and teamwork, as well as developed their academic independence. They learned how to problem solve and troubleshoot when addressing issues in experiments. It is known...
that the greatest potential for growth occurs when engineering students deal with issues that fall outside of their frame of reference (Culver et al. 1990).

The students in the current study were assigned to give periodic presentations on the results of their work. This fostered a research-team atmosphere where students felt that they were part of an actual research project. Biweekly research meetings were held with each student, and they were assigned a graduate student as a mentor. The student-mentor contact, as well as the skills gained, were uniquely different from that encountered in the classroom. The approach fostered a supportive atmosphere of learning and research. Harnessing the experience and knowledge of a senior person (i.e., graduate student mentor) in the group to mentor a more junior person (i.e., undergraduate student) had many positive outcomes including improved teaching ability for the graduate student mentor, teamwork, and problem-solving. Some of the students enrolled in independent study and received academic credit for their work, while others received a stipend. In most cases, the stipends were partially supported through College of Engineering programs that were established to promote undergraduate research.

The basis for the projects was to allow them to work within a scientific atmosphere in state-of-the-art facilities. Their involvement in the research projects provided them hands-on experience and exposed them to active learning for the entire semester, which is usually not possible in traditional lectures or 2–3 h of laboratory sessions. This involvement also broadened their exposure to science and engineering as reported in the previous studies. For instance, Pickett et al. (2000) reported the findings of a study in which a set of hands-on experiments were taught to teachers in order that they would bring them back to their classrooms. The results of their study showed that after the performance of these hands-on experiments, about 80% of the students stated that their enjoyment and interest in engineering had increased.

**Project I**

One of the projects was about pore structure evaluation of geosynthetic filters (geotextiles) using digital image analysis. Filtration performance of these fabrics is controlled by their pore structure parameters, namely percent open area (POA) for woven geotextiles, and pore opening size distribution (PSD) for both woven and nonwoven geotextiles.

Due to the two-dimensional structure of woven geotextiles and the presence of relatively large pore openings, a direct method such as digital image analysis was very appropriate for this purpose. The undergraduate research students were involved both in capturing and processing the images of geotextiles using the most recent advancements in technology. In this study, the students worked with a graduate student mentor to determine these parameters for over 30 different geotextiles. Images of geotextiles were captured by a charged couple device (CCD) monochrome camera. The captured images were processed using mathematical morphology algorithms previously developed by the graduate student mentor. Finally, the students calculated POA and PSD using codes developed in LabVIEW, an image processing and instrumentation software.

The three-dimensional structure of nonwoven geotextiles required capturing pore structures from two-dimensional images. Planar and cross-sectional thin sections of these geotextiles were necessary to provide detailed information. The thin sections of the geotextiles investigated in this project were prepared by the undergraduate students and the graduate student mentor in the Department of Geology laboratories (Aydilek et al. 2002). Pore structure images of nonwoven geotextiles were captured using an optical light microscope equipped with an image-capturing program. Following a series of morphological operations, PSD of nonwoven geotextiles were calculated using a code developed in LabVIEW.

As part of the study, the students were also asked to determine the pore structure parameters using traditional (manual) measurement techniques. The manual method for POA is called the light projection method in which a sample of geotextile (usually 50 mm × 50 mm) is placed in the holder of a slide projector. The image from the center of the sample is projected onto a screen, and POA is determined by dividing the total area of openings in this area by the area of measurement (U.S. Army Corps of Engineers 1986). The process was simple but extremely time-consuming. To determine the PSD of the geotextiles, laboratory dry sieving tests were performed following the procedures outlined in ASTM D 4751 in which varying sizes of glass beads were sieved through a geotextile sample. Similarly, this method took significantly more time than the image analysis. Each student was assigned to provide a quantitative comparison of the image-based measurements to those made manually.

**Project II**

The second project used the imaging method to define strain distribution in geosynthetics during tension testing. An accurate determination of such strain distributions can be highly important in soil reinforcement applications. The project involved laboratory tension testing of different types of geosynthetics and the evaluation of strain fields using digital image analysis during the tests. As a result, undergraduate students had a chance to gain hands-on experience with the experimental apparatus as well as with an innovative nondestructive strain determination technique, i.e., image analysis.

The students mounted a CCD monochrome camera apart from the test setup to simultaneously capture digital pictures of the test specimens at 2 or 5 s intervals depending on the rate of displacement applied during testing. The images did not require significant processing or restoration (if needed the images were processed by the graduate student mentors); however, the undergraduate research students gained significant experience in image-based particle tracking techniques. The undergraduate research students were assigned minimum duties in development of the tracking algorithms; however, they were directly involved in analysis and data reduction. Example images of a geosynthetic specimen captured at the beginning and end of the test, as well as their corresponding measured strain distributions, are given in Fig. 1. In addition, extensometers and strain gauges were also placed on geosynthetic specimens to determine localized strains (manually) during tensile testing. The students were assigned to compare the strains measured by these devices and image-based measurements at those particular locations. The students were expected to explain the observed behavior and relate the collected data to the anticipated field engineering behavior. At the end of the project, the students were asked to provide a quantitative comparison of the image-based measurements to those made manually.

**Student Assessment of the Educational Initiatives**

In order to evaluate the success of engaging undergraduate students in research, the students were asked to fill out an evaluation...
form at the end of their project. The questions provided in Tables 1 and 2 were prepared based on the two projects and followed the suggestions of Sabatini (1997). The students involved in Projects I and II were asked to respond to the questions in Table 1 on a 1-to-4 scale. The average response level for each question is plotted in Fig. 2(a). The results show that the undergraduate researchers were overall satisfied with the digital image analysis. They believed that the image analysis enhanced their understanding of the research topic (e.g., definition of strain distributions in geosynthetics). The technique was straightforward and more accurate than traditional measurement techniques (e.g., light projection, extensometer). The assessment indicates that they did not need to have a strong background in image processing for implementing the codes. The students also gained invaluable skills from the study such as hands-on experience and familiarity with recent technologies, and one-on-one interaction with other researchers which ultimately improved their teamwork skills. Furthermore, they gained this experience during an active-learning process. Evidence concerning learning gains from the use of computer-assisted experiments in the classroom was also reported by previous researchers (Ball and Eckel 2004).

Similar evaluation forms were also given to the graduate student mentors. The questions were prepared considering a study conducted by Sabatini (1997). Table 2 and Fig. 2(b) provide the questions and the results of the assessment, respectively. The results are quite encouraging. The graduate students improved their communication, supervisory, and mentoring skills as a result of

Fig. 1. Captured images and strain contours (in percentage units) of a geosynthetic specimen at initial and at failure
graduated students were included in ongoing research programs that involve image-based geotechnical material characterization. The students worked with graduate student mentors during the project, and responded to a questionnaire at the end of their research to further evaluate the success of the activities.

It was recognized that digital image analysis can enhance the understanding of the engineering phenomenon for undergraduate students. The hands-on experience and visual demonstration improved the grasp of fundamental concepts in research projects. The students strongly agreed that the image analysis method helped them to better understand how to conduct experiments and provided an active learning environment. The research experience allowed the students to build a connection between the classroom and current scientific problems. It also taught them about cooperation and teamwork, as well as academic independence. Such involvement was a good start to the life-long learning skills that will make a successful engineer. It is believed that such research experience starting during the college years will potentially enable students to make more informed decisions about their further studies.

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References


